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Quantifying the Impact of Bridge Maintenance Activities on Deterioration: A Survey of Practice and Related Resources

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT. This TRS does not represent the conclusions of either CTC & Associates or MnDOT.

Introduction

MnDOT is interested in learning about practices to quantify the benefits of various bridge maintenance treatments in relation to remaining service life and bridge life-cycle costs. In addition, the agency is interested in knowing how maintenance treatments may be incorporated into deterioration models.

To support this effort, CTC & Associates conducted a literature search and a survey of domestic and international transportation agencies to learn about the type and frequency of bridge maintenance activities, practices for quantifying the impact of bridge maintenance activities on deterioration, and the use of deterioration models to examine the benefits of bridge maintenance.

Summary of Findings

This Transportation Research Synthesis is divided into two sections:

- Survey of Practice.
- Related Resources.

Survey of Practice

An online survey was distributed to members of the AASHTO Subcommittee on Bridges and Structures and representatives from transportation agencies in Canada, Denmark, Finland and Norway to gather information

about the use of various bridge maintenance treatments, efforts to quantify the benefits of bridge maintenance treatments, and the use of deterioration models in examining the impact of bridge maintenance. While all of the 22 agencies responding to the survey provided information about their experience with bridge maintenance treatments, relatively few agencies reported efforts to quantify the benefits of bridge maintenance activities or have experience with deterioration models. None of the agencies provided significant details about quantification efforts that relate to extended service life or reduced life-cycle cost.

The online survey gathered information in four topic areas:

- Use and frequency of bridge maintenance treatments.
- Quantifying the benefits of bridge maintenance treatments.
- Use of bridge deterioration models.
- Other respondent feedback.

The following summarizes findings in each topic area.

Use and Frequency of Bridge Maintenance Treatments

Approximately three-quarters of respondents employ crack sealing, expansion joint gland repair and poured joint sealing in their bridge maintenance programs; bridge flushing (washing) is used by slightly less than three-quarters of respondents. Spot painting is used by slightly less than half of respondents, with deck silane/siloxane sealers applied by the fewest respondents—just 36 percent.

Most respondents reported a flexible schedule for maintenance treatments, applying treatments on an as-needed basis. Bridge flushing or washing is an exception to this as-needed approach, with more agencies adopting a specific schedule for the treatment (biannually, annually or every two years).

Quantifying the Benefits of Bridge Maintenance Treatments

Only five state departments of transportation—California, Kansas, Michigan, New Jersey and North Carolina—addressed questions about quantifying the benefits of bridge maintenance treatments. Four of the five respondents provided anecdotal evidence, such as the reduction in deficiency reports noted by New Jersey DOT's structural inspection teams as bridges are inspected, or commented more generally on the benefits of bridge maintenance. The Kansas DOT respondent addressed the use of data to examine the impact of bridge maintenance activities. Through data analysis, Kansas DOT has shown that funds invested in bridge maintenance are a better investment in the long run when bridge performance measures are considered. The Kansas DOT respondent also noted that most life-cycle cost analyses have shown that, over time, maintenance actions are more cost-effective than bridge replacement.

Quantification Methods

All five respondents apply engineering judgment when attempting to quantify the benefits of bridge maintenance, and all but Michigan DOT also use condition rating information. Only Kansas DOT uses funding models compared to performance measure targets.

Use of Bridge Deterioration Models

Eight respondents—California, Delaware, Indiana, Iowa, Kansas, Maryland Transportation Authority, Michigan and North Carolina—reported the current or planned use of bridge deterioration models.

- California and Delaware use Pontis for deterioration modeling. There was no consensus among the remaining respondents in terms of the type of deterioration model used.
- Three states—Delaware, Iowa and Michigan—are waiting for an update to the AASHTOWare Bridge Management software (BrM) to apply the modeling capability of that software. (BrM is the software formerly known as Pontis.)
- Two agencies—Iowa DOT and MDTA—are developing deterioration models.

- MDTA's unspecified model is in development, along with the agency's asset management plan, and is expected to be completed within one year.
- Iowa DOT is developing deterioration models based on National Bridge Inventory condition ratings. This is an interim process until the agency begins using BrM with new element data it has collected since January 2014.

Model Applications
Six of the seven respondents use their deterioration models (or, in the case of MDTA, plan to use their model) for long-range budget planning. The next most frequently cited model application is for life-cycle cost analyses (five respondents). Michigan DOT also uses its deterioration model to evaluate conventional and innovative materials.

Adjusting the Model for Specific Parameters
Only four respondents—California, MDTA, Michigan and North Carolina—indicated that their deterioration models can or will be adjusted for specific parameters. All four agency models can be adjusted for construction materials and design type.

Bridge Elements Included in the Model
All major bridge elements—deck, substructure and superstructure—are included in six of the seven respondents' deterioration models. Rather than including these bridge elements in its model, Michigan DOT uses the minimum condition rating of all major NBI components. Kansas and North Carolina DOTs also include culverts in their models, and Indiana DOT includes arches and expansion joints.

Bridge Maintenance Treatments Accounted for in the Model
Only four transportation agencies—Delaware, Indiana, MDTA and North Carolina—responded affirmatively when asked whether their models could account for specific bridge maintenance treatments. The type of treatment varies by respondent.

Isolating the Benefits of Bridge Maintenance Treatments

Only three respondents reported on efforts to isolate the benefits of specific maintenance treatments. The Kansas DOT respondent noted that deck condition and maintenance actions to the bridge deck have the greatest impact, while the Indiana DOT respondent indicated that his agency has not been able to measure the additional service life or money saved in connection with specific maintenance treatments. North Carolina DOT reported that an approach to isolating the benefits of bridge maintenance is in development. (See page 43 of this report for information about two North Carolina DOT research projects related to bridge maintenance and deterioration.)

Other Respondent Feedback
Three state DOTs—Missouri, New Jersey and Vermont—reported the availability or planned development of bridge maintenance guidelines. The Vermont project has the added goal of quantifying the benefits of a sound bridge preservation program.

Further Examination of Deterioration Models
Representatives from a small group of agencies responding to this survey and another recent MnDOT inquiry were contacted to gather additional information about their use of deterioration models. The following summarizes the information provided by the five agencies responding to this request:

- In Delaware, the Maximo program is used to track maintenance activities but is not used by the agency to determine how maintenance tasks affect condition ratings. Engineering judgment with some qualitative knowledge of historical data is used to determine the impact of maintenance on condition ratings.
- A customized modeling program focused on deck deterioration using NBI data is being tested by Iowa DOT. This customized tool is being used on an interim basis until the agency can gather enough new bridge element data to populate BrM. The interim software is continually updated and will eventually consider element-level preservation planning and life-cycle cost analysis.

- The deterioration model in development by Maryland Transportation Authority is too early in its development phase for the survey respondent to provide additional information about the tool's structure and expected functionality.
- Michigan DOT's spreadsheet-based Bridge Condition Forecast System is used to determine the value of bridge preservation at the network level. The tool identifies the ideal mix of fixes, assesses the impact of revised budgets and identifies the funding needed to meet goals. A Transition Probability Matrix generated by the tool identifies how the NBI condition ratings of bridges in the network will change over time based on budget and type of activity (preventive maintenance, rehabilitation or replacement).
- A respondent to another recent MnDOT inquiry, Virginia DOT was contacted to learn more about the agency's deterioration model for culverts. This model uses commonly recognized (CoRe) element data to help the agency understand average condition and determine when repair is required. With the Virginia Health Index, which will be launched over the coming months, the agency can compare the results of possible interventions by examining the resulting values of the bridge and comparing the cost/benefit ratios for each intervention.

Related Resources

Quantifying the Benefits of Bridge Maintenance Activities

National Guidance

An NCHRP project just getting underway (Project 14-36) will develop a catalog of bridge preservation actions, including associated costs and benefits, for use in life-cycle cost analysis and possible integration into a bridge management system. Publications developed in conjunction with an associated discontinued NCHRP project provide a preliminary look at the type of data the new NCHRP project may develop. A second NCHRP project in progress (Project 14-20A) that will consider the consequences of delayed bridge maintenance is expected to help assess economic benefits of maintenance actions. A third project in progress, a University Transportation Centers project, will consider sustainability in developing a tool for making bridge retrofit decisions.

State Research

An Indiana DOT project in progress will examine cost-effective treatment types and their respective timing over a bridge's life cycle. Results of a recently completed Indiana DOT project include a list of effective bridge preventive maintenance operations and recommendations for when they should occur. Researchers based these recommendations on quantitative cost/benefit results and a qualitative assessment. In a project related to the impact of a specific maintenance treatment, a 2013 Washington State DOT study sought to develop a framework for assessing the impact of bridge washing on paint life. Researchers concluded that "little information on the effects of bridge washing exists and it is only deemed beneficial based on anecdotal assumptions."

Additional Resources

Journal articles highlight maintenance optimization methods or strategies, including:

- A risk-based maintenance optimization methodology for deteriorating bridges to find the optimum maintenance options and their timing.
- A maintenance strategy optimization method for reinforced concrete girder bridges that considers performance indicators, service life and life-cycle maintenance cost.
- A comprehensive bridge management system that optimizes repair decisions by considering multiple bridge elements and large networks of bridges.

A 2012 journal article compares the effect of maintenance strategies on the timing, extent and cost of remediation actions over the service life of a reinforced concrete structure in a chloride environment.

Deterioration Models

National Research and Guidance

An interim report for a discontinued NCHRP project discusses two approaches to modeling used to forecast deterioration: the Delphi and data-driven methods. The authors examine five bridge management systems or tools that apply these basic modeling approaches. A 2007 NCHRP report describes the development of two preservation models: a network-level model that provides a decision-making tool to optimize bridge actions for multiple performance criteria, and a bridge-level model that evaluates the effect of bridge action alternatives on life-cycle cost and other performance criteria.

State Research

A Colorado DOT project developed element-level repair and rehabilitation actions, costs for these actions and transition probabilities for models of deterioration of bridge elements. An Indiana DOT project in process, expected to conclude at the end of 2015, will develop a set of deterioration models for bridge deck, superstructure, substructure and the entire bridge. Other examples of state activities include improvements to deterioration and action effectiveness models for Florida DOT's Project Level Analysis Tool, and Michigan DOT's Bridge Condition Forecast System, a spreadsheet-based method to forecast network conditions that may result from various maintenance strategies. A Minnesota DOT report describes a technique for computing deterioration curves using inspection data from the NBI, and in Nebraska, researchers performed life-cycle cost analysis on different maintenance strategies using deterioration models developed in a 2011 project.

A North Carolina DOT project in process, expected to conclude in July 2017, will develop formulas for performance metrics to revise the agency's current bridge priority replacement index. Prioritization indices associated with bridge rehabilitation projects and preservation actions, and the first culvert priority replacement index, will also be developed. A recently concluded North Carolina DOT research project provided the agency with updated deterioration models and user cost tables for use in its bridge management software. Researchers developed "a unique statistical regression methodology applying survival analysis techniques to better address characteristics of the historical condition rating data," resulting in "probabilistic deterioration models for bridge components and culverts that provide significantly improved predictive accuracy and precision over prior deterministic models."

Additional Resources

A new version of AASHTOWare Bridge Management software will include enhanced deterioration models that implement new deterioration model logic. Also included will be new life-cycle cost analysis tools and project planning modules. New approaches to deterioration modeling are addressed in publications that describe the use of the NBI database to develop bridge deck degradation models and propose an alternative or modifications to the Markov model used in bridge management software such as AASHTOWare Bridge Management.

Detailed Findings

Survey of Practice

Survey Approach

An online survey was distributed to members of the AASHTO Subcommittee on Bridges and Structures and representatives from transportation agencies in Canada, Denmark, Finland and Norway to gather information about the use of various bridge maintenance treatments, efforts to quantify the benefits of bridge maintenance treatments, and the use of deterioration models to examine the impact of bridge maintenance.

The survey consisted of the following questions:

1. What bridge maintenance treatments does your agency employ and on what frequency? Please enter below the frequency in years for all maintenance treatments that apply.
   - Bridge flushing (washing).
   - Crack sealing.
   - Expansion joint gland repair.
   - Poured joint sealing.
   - Spot painting.
   - Deck silane/siloxane sealing.
   - Other (please describe the treatment and indicate frequency).

2. Has your agency attempted to quantify the benefits of bridge maintenance treatments?

2a. Please describe your quantification efforts in terms of extended service life or reduced life-cycle cost for each bridge maintenance treatment.

2b. What method(s) do you use to quantify the benefits of bridge maintenance treatments? Please select all that apply.
   - Chloride sampling.
   - Condition rating information.
   - Deterioration models.
   - Engineering judgment.
   - Other (please specify).

3. Does your agency use a bridge deterioration model?

4. What bridge deterioration model do you use?

5. What are you using the model for? Please select all that apply.
   - Project scoping and/or planning.
   - Long-range budget planning.
   - Life-cycle cost analyses.
   - Legislative reporting.
   - Resource demand models.
   - Other (please specify).

6. Can the model be adjusted for specific parameters?

6a. Please select all model parameters that apply.
   - Construction materials.

- Design type.
- Average daily traffic (ADT).
- Rebar coating.
- Use of deck overlays.
- Other (please specify).

7. What bridge elements are included in the model? Please select all that apply.
   - Deck.
   - Superstructure.
   - Substructure.
   - Other (please specify).
8. Does the model take into account specific bridge maintenance treatments?
9. Have you found a good approach to isolate the benefit for each specific bridge maintenance treatment? Please describe.
10. Please use this space to provide any additional comments about your answers above.

Twenty-two agencies responded to the survey:

State Transportation Agencies

- Arizona.
- California.
- Delaware.
- Hawaii.
- Indiana.
- Iowa.
- Kansas.
- Michigan.
- Missouri.
- Montana.
- New Hampshire.
- New Jersey.
- North Carolina.
- Oklahoma.
- Tennessee.
- Vermont.
- Washington.
- West Virginia.

Other Domestic Bridge-Related Agencies

- Golden Gate Bridge, Highway and Transportation District.
- Maryland Transportation Authority (MDTA).

International Transportation Agencies

- Denmark.
- Norway.

Summary of Survey Results

While all 22 respondents provided information about their experience with the range of bridge maintenance treatments addressed in the survey, relatively few agencies reported efforts to quantify the benefits of bridge maintenance activities or have experience with deterioration models. None of the agencies provided significant details about quantification efforts that relate to extended service life or reduced life-cycle cost.

The online survey gathered information in four topic areas:

- Use and frequency of bridge maintenance treatments.
- Quantifying the benefits of bridge maintenance treatments.
- Use of bridge deterioration models.
- Other respondent feedback.

The full text of the survey responses begins on page 16 of this report.

Following is a summary of findings by topic area.

Use and Frequency of Bridge Maintenance Treatments
Respondents were asked to indicate their use of the following bridge maintenance treatments and how often the treatments were applied:

- Bridge flushing (washing).
- Crack sealing.
- Expansion joint gland repair.
- Poured joint sealing.
- Spot painting.
- Deck silane/siloxane sealing.

The following treatments are used most often by more than three-quarters of respondents:

- Crack sealing.
- Expansion joint gland repair.
- Poured joint sealing.

Slightly less than three-quarters of respondents reported the use of bridge flushing (washing). Less frequently used treatments include spot painting (slightly less than half of respondents) and deck silane/siloxane sealing (36 percent of respondents).

Most respondents reported a flexible schedule for maintenance treatments, applying the treatment on an as-needed basis. For two respondents—Delaware and MDTA—this means applying treatments after identifying the need during bridge inspections. Bridge flushing or washing is an exception to this as-needed approach, with more agencies adopting a specific schedule for the treatment (biannually, annually or every two years).

The table below summarizes survey responses.

Use and Frequency of Bridge Maintenance Treatments

Maintenance Activity	Frequency	Agency	Comment
Crack sealing	**Annually**	Golden Gate Bridge, Denmark	N/A.
	Every 5 years	New Hampshire	N/A.
	10 years	California	Once at 10 years unless required again.
	As needed	Delaware, Hawaii, Kansas, MDTA, Michigan, Montana, New Jersey, North Carolina, Vermont	*Delaware*. As needed according to biannual bridge inspection. *Kansas*. On an as-needed basis. There is no official crack sealing effort or policy. *MDTA*. Per condition inspection.
	Other	Arizona, Missouri, Oklahoma, Washington	*Arizona*. Project opportunity (tag along with pavement preservation). *Missouri*. Crack sealing occurs on a 3- to 5-year cycle depending on the product. *Oklahoma*. We seal the cracks on all new on-system bridges the summer after construction. *Washington*. Just starting to do select bridges.
	Plan to start	Indiana	N/A.

Use and Frequency of Bridge Maintenance Treatments			
Maintenance Activity	**Frequency**	**Agency**	**Comment**
Expansion joint gland repair	**Annually**	Golden Gate Bridge	N/A.
	Every 5 years	New Jersey	N/A.
	Every 15 years	California	N/A.
	As needed	Hawaii, Indiana, Iowa, Kansas, MDTA, Michigan, Missouri, Montana, New Hampshire, North Carolina, Tennessee, Vermont	*Iowa*. 5 to 10 years is our goal. *Kansas*. As needed after failure of the gland or header. *MDTA*. Per condition inspection. *New Hampshire*. As needed (15).
	Other	Delaware, Washington	*Delaware*. Replaced during structure maintenance projects. *Washington*. Minimal.
Poured joint sealing	**Every 2 years**	New Hampshire	N/A.
	Every 5 years	Vermont, Washington	*Washington*. Deck joints in steel truss bridges every 5 years.
	Every 7 years	California	N/A.
	Every 10 years	New Jersey	N/A.
	As needed	Delaware, Hawaii, Iowa, Kansas, MDTA, Michigan, Missouri, Montana, North Carolina, Tennessee, Denmark	*Delaware*. As needed according to biannual bridge inspection. *Iowa*. As needed. Not enough resources to do it on a regular schedule. *MDTA*. Per condition inspection. *Tennessee*. Usually lasts only 5 or so years.
	Other	Oklahoma	This activity is done on rehab projects.
Bridge flushing (washing)	**Biannually**	New Jersey	N/A.
	Annually	Indiana, Iowa, Kansas, Missouri, Washington, West Virginia, Norway	*Indiana*. Except for truss bridges, which are twice a year. *Iowa*. Only border bridges on an annual basis. *Kansas*. Yearly in some areas/districts, more frequently in others. *Missouri*. We prescribe cleaning/flush decks in the fall and the entire bridge in the spring. In reality, we flush decks/drains at least once a year and the superstructure and substructure occurs less frequently. *Washington*. Annually on steel truss bridges. *West Virginia*. We try every year, but it depends on manpower.
	Every 2 years	New Hampshire, Vermont	*New Hampshire*. Target is annually.

Use and Frequency of Bridge Maintenance Treatments			
Maintenance Activity	**Frequency**	**Agency**	**Comment**
	As needed	Delaware, Michigan, North Carolina	*Delaware*. As needed according to biannual bridge inspection.
	Other	Oklahoma, Denmark	*Oklahoma*. Some of our field divisions have done this; once a year if at all. *Denmark*. Only few big bridges few times a year.
	Just started	MDTA	N/A.
Spot painting	**Every 10 years**	New Jersey	N/A.
	Every 15 years	California	N/A.
	As needed	Hawaii, Indiana, Kansas, MDTA, Missouri, North Carolina, Vermont, Denmark	*Kansas*. As needed and as funding allows. *MDTA*. Per condition inspection.
	Not used; found to be impractical	Iowa	N/A.
Deck silane/siloxane sealing	**New bridges**	Hawaii, Missouri, Oklahoma	*Hawaii*. Only recently with new bridge projects. *Missouri*. Silane is applied on all new concrete bridge decks. If additional cracking occurs, reapplication is considered in the first 3 years. Additional applications are recommended at 7- to 10-year intervals. *Oklahoma*. New bridges receive silane treatment the summer following construction. Research shows that silane treatments last 15 years. In order to seal the bridge decks on our post-tensioned box girders, we are doing a shot blast, followed by a silane treatment followed by a flood coat (about 35 structures).
	Every 5 years	New Hampshire, Vermont	N/A.
	Every 10 years	Delaware	Just beginning program; every 10 years planned.
	As needed	MDTA	Per condition inspection.
	Other	Arizona	Project opportunity (tag along with pavement preservation).
	Potential use	Iowa	We are investigating sealing decks with silane.
Other practices		California	Deck wearing surface at 15 years.
		Michigan	Epoxy penetrating healer sealer, thin epoxy overlay, barrier wall silane sealing (all as needed).
		Golden Gate Bridge	Ongoing major painting projects.

Quantifying the Benefits of Bridge Maintenance Treatments
The five respondents—California, Kansas, Michigan, New Jersey and North Carolina—responding to questions about efforts to quantify the benefits of bridge maintenance treatments offered little about relating bridge maintenance to extended service life or reduced life-cycle cost.

For Kansas DOT, bridge performance measures are a tool used to measure the past and potential future condition of the system, and to present future condition predictions based on different levels of funding. Using data analysis, the agency has shown that funds invested in bridge maintenance are a better investment in the long run when bridge performance measures are considered. The Kansas DOT respondent also noted that in most life-cycle cost analyses conducted, maintenance actions over time have typically been shown to be more cost-effective than replacement.

Anecdotal evidence or other comments were offered by:

- Caltrans, which has noted a reduction in major rehabilitation needs since the agency increased its preventative maintenance actions.
- Michigan DOT respondent, who observed that "engineering reasoning would say that any effort to slow the ingress of harmful deicing chemicals into a bridge element will slow its deterioration."
- New Jersey DOT, which has noted a reduction in deficiency reports by the agency's structural inspection teams as bridges are inspected.
- North Carolina DOT, which works toward condition improvement, leading to extended service life.

MDTA is in the process of quantifying the benefits of bridge maintenance activities. This issue will be addressed in the agency's asset management plan now in development.

Quantification Methods
Survey respondents were asked to identify the methods used to quantify the benefits of bridge maintenance. All five respondents apply engineering judgment, with all but Michigan DOT also using condition rating information. Only Kansas DOT uses funding models compared to performance measure targets.

The table below summarizes survey responses.

Methods Used to Quantify the Benefits of Bridge Maintenance Treatments

Quantification Method	Agency
Engineering judgment	California, Kansas, Michigan, New Jersey, North Carolina
Condition rating information	California, Kansas, New Jersey, North Carolina
Funding models compared to performance measure targets	Kansas
Chloride sampling	None
Deterioration models	None

Use of Bridge Deterioration Models
Eight respondents—California, Delaware, Indiana, Iowa, Kansas, MDTA, Michigan and North Carolina—reported the current or planned use of bridge deterioration models. Three states—Delaware, Iowa and Michigan—are waiting for an update to the AASHTOWare Bridge Management software, or BrM, to apply the modeling

capability of that software. (BrM is the software formerly known as Pontis. See page 44 of this report for more information about BrM.)

Two agencies—Iowa DOT and MDTA—are developing deterioration models. MDTA's unspecified model is in development, along with the agency's asset management plan, and is expected to be completed within one year. Iowa DOT is developing deterioration models based on NBI condition ratings. This is an interim process until the agency begins using BrM with new element data that has been collected since January 2014.

Rather than employing a bridge deterioration model, Washington State DOT uses bridge management system data to identify preservation needs.

The table below summarizes survey responses.

Note: Only seven respondents are reflected in the table below summarizing survey responses. Iowa DOT did not respond to the survey questions related to deterioration models, instead providing information about its model development plans in response to a final wrap-up survey question.

Deterioration Models Used by Respondents

Bridge Deterioration Model	Agency
Pontis	California, Delaware*
In-house program	Kansas
In process	MDTA
dTIMS Bridge Management System	Indiana**
Markov transition probabilities using minimum NBI condition ratings and element level deterioration	Michigan***
Piece-wise linear deterministic model	North Carolina

* Delaware DOT is using Pontis until BrM has modeling capability.

** The Indiana DOT respondent identified the types of deterioration models (curves) used—wearing surface, deck, superstructure, substructure and arches.

*** Michigan DOT is waiting to upgrade to the next version of BrM.

Model Applications

Six of the seven respondents use their deterioration models (or, in the case of MDTA, plan to use their model) for long-range budget planning. The next most frequently cited model application is for life-cycle cost analyses (five respondents). The table below summarizes survey responses.

Applications of Respondents' Deterioration Models

Model Use	Agency
Long-range budget planning	Delaware, Indiana, Kansas, MDTA, Michigan, North Carolina
Life-cycle cost analyses	California, Indiana, MDTA, Michigan, North Carolina

Applications of Respondents' Deterioration Models	
Model Use	**Agency**
Project scoping and/or planning	California, Delaware, Indiana, MDTA
Legislative reporting	MDTA, Michigan, North Carolina
Resource demand models	MDTA
Evaluating materials (conventional and innovative)	Michigan

Adjusting the Model for Specific Parameters
Only four respondents—California, MDTA, Michigan and North Carolina—indicated that their deterioration models can or will be adjusted for specific parameters. The table below summarizes survey responses.

Adjustable Parameters in Respondents' Deterioration Models	
Model Parameter for Adjustment	**Agency**
Construction materials	California, MDTA, North Carolina
Design type	California, MDTA, North Carolina
Average daily traffic (ADT)	MDTA, North Carolina
Rebar coating	MDTA
Use of deck overlays	MDTA
Budgetary consideration of the parameters above based on selecting the correct inventory	Michigan

Bridge Elements Included in the Model
All major bridge elements—deck, substructure and superstructure—are included in six of the seven respondents' deterioration models. Rather than including these bridge elements in its model, Michigan DOT uses the minimum condition rating of all major NBI components. Kansas and North Carolina DOTs also include culverts in their models, and Indiana DOT includes arches and expansion joints.

Bridge Maintenance Treatments Accounted for in the Model
Only four respondents responded affirmatively when asked whether their models could account for specific bridge maintenance treatments:

- In Delaware, the deterioration model will consider a maintenance treatment only if it changes the condition state of the element that received the maintenance treatment (i.e., a gland is replaced and the joint goes from CS 3 to CS 1).
- Indiana DOT's model accounts for deck overlay, deck patching and joint repair/replacement.
- The MDTA model in development will address bridge washing, painting, deck sealing, joint sealing and debris removal.
- North Carolina DOT's model accounts for deck treatments and overlays, steel painting and repairs, and concrete repairs.

Isolating the Benefits of Bridge Maintenance Treatments
When asked whether they had identified effective approaches to isolating the benefits of bridge maintenance treatments, only three respondents offered comments:

- In Indiana, the general consensus is that bridge maintenance activities provide benefits by prolonging the service life of bridge components and delaying major repair and construction. However, the agency has not been able measure the additional service life or money saved.
- The Kansas DOT respondent noted that deck condition and maintenance actions to the bridge deck have the greatest impact.
- North Carolina DOT is working on developing an approach that will isolate the benefits of bridge maintenance treatments. (See page 43 of this report for information about a project in process that is developing formulas for performance metrics to revise North Carolina DOT's current bridge priority replacement index, and a recently concluded project that provided the agency with updated deterioration models and user cost tables for use in its bridge management software.)

Other Respondent Feedback
Three respondents reported the availability or planned development of bridge maintenance guidelines:

- Missouri DOT's bridge preventive maintenance guidelines are available at http://epg.modot.org/index.php?title=Category:771_Bridge_Preventative_Maintenance_Guidelines.
- New Jersey DOT has developed a bridge preventive maintenance manual for various bridge treatments. See **Appendix B** for the January 2015 revision of the agency's Bridge Preventive Maintenance Program. An update to this document is awaiting Federal Highway Administration approval.
- Vermont recently developed an outline for a bridge maintenance/preservation guide with the goal of quantifying the benefits of a sound bridge preservation program. The agency is attempting to secure the required funding to begin the program as part of its 2017 capital program budget.

Further Examination of Deterioration Models
Representatives from a small group of agencies responding to this survey and another recent MnDOT inquiry were contacted to gather additional information about their use of deterioration models. The following summarizes the information provided by the five agencies responding to this request:

- Delaware DOT uses Maximo to track maintenance activities but has not used this information to determine how maintenance tasks affect condition ratings. The agency uses engineering judgment with some qualitative knowledge of historical data to determine the impact of maintenance on condition ratings. The results of a deterioration model associated with a given element are compared to what the agency would expect using engineering judgment and examining inspection data for a sample set of the element.

- Iowa DOT is testing a customized, vendor-supplied modeling program focused on deck deterioration using NBI data. The vendor has developed risk-based optimal preservation plans under a wide range of scenarios, including investment level and performance target scenarios. The program creates a deterioration model for each bridge, not by bridge type. The survey respondent noted that it is difficult to identify the type of work that has to be completed to raise the NBI condition rating of the superstructure or substructure by a specified number of points. For this reason, while the program will create a deterioration model for the superstructure and substructure, the software does not recommend specific work items to improve the condition rating of specific elements.

  Use of this customized tool is an interim process until the agency can gather enough new element data to populate BrM. The interim software is continually updated and will eventually consider element-level preservation planning and life-cycle cost analysis. When the data is available to populate BrM, the agency

may opt to continue to use the current NBI modeling while also using BrM to provide a second look at maintenance impacts and permit the comparison of the two systems.

- Maryland Transportation Authority's deterioration model is too early in its development phase for the survey respondent to provide additional information about the tool's structure and expected functionality.

- Michigan DOT's Bridge Condition Forecast System is a spreadsheet-based tool that forecasts network conditions when considering a range of bridge maintenance strategies. Lacking actual deterioration data, the agency uses engineering judgment when making determinations with regard to deterioration.

  BCFS users begin by adding budget data and data imported from the bridge inventory that reflect condition ratings resulting from the most recent biennial inspection cycle. This data is applied in three scenarios:

  - A project-based strategy that imports the agency's five-year call for projects.
  - Two potential strategies that do not include specific projects to determine the optimal strategy on a network basis.

  BCFS is used to determine the value of bridge preservation at the network level and identify the ideal mix of fixes, assess the impact of revised budgets and identify the funding needed to meet goals. The resulting Transition Probability Matrix identifies how the NBI condition ratings of bridges in the network will change over time based on budget and type of activity (preventive maintenance, rehabilitation or replacement).

- While Virginia DOT did not respond to the survey conducted for this project, an agency representative did respond to interview questions posed in connection with another MnDOT inquiry that addressed deterioration models used with culverts (see TRS 1508, State of the Practice for Managing, Maintaining and Operating Culverts: A Review of Deterioration Curves and Tools, available at http://www.dot.state.mn.us/research/TRS/2015/TRS1508.pdf). A follow-up contact to Virginia DOT gathered additional information about culvert modeling.

  The Virginia DOT deterioration model uses data gathered on commonly recognized (CoRe) elements to help the agency understand average condition and determine when repair is required. The survey respondent noted that this approach is a more refined way of examining a bridge rather than looking only at the deck, superstructure and substructure. The agency's planned use of metrics will optimize spending on culvert maintenance. Use of the Virginia Health Index, which will be launched over the coming months, will allow the agency to monetize assets in terms of equity by identifying the current valuation of the asset. With the index, the agency can compare the results of possible interventions by examining the resulting values of the bridge and comparing the cost/benefit ratios for each intervention.

Survey Results

The full text of survey responses is provided below. Responses are organized in two categories: domestic and international. For reference, an abbreviated version of each question is included before the response. Where applicable, questions have been omitted that are not relevant based on a previous negative response provided by the respondent. The full question text appears on page 6 of this report.

Domestic Responses

Arizona

Contact: Pe-Shen Yang, ITD/Assistant State Bridge Engineer, Arizona Department of Transportation, pyang@azdot.gov, 602-712-8606.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): No.

   Crack sealing: Project opportunity (tag along with pavement preservation).

   Expansion joint gland repair: No.

   Poured joint sealing: Do not use.

   Spot painting: No.

   Deck silane/siloxane sealing: Project opportunity (tag along with pavement preservation).

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** [No response.]

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

   Condition rating information

   Engineering judgment

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** [No response.]

California

Contact: Paul Cooley, Structure Maintenance and Investigations/Senior Bridge Engineer, California Department of Transportation, paul.cooley@dot.ca.gov, 916-227-8041.

1. **Bridge maintenance treatments—type and frequency in years:**

   Crack sealing: Once at 10 years unless required again.

   Expansion joint gland repair: 15 years.

   Poured joint sealing: 7 years.

   Spot painting: 15 years.

   Other (please describe the treatment and indicate frequency): Deck wearing surface at 15 years.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** We have seen a reduction in major rehab needs since we increased our preventative maintenance actions.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

Condition rating information

Engineering judgment

3. **Use a bridge deterioration model?** Yes.

4. **Bridge deterioration model:** Pontis (BrM) software is used.

5. **Using the model for:**

Project scoping and/or planning

Life-cycle cost analyses

6. **Model adjusted for specific parameters?** Yes.

6a. **Parameters:**

Construction materials

Design type

7. **Bridge elements included in the model:**

Deck

Superstructure

Substructure

8. **Model takes into account specific bridge maintenance treatments?** No.

9. **Approach to isolate benefit for each specific bridge maintenance treatment:** N/A.

10. **Additional comments:** [No response.]

Delaware

Contact: Calvin Weber, Bridge Maintenance Engineer, Delaware Department of Transportation, calvin.weber@state.de.us, 302-760-2324.

1. **Bridge maintenance treatments—type and frequency in years:**

Bridge flushing (washing): As needed according to biannual bridge inspection.

Crack sealing: As needed according to biannual bridge inspection.

Expansion joint gland repair: Replaced during structure maintenance projects.

Poured joint sealing: As needed according to biannual bridge inspection.

Deck silane/siloxane sealing: Just beginning program; every 10 years planned.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** Yes.

4. **Bridge deterioration model:** Pontis (until BrM has modeling capability).

5. **Using the model for:**

Project scoping and/or planning

Long-range budget planning

6. **Model adjusted for specific parameters?** No.

7. **Bridge elements included in the model:**

   Deck

   Superstructure

   Substructure

8. **Model takes into account specific bridge maintenance treatments?** Yes. Only if it changes the condition state of the element that received the maintenance treatment (i.e., a gland is replaced and the joint goes from CS 3 to CS 1).

9. **Approach to isolate benefit for each specific bridge maintenance treatment:** [No response.]

10. **Additional comments:** [No response.]

Further Examination of Delaware DOT's Deterioration Model

The survey respondent was asked to respond to additional questions about Delaware DOT's process to incorporate bridge maintenance treatments into the agency's deterioration model. Calvin Weber's responses appear below.

1. **How are maintenance tasks tracked and associated with condition ratings?** There are a few ways we can track maintenance activities: Maximo program for in-house work orders and contract documents and pay estimates for Structure Maintenance Contract. Of course condition ratings are assessed during routine inspections. Although we have this maintenance information in some form, we have not used this information to take a detailed look at how maintenance tasks affect condition ratings. For determining this for our previous Pontis deterioration model, we used "Expert Elicitation," i.e., engineering judgment and experience.

2. **Does the process isolate specific maintenance treatments and treatment categories, or does it look at maintenance as a whole?** As mentioned above, we have maintenance information and we could look at it in all the ways mentioned, but the information would need to be transferred to a more useful format to allow for meaningful data manipulation.

3. **Are the deterioration models for superstructure and substructure based on engineering judgment, historical data, research or something else?** Engineering judgment with some qualitative knowledge of historical data. We would then run a deterioration model for a given element and compare to what we would expect using engineering judgment and look at the inspection data for a sample set of the element to see if the deterioration falls in line with what we would expect and have observed for the sample of that element population. For example, for "old Pontis" bare deck element, using engineering judgment we would expect to repair and place a concrete overlay in 35-40 years. [T]his is backed up by looking at average deck condition vs. age, and the deterioration model was calibrated to give this result.

Related Resources:

"DelDOT Bridge Management Program," Jason Arndt, *2015 Northeast Bridge Preservation Partnership Annual Meeting*, September 2015.
https://pavementvideo.s3.amazonaws.com/2015_NEBPP/PDF/8%20-%20DelDOT%20Bridge%20Program_Arndt.pdf
This meeting presentation addresses the agency's deficiency formula prioritization process and bridge preservation mechanisms.

Best Practices in Bridge Management Decision-Making, Scan 07-05, NCHRP Project 20-68A U.S. Domestic Scan, National Cooperative Highway Research Program, November 2009. http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_07-05.pdf
See Chapter 5, which begins on page 65 of the PDF, for a discussion of Delaware DOT's bridge management. The scan report addresses the agency's use of Maximo.

Golden Gate Bridge, Highway and Transportation District

Contact: Noel Stampfli, Senior Engineer, Golden Gate Bridge, Highway and Transportation District, nstampfli@goldengate.org.

1. **Bridge maintenance treatments—type and frequency in years:**

   Crack sealing: Annual.

   Expansion joint gland repair: Annual.

   Other (please describe the treatment and indicate frequency): Ongoing major painting projects.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** [No response.]

Hawaii

Contact: Paul Santo, Highways Division, Hawaii Department of Transportation, paul.santo@hawaii.gov, 808-692-7611.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): No.

   Crack sealing: Yes; as needed.

   Expansion joint gland repair: Yes; as needed.

   Poured joint sealing: Yes; as needed.

   Spot painting: Yes; as needed.

   Deck silane/siloxane sealing: Only recently with new bridge projects.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** None.

Indiana

Contact: Jaffar Golkhajeh, Division of Bridges/Bridge Asset Manager, Indiana Department of Transportation, jgolkhajeh@indot.in.gov, 317-232-5453.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Every year, except for truss bridges twice a year.

   Crack sealing: Plan to start this activity.

Expansion joint gland repair: As needed.

Spot painting: As needed.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** Yes.
4. **Bridge deterioration model:** Deterioration models (curves) for wearing surface, deck, superstructure, substructure and aches. Implemented in the Bridge Management System (dTIMS).
5. **Using the model for:**

   Project scoping and/or planning

   Long-range budget planning

   Life-cycle cost analyses
6. **Model adjusted for specific parameters?** No.
7. **Bridge elements included in the model:**

   Deck

   Superstructure

   Substructure

   Other (please specify): Arches and expansion joints.
8. **Model takes into account specific bridge maintenance treatments?** Yes. Deck overlay, deck patching and joint repair/replacement.
9. **Approach to isolate benefit for each specific bridge maintenance treatment:** The general consensus is that the bridge maintenance activities provide benefits in term[s] of prolonging the service life of bridge components and delays the major repair and constructions. But, for how long, we have not been able to measure the additional service life provided or explain it in term[s] of money saved.
10. **Additional comments:** [No response.]

Iowa

Contact: Scott Neubauer, Bridge Maintenance Engineer, Office of Bridges and Structures, Iowa Department of Transportation, scott.neubauer@dot.iowa.gov, 515-239-1165.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Only border bridges on an annual basis.

   Crack sealing: We do not seal cracks.

   Expansion joint gland repair: As needed. 5 to 10 years is our goal.

   Poured joint sealing: As needed. Not enough resources to do it on a regular schedule.

   Spot painting: Spot painting has been found to be impractical.

   Deck silane/siloxane sealing: We are investigating sealing decks with silane.
2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** We are developing deterioration models based on [National Bridge

Inventory] condition ratings. This is an interim process until we start using AASHTOWare BrM with the new element data we began collecting in January 2014. We are also in the process of creating a system to track costs for maintenance done by our own forces.

Further Examination of Iowa DOT's Deterioration Model

The survey respondent was asked to respond to additional questions about the deterioration model now in development. The following summarizes the results of a follow-up interview with Scott Neubauer.

1. **How will the new model or models quantify the benefits of bridge maintenance activities?** The agency is testing a customized modeling program based on NBI condition ratings. Developed by IDS [Infrastructure Data Solutions, Inc.], the tool has gone through several iterations as more information becomes available to populate it. The IDS project includes:

   - Development of deterioration models to predict bridge performance based on historical Iowa NBI data from 1992 to 2012.
   - Development of a risk-based prioritization model to rank bridges based on the likelihood of failure and consequence of failure; assignment of priority indices to indicate the relative urgency of preservation actions.
   - Development of 20-year optimal preservation plans that maximize systemwide performance and minimize risks under a range of budget and performance target scenarios.
   - Investigation of trade-offs between funding levels and systemwide performance and risk levels.

   The customized tool is being used on an interim basis until the agency can gather enough new element data to populate BrM. The program, intended to overcome some of the limitations of Pontis, is continually updated and will eventually consider element-level preservation planning and life-cycle cost analysis.

   From April 2014 through April 2016, data will be gathered for every bridge for the bridge elements the agency is monitoring. This additional cycle of biennial inspection data is needed before the model can be used to determine the impact of maintenance activities. When more data is available, the agency may opt to continue to use the current NBI modeling while also using BrM to provide a second look at maintenance impacts and permit comparison of the two systems.

2. **What types of deterioration curves will be used—deck, superstructure, substructure and others?**

   The IDS program creates a deterioration model for each bridge, not by bridge type. The current model is more focused on deck deterioration using NBI data. Neubauer noted that it is difficult to identify the type of work that has to be completed to raise the condition rating of the superstructure or substructure by a specified number of points. For this reason, while the program will create a deterioration model for the superstructure and substructure, the software does not recommend specific work items to improve the condition rating of specific elements.

3. **What parameters will be used in the development of deterioration curves for the deck, substructure and superstructure and other bridge elements? Will you use engineering judgment, historical data, research or something else?** Deterioration curves use historical data based on NBI condition ratings. The software also uses a bridge condition index Neubauer developed to compare bridges in the inventory. The index is similar to the FHWA sufficiency rating but has been modified to be more sensitive to minor changes. Neubauer noted that the modified index is also more condition-oriented. Developed several years ago, the condition index is used:

   - When programming bridge projects.

- To determine the good/fair/poor ratings used in the agency's performance measures.

The bridge condition index calculations are cited below in Related Resource.

4. **Will the deterioration model address culverts?** No.

5. **Other comments.** Neubauer noted these challenges associated with modeling:

   - Determining the budget ranges to use.
   - Identifying the percentage of the budget to use for different repair and maintenance scenarios.
   - Addressing the level of work recommended by the model when limits are not applied. For example, when applying no limits, modeling has recommended deck repair for 300 to 400 projects in one year. This volume of repairs was not considered reasonable to complete in this short period of time.

   Also presenting challenges are funding constraints and the limited number of contractors available to perform the maintenance work. Neubauer noted that new or enhanced modeling tools are not likely to dramatically change how the agency manages its bridge maintenance. Instead, modeling tools will continue to be used to validate and quantify the decisions already being made.

Related Resource:

Revised Iowa DOT Bridge Condition Index, Iowa Department of Transportation, undated.
See **Appendix A**.
This document presents the calculations associated with the customized bridge condition index applied by Iowa DOT.

Kansas

Contact: Paul Kulseth, Bridge Management Engineer, Kansas Department of Transportation, kulseth@ksdot.org, 785-296-5510.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Yearly in some areas/districts, more frequently in others.

   Crack sealing: On an as-needed basis. There is no official crack sealing effort or policy.

   Expansion joint gland repair: As needed after failure of the gland or header.

   Poured joint sealing: As needed.

   Spot painting: As needed and as funding allows.

   Deck silane/siloxane sealing: Kansas does not use silane/siloxane sealants.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** Bridge performance measures are for us to use as a tool to measure the condition of the system, past and future, and to present future condition predictions based on different levels of funding. When presented in the right way, it makes a very defendable case for future funding. Through analysis of the data, we have shown that money invested in bridge maintenance is a better investment in the long run when bridge performance measures are considered. In most life-cycle cost analyses conducted, the maintenance actions over time typically beat out the replacement option.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

   Condition rating information

Engineering judgment

Other (please specify): Funding models compared to performance measure targets

3. **Use a bridge deterioration model?** Yes.
4. **Bridge deterioration model:** An in-house developed program.
5. **Using the model for:**

   Long-range budget planning

6. **Model adjusted for specific parameters?** No.
7. **Bridge elements included in the model:**

   Deck

   Superstructure

   Substructure

   Other (please specify): Culvert rating

8. **Model takes into account specific bridge maintenance treatments?** No.
9. **Approach to isolate benefit for each specific bridge maintenance treatment:** Not that I am aware of, other than we know that as deck condition goes, so goes our analysis. The deck condition and maintenance actions to the bridge deck have the greatest [e]ffect on the results.
10. **Additional comments:** [No response.]

Maryland Transportation Authority

Contact: Ruel Sabellano, Structures System Preservation, Maryland Transportation Authority, rsabellano@mdta.state.md.us, 410-537-7850.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Just started.

   Crack sealing: Per condition inspection.

   Expansion joint gland repair: Per condition inspection.

   Poured joint sealing: Per condition inspection.

   Spot painting: Per condition inspection.

   Deck silane/siloxane sealing: Per condition inspection.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** Yes, we are in the process of quantifying. This will be included in our asset management plan.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

   We are still in the process of quantifying through our asset management plan.

3. **Use a bridge deterioration model?** Yes.
4. **Bridge deterioration model:** [To be determined]. We have just started our asset management plan.
5. **Using the model for:**

   Project scoping and/or planning

Long-range budget planning

Life-cycle cost analyses

Legislative reporting

Resource demand models

6. **Model adjusted for specific parameters?** Yes.

6a. **Parameters:**

Construction materials

Design type

Average daily traffic (ADT)

Rebar coating

Use of deck overlays

7. **Bridge elements included in the model:**

Deck

Superstructure

Substructure

8. **Model takes into account specific bridge maintenance treatments?** Yes. Bridge washing, painting, deck sealing, joint sealing, debris removal.

9. **Approach to isolate benefit for each specific bridge maintenance treatment:** [To be determined] in a year.

10. **Additional comments:** [No response.]

Further Examination of Maryland Transportation Authority's Deterioration Model

When asked to provide additional details about the deterioration model in development, the survey respondent indicated that Maryland Transportation Authority's deterioration model and asset management plan are too early in their respective development phases for him to provide further information about the structure of those tools. Ruel Sabellano indicated that he will contact MnDOT when further details of the model and plan are available.

Michigan

Contact: Rebecca Curtis, Design Division/Bridge Development Engineer, Michigan Department of Transportation, curtisr4@michigan.gov, 517-449-5243.

1. **Bridge maintenance treatments—type and frequency in years:**

Bridge flushing (washing): As needed.

Crack sealing: As needed.

Expansion joint gland repair: As needed.

Poured joint sealing: As needed.

Other (please describe the treatment and indicate frequency): Epoxy penetrating healer sealer, thin epoxy overlay, barrier wall silane sealing—all as needed.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** Engineering

reasoning would say that any effort to slow the ingress of harmful deicing chemicals into a bridge element will slow its deterioration.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

Engineering judgment

3. **Use a bridge deterioration model?** Yes.

4. **Bridge deterioration model:** Markov transition probabilities using minimum NBI condition ratings as well as element level deterioration (although waiting to upgrade to next version of BrM to do this again).

5. **Using the model for:**

Long-range budget planning

Life-cycle cost analyses

Legislative reporting

Other (please specify): Evaluating materials (conventional and innovative)

6. **Model adjusted for specific parameters?** Yes.

6a. **Parameters:**

Other (please specify): Budget, the items above based on selecting the correct inventory.

7. **Bridge elements included in the model:**

Other (please specify): Uses minimum condition rating of all major NBI components.

8. **Model takes into account specific bridge maintenance treatments?** No.

9. **Approach to isolate benefit for each specific bridge maintenance treatment:** [No response.]

10. **Additional comments:** [No response.]

Further Examination of Michigan DOT's Deterioration Model

The following summarizes the results of a follow-up interview with Rebecca Curtis, the survey respondent, and an examination of presentations describing Michigan DOT's Bridge Condition Forecast System (see Related Resources on page 27).

Use of Markov Transition Probabilities to Assess Deterioration

Michigan DOT's Bridge Condition Forecast System is a spreadsheet-based tool that forecasts network conditions when considering a range of bridge maintenance strategies. The tool is used to manage populations of bridges rather than prioritize individual projects. Lacking actual deterioration data, the agency uses engineering judgment in making determinations with regard to deterioration.

BCFS uses Markov chain transition probabilities to deteriorate NBI condition ratings of the bridge network while evaluating a mix of three types of activities (preventive maintenance, rehabilitation and replacement). The analysis compares different annual budgets using average cost per deck area.

BCFS Inputs and Outputs

Inputs into BCFS include:

- Current bridge conditions using NBI condition ratings derived from biennial bridge inspection data.
- Annual budgets.
- Strategies that include what Michigan DOT calls a "mix of fixes," identifying the percent of the budget dedicated to each work category (preventive maintenance, rehabilitation and replacement).

- Project costs by work category, including expected inflation.
- Preservation path, which indicates the anticipated benefits of each work category.

The analysis incorporates programmed projects and unprogrammed dollars to compare alternative scenarios. Condition over time is assessed and plotted for a standard deterioration rate. Comparisons are made to assess the impact of more or less funding. Factors can also be adjusted to assess the impact of the use of better, longer-lasting materials on deterioration rates. Outputs include a Transition Probability Matrix and forecasts of statewide bridge deterioration rates and bridge condition.

Typically, the model forecasts out 10 years, separating out freeway and nonfreeway bridges, but can be adjusted to reflect a longer timeline to meet the needs of the state's long-range plan.

Using the Model
BCFS users begin by adding budget data and data imported from the bridge inventory that reflect condition ratings resulting from the latest biennial inspection cycle. This data is used in three scenarios:

- A project-based strategy that imports the agency's five-year call for projects.
- Two potential strategies that do not include specific projects to determine the optimal strategy on a network basis.

Using the data entered, the BCFS spreadsheet uses Markov chains to determine the deterioration rate of the network. Under the Transition Probabilities page, users can adjust the expected impact of the work types (preventative maintenance, rehabilitation or replacement) with regard to the minimum condition rating expected for a structure following a specific work type. This is where adjustments can be made to reflect the impact of innovative and longer-lasting materials. Plots using average costs of a typical improvement and its expected effect on condition rating can be compared to more expensive interventions that employ innovative, longer-lasting materials to identify when the agency would achieve a return on its investment in the new material or technology.

Parameters that can be edited include allocations based on type of work (preventative maintenance, rehabilitation or replacement) and the effectiveness of the work completed (impact on NBI rating).

BCFS Results
The model is used to determine the value of bridge preservation at the network level and identify the ideal mix of fixes, assess the impact of revised budgets and identify the funding needed to meet goals, and determine the value of innovative materials. A Transition Probability Matrix identifies how the NBI condition ratings of bridges in the network will change over time based on budget and the type of activity. The agency monitors the number of bridges in each NBI condition state (0 through 9) and sets goals for the percent of bridges in good/fair condition based on NBI condition ratings.

BCFS and AASHTOWare Bridge Management Software
Curtis is a member of the AASHTOWare Bridge Management Task Force, which is assisting in the development and direction of the BrM software. Version 5.2.3 of BrM is expected to include a Markov-based NBI determination model that is similar to BCFS but will have more bridge-specific data. Curtis noted that Michigan DOT expects to transition to Version 5.2.3 of BrM when it becomes available (estimated to be late summer 2016) for most of the agency's bridge management purposes, noting that the BrM evaluation is made at a bridge-specific level, not at the network level analyzed by BCFS. BCFS, with its spreadsheet-based model that can be adjusted more easily than a database to produce comparable results, will continue to be used to recast historical data and determine the impacts of varying maintenance strategies.

Lessons Learned
Curtis noted that a network-level assessment of deterioration rates such as the one conducted using BCFS should not be done on a too-small network. The network being analyzed must be of sufficient size to reduce the impact of outliers. Curtis recommends importing the deterioration rates from a larger network when applying the deterioration model to a small network.

Related Resources:

"Network Life Cycle Analysis for Bridge Management," Rebecca Curtis, Michigan Department of Transportation, *2015 Transportation Asset Management Expert Task Group Webinar Series*. http://www.tam-portal.com/wp-content/uploads/2015/09/Michigan-DOT-2015-AASHTO-Asset-Management-Webinar-RLC.pptx
This webinar provides a high-level overview of the role played by BCFS in managing Michigan DOT's bridges, and includes sample screen shots and reports.

"Instituting a Successful Approach to Bridge Management in Michigan," Dave Juntunen, Michigan Department of Transportation, *National Bridge Management, Inspection and Preservation Conference*, November 2011.
https://pavementvideo.s3.amazonaws.com/2011_Bridge_National/PDF/Instituting%20a%20Successful%20Approach%20to%20Bridge%20Management%20in%20Michigan%20-%20Dave%20Juntunen.pdf
This description of bridge management in Michigan includes a discussion of BCFS.

Missouri
Contact: Scott Stotlemeyer, Bridge/Assistant State Bridge Engineer, Missouri Department of Transportation, scott.stotlemeyer@modot.mo.gov, 573-522-8752.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): We prescribe cleaning/flush[ing] decks in the fall and the entire bridge in the spring. In reality, we flush decks/drains at least once a year and the superstructure and substructure occurs less frequently.

   Crack sealing: Crack sealing occurs on a 3- to 5-year cycle depending on the product.

   Expansion joint gland repair: As needed (condition-based).

   Poured joint sealing: As needed (condition-based).

   Spot painting: As needed (condition-based).

   Deck silane/siloxane sealing: Silane is [to] be applied on all new concrete bridge decks. If additional cracking occurs, reapplication is considered in the first 3 years. Additional applications are recommended at 7- to 10-year intervals.

   Other (please describe the treatment and indicate frequency): Our bridge preventive maintenance guidelines can be found at http://epg.modot.org/index.php?title=Category:771_Bridge_Preventative_Maintenance_Guidelines.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** [No response.]

Montana
Contact: Kent Barnes, Bridge Engineer, Montana Department of Transportation, kbarnes@mt.gov, 406-444-6260.

1. **Bridge maintenance treatments—type and frequency in years:**

   Crack sealing: As needed.

   Expansion joint gland repair: As needed.

   Poured joint sealing: As needed.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** [No response.]

New Hampshire
Contact: Doug Gosling, Bridge Maintenance Engineer, New Hampshire Department of Transportation, dgosling@dot.state.nh.us, 603-271-3667.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): 2 (target is annually).

   Crack sealing: 5.

   Expansion joint gland repair: As needed (15).

   Poured joint sealing: 2.

   Deck silane/siloxane sealing: 5.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** [No response.]

New Jersey
Contact: Gerald Oliveto, Operations Support, New Jersey Department of Transportation, gerald.oliveto@dot.nj.gov, 609-462-6229.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Biannually.

   Crack sealing: As needed.

   Expansion joint gland repair: Every five years.

   Poured joint sealing: Every ten years.

   Spot painting: Every ten years.

   Deck silane/siloxane sealing: N/A.

   Other (please describe the treatment and indicate frequency): NJDOT has a complete bridge preventive maintenance manual for various bridge treatments. [See **Appendix B** for the January

2015 revision of the agency's Bridge Preventive Maintenance Program. An update to this document is awaiting Federal Highway Administration approval. As the agency notes, the document identifies New Jersey DOT's "systematic approach to selecting structures and the specific maintenance activities that will be performed on each structure."]

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** A reduction in deficiency reports has been noted by our structural inspection teams as bridges are inspected.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

Condition rating information

Engineering judgment

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** NJDOT utilizes contractor repair forces through contracts issued and bid annually. We attempt to utilize [Federal Highway Administration] funding for as much repair work as possible, as is outlined in our Bridge Preventive Maintenance Guideline document.

North Carolina

Contact: Tim Sherrill, Structures Management Unit, North Carolina Department of Transportation, tmsherrill@ncdot.gov, 919-707-6423.

1. **Bridge maintenance treatments—type and frequency in years:**

Bridge flushing (washing): As needed.

Crack sealing: As needed.

Expansion joint gland repair: As needed.

Poured joint sealing: As needed.

Spot painting: As needed.

Deck silane/siloxane sealing: Not yet using this treatment.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** We work toward condition improvement, which leads to extended service life.

2b. **Method(s) used to quantify benefits of bridge maintenance treatments:**

Condition rating information

Engineering judgment

3. **Use a bridge deterioration model?** Yes.

4. **Bridge deterioration model:** Piece-wise linear deterministic model.

5. **Using the model for:**

Long-range budget planning

Life-cycle cost analyses

Legislative reporting

6. **Model adjusted for specific parameters?** Yes.

6a. **Parameters:**

Construction materials

Design type

Average daily traffic (ADT)

7. **Bridge elements included in the model:**

Deck

Superstructure

Substructure

Other (please specify): Culverts

8. **Model takes into account specific bridge maintenance treatments?** Yes. Deck treatments and overlays; steel painting and repairs; concrete repairs.

9. **Approach to isolate benefit for each specific bridge maintenance treatment:** Not at the present time, but we are working on developing an approach.

10. **Additional comments:** [No response.]

Oklahoma

Contact: Walter Peters, Assistant Bridge Engineer–Maintenance, Oklahoma Department of Transportation, wpeters@odot.org, 405-521-2606.

1. **Bridge maintenance treatments—type and frequency in years:**

Bridge flushing (washing): Some of our field divisions have done this. Once a year if at all.

Crack sealing: On all new on-system bridges we seal the cracks the following summer after construction.

Expansion joint gland repair: No.

Poured joint sealing: This activity is done on rehab projects.

Spot painting: No.

Deck silane/siloxane sealing: New bridges receive silane treatment the summer following construction; research shows that silane treatments last 15 years.

Other (please describe the treatment and indicate frequency): None.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** We do combination silane/crack seal on new bridges the summer following construction. We currently have a contract for 170 railroad bridges which combines bridge washing with bridge inspection. This may be a one-time effort, but it allowed us to explore the environmental aspects of bridge washing with the [Department of Environmental Quality]. In order to seal the bridge decks on our post-tensioned box girders, we are doing a shot blast, followed by a silane treatment followed by a flood coat (about 35 structures).

Tennessee
Contact: Thomas E. Quinn, C.E. Manager 2, Structures Division–Bridge Repair, Tennessee Department of Transportation, tom.quinn@tn.gov, 615-741-8400.

1. **Bridge maintenance treatments—type and frequency in years:**

   Expansion joint gland repair: As needed.

   Poured joint sealing: As needed, usually last only 5 or so years.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** We really don't have [a] set schedule for maintenance activities or routine activities. They are completed as needed. In the past we have not tracked the maintenance activities in a central location. MAP 21 will be changing this. We do have Pontis but have not used it for scheduling to date (just run test scenarios).

Vermont
Contact: J.B. McCarthy, Structures/Bridge Maintenance Engineer, Vermont Agency of Transportation, jb.mccarthy@vermont.gov, 802-505-1451.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): 2.

   Crack sealing: As needed.

   Expansion joint gland repair: As needed.

   Poured joint sealing: 5.

   Spot painting: As needed.

   Deck silane/siloxane sealing: 5.

   Other (please describe the treatment and indicate frequency): N/A.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** We have recently developed an outline for a bridge maintenance/preservation guide with the goal of quantifying the benefits of a sound bridge preservation program. We are working on securing the required funding to begin such a program in our 2017 capital program budget.

Virginia
Contact: Adam Matteo, Assistant State Structure and Bridge Engineer, Bridge Maintenance, Virginia Department of Transportation, adam.matteo@vdot.virginia.gov, 804-786-5171.

While Virginia DOT did not respond to the survey conducted for this project, an agency representative did respond to interview questions posed in connection with another recent MnDOT inquiry. That MnDOT project examined the use of culvert deterioration models (see TRS 1508, State of the Practice for Managing, Maintaining and Operating Culverts: A Review of Deterioration Curves and Tools, available at

http://www.dot.state.mn.us/research/TRS/2015/TRS1508.pdf). The following is an excerpt from Virginia DOT's interview responses related to deterioration modeling for culverts:

1. **Does your agency use deterioration models for culverts? Can you provide documentation of these models?** Yes for culverts meeting NBI criteria for inspection (about 8,000 total) via Pontis: See Appendix D.1 [see **Appendix C** in Related Resource below] and Appendix D.2. For its tens of thousands of smaller pipes under 10 feet in diameter, it uses a service life rating system based on site conditions, such as pH.
2. **Do your models incorporate the effects of culvert maintenance? If not, have you quantified the benefits of culvert maintenance in other ways?** Virginia DOT's models do not incorporate the effects of culvert maintenance, and they have not quantified maintenance benefits in other ways.
3. **What assumptions do you make when tracking culvert life-cycle costs? How do you factor in a) type of pipe material and b) culvert maintenance?** Virginia DOT bases its models on the current valuation of structures. It looks at depreciation caused by deterioration.
4. **How does your agency define culvert failure? How do you take into account different failure modes (such as material deterioration, unexpected settling due to poor compaction, joint separation and so on)?** A condition rating of 4 or less, which indicates it is structurally deficient. These ratings are based on a nationally published standard from FHWA.

Further Examination of Virginia DOT's Culvert Deterioration Model

A follow-up contact to Virginia DOT's Adam Matteo sought additional information about the modeling used for culverts rated with NBI criteria (for MnDOT, these culverts are 10 feet and greater in diameter). The following summarizes interview results.

1. **For culverts that are rated with the NBI criteria, is the model used to manage these culverts based on engineering judgment, historical data, research or something else?** The model uses historical data. Beginning in the late 1990s, the agency graded a bridge (or bridge-rated culvert) using commonly recognized (CoRe) element data to understand the average condition and determine when repair is required. Matteo noted that this is a more refined way of examining a bridge rather than looking only at the deck, superstructure and substructure.
2. **Can you tell me more about VDOT's use of the Virginia Health Index and equity calculations in making bridge management decisions?** The agency's planned use of metrics will optimize spending on culvert maintenance. Use of the Virginia Health Index, which will be launched over the coming months, will allow the agency to monetize assets in terms of equity by identifying the current valuation of the asset. With the index, the agency can compare the results of possible interventions by examining the resulting values of the bridge and comparing cost/benefit ratios for each intervention. When the transition to the new evaluation process is complete, the calculations, which are described in **Appendix C** cited below, and element data will be incorporated into the agency's deterioration model. Documentation about the new process is expected to be available later in January 2016.

Related Resource:

"Using Current Valuation to Direct Maintenance Decisions," Jeff Milton, *2015 AASHTO Subcommittee on Maintenance Conference*, July 2015.
See **Appendix C**.
This conference presentation describes the agency's maintenance prioritization process and the Virginia Health Index, including sample calculations. The benefits of using equity to guide maintenance decisions:

- Can determine the most cost-effective actions on a given structure.
- Helpful in selecting which structures should be worked on.

- Can be used to measure effectiveness of various work programs.
- Helpful as a measurement of progress.

Washington
Contact: DeWayne Wilson, Bridge Asset Management Engineer, Washington State Department of Transportation, wilsond@wsdot.wa.gov, 360-705-7214.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Annually on steel truss bridges.

   Crack sealing: Just starting to do select bridges.

   Expansion joint gland repair: Minimal.

   Poured joint sealing: Deck joints in steel truss bridges every 5 years.

   Spot painting: None.

   Deck silane/siloxane sealing: None.
2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
4. **Bridge deterioration model:** WSDOT has good [bridge management system] data that is used to develop preservation needs.
10. **Additional comments:** [No response.]

West Virginia
Contact: William Varney, State Bridge Engineer, West Virginia Department of Transportation, william.h.varney@wv.gov, 304-558-9490.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): We try every year, but it depends on manpower.
2. **Attempted to quantify benefits of bridge maintenance treatments?** No.
3. **Use a bridge deterioration model?** No.
10. **Additional comments:** [No response.]

International Responses

Danish Road Directorate
Contact: Arne Henriksen, Project Manager, Danish Road Directorate, arh@vd.dk, 45-4046-2443.

1. **Bridge maintenance treatments—type and frequency in years:**

   Bridge flushing (washing): Only few big bridges few times a year.

   Crack sealing: In pavement once every year.

   Expansion joint gland repair: ?

Poured joint sealing: When needed.

Spot painting: We have very few painted structures, when needed.

Deck silane/siloxane sealing: We will not use these products on bridge decks.

Other (please describe the treatment and indicate frequency): We make work orders for minor maintenance yearly.

2. **Attempted to quantify benefits of bridge maintenance treatments?** Yes.

2a. **Quantification efforts in terms of extended service life or reduced life-cycle cost:** We do not quantify but know this work is important to prevent major repair later, thus prolong the lifetime of bridge elements.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** You don't need to use a specific model to estimate deterioration, but a combination of many parameters.

Norwegian Public Roads Administration
Contact: Knut A. Grefstad, Bridge Department, Norwegian Public Roads Administration, knut.grefstad@vegvesen.no, 47-4814-96655.

1. **Bridge maintenance treatments—type and frequency in years:**

Bridge flushing (washing): Every year.

2. **Attempted to quantify benefits of bridge maintenance treatments?** No.

3. **Use a bridge deterioration model?** No.

10. **Additional comments:** [No response.]

Related Resources

The literature search identified publications, some highly technical, that address the quantification of bridge maintenance activities and the development and use of bridge deterioration models. The citations below are organized in two sections:

- Quantifying the benefits of bridge maintenance activities.
- Deterioration models.

Within each section, citations are organized by:

- National research and guidance.
- State research.
- Additional resources.

Quantifying the Benefits of Bridge Maintenance Activities

National Research and Guidance

Research in Progress: Proposed AASHTO Guide for Bridge Preservation Actions, NCHRP Project 14-36.
Abstract at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3951
From the abstract:

> The objective of this research is to develop a bridge preservation guide for possible adoption by AASHTO. The proposed AASHTO guide shall be developed based on data to be collected from representative agencies. At the minimum, the guide shall include: (1) a catalog of bridge element preservation actions and (2) the criteria and selection methodology of bridge preservation actions with associated costs and benefits for use in life cycle cost analysis and possible integration into a bridge management system.

The research contractor has been selected for this project; the contracting process is underway. The expected project duration is 27 months.

Practical Bridge Preservation Actions and Investment Strategies, NCHRP Project 14-23.
Abstract at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2968

Note: A decision was made to discontinue work on this project beyond Phase II. While work was completed under Phases I and II of this project, the three deliverables submitted by the research team were not reviewed by the NCHRP project panel (see Related Resources below for these documents). Further research on bridge preservation activities is being conducted under NCHRP Project 14-36, which is cited above.

From the abstract:

> The objective of this research is to develop a handbook for possible adoption by AASHTO that will assist state departments of transportation in making bridge preservation investment decisions for an individual bridge, for a category of bridges with similar characteristics, and at the network level. The handbook should include a decision-making process and associated tools to assist in quantifying the benefits of selecting appropriate bridge preservation actions and investment strategies.

Related Resources:

Practical Bridge Preservation Actions and Investment Strategies, David W. Johnston, John M. Hooks, Edward S. Welch, Allen R. Marshall and Jeremy K. Shaffer, Final Report on NCHRP Project 14-23, November 2014.
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP14-23_FR-ReportSections.pdf
Topics addressed in this report include cataloging bridge element preservation actions; assessing the preservation impacts on aspects of bridge service life; metrics for analysis of bridge preservation action effectiveness; element condition deterioration and impact of preservation; methodologies to prioritize preservation actions; and development of a decision and analysis support tool.

Handbook for Practical Bridge Preservation Actions and Investment Strategies, David W. Johnston, John M. Hooks, Edward S. Welch, Allen R. Marshall and Jeremy K. Shaffer, Final Report – Handbook Sections on NCHRP Project14-23, November 2014.
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP14-23_FR-HandbookSections.pdf
The following description of this handbook is from page 4 of the PDF:

> This Handbook has multiple uses. Chapter 2 provides detailed information on bridge elements, preservation actions that may be applied to elements and the service conditions that impact action effectiveness. Chapter 3 includes a catalog of preservation actions that can be applied to selected bridge elements as defined in the AASHTO Manual for Inspection of Bridge Elements, First Edition, 2013.

Appendix E: Sample Catalog of Bridge Preservation Actions, Impacts, and Metrics, Final Report on NCHRP Project 14-23, November 2014.
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP14-23_FR-AppendixETables.pdf
The project's final report includes multiple references to this document. A description on page 120 of the final report (cited above) describes the contents of this appendix:

> Appendix III: This appendix contains tables displaying the catalog of actions, their resulting impacts and metrics that measure those impacts. The tables are organized for inclusion in Appendix E of the Handbook formatted in groups of three, for example, Tables E-1.1a, E-1.1b, and E-1.1c for the catalog of actions, impacts, and metrics respectively. The line numbers in the tables match in each set of three tables and each line number correspond to a single preservation action.

Research in Progress: Consequences of Delayed Maintenance of Highway Assets, NCHRP Project 14-20A, expected completion date: March 2016.
Abstract at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3533
From the abstract:

> Recent work completed under NCHRP Project 14-20 provided further review of some of the issues related to quantifying the consequences of delayed application of maintenance treatments and identified processes applicable to pavements and bridges (see Special Note A). However, additional research is needed to address these and other issues associated with delayed maintenance treatments, particularly for assets other than bridges and pavements, and to develop processes for quantifying the consequences of such delays and help assess the economic benefits of maintenance actions.
>
> OBJECTIVE: The objective of this research is to develop processes for quantifying the consequences of delayed application of maintenance treatments on highway pavements, bridges, and other physical assets. Consequences shall be expressed in terms of performance indicators (e.g., distress and level of service), costs to owners and road users, and other relevant factors. Delayed maintenance applications may be defined by (1) the inability to meet the agency-defined application schedule or (2) the available budget relative to an unconstrained budget (i.e., availability of the funds required to perform all needed maintenance).

Research in Progress: Bridge Retrofit or Replacement Decisions: Tools to Assess Sustainability and Aid Decision-Making, University Transportation Centers Program, Research and Innovative Technology Administration, expected completion date: December 2015.
Project Overview Report at http://cait.rutgers.edu/files/CAIT-UTC-NC5_0.pdf
From the Project Overview Report:

> This research will set up the framework for a life cycle inventory database for bridge repair and construction techniques including social and environmental sustainability concerns. Bridge experts and practitioners will be recruited to upload their information about the service life of bridges and sustainability impacts to this database. This research will also modify existing early-state commercial product design decision-making tools to create an applicable tool for bridge retrofit decisions utilizing sustainability information available in the life cycle inventory database.

State Research

Indiana

Research in Progress: Strategic Scheduling of Infrastructure Maintenance and Rehabilitation Funding, Purdue University and Indiana Department of Transportation, expected completion date: August 2016.
Citation at http://trid.trb.org/view.aspx?id=1300132
From the abstract:

> It is anticipated that the agency will use results of this study to enhance its decisions with regard to four key elements of asset management: determine the optimal timing of specific treatments for bridge and pavement preventive maintenance and rehabilitation (M&R); establish cost-effective long-term M&R schedules

(treatment types and their respective timings) over asset life cycle; quantify the consequences of delayed M&R; develop network-level performance measures for purposes of benchmarking its overall performance vis-à-vis those of other state agencies.

Recently Completed Research: Bridge Preservation Treatments and Best Practices, Purdue University and Indiana Department of Transportation, completion date: October 28, 2015. (The final report for this project was in production at the time of publication of this report and is expected to be published in March 2016.)
https://engineering.purdue.edu/JTRP/projects
(Scroll down to SPR-3617 to view this project abstract.)
From the project's abstract:

> Cost-effective bridge maintenance practices need to be formulated and implemented to prolong the useful service life of Indiana bridges. This project will examine bridge maintenance operations being conducted in other states, as well as the maintenance being done within the various INDOT Districts. A list of the most promising maintenance activities will then be developed and a thorough assessment of the activities will be performed. The deliverable product is a list of effective maintenance operations and recommendations of when they need to occur. Recommendations for training will also be provided.

Related Resource:

> **"Bridge Preservation Treatments and Best Practices,"** Mark D. Bowman and Luis Moran, *Purdue Road School 2015*, March 2015.
> http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1472&context=roadschool
> This presentation summarizes the objectives of research project SPR-3617 cited above.

Washington

Determining the Cost/Benefit of Routine Maintenance Cleaning on Steel Bridges to Prevent Structural Deterioration, Jeffrey Berman, Charles Roeder and Ryan Burgdorfer, Washington State Department of Transportation, September 2013.
http://www.wsdot.wa.gov/research/reports/fullreports/811.1.pdf
From the abstract:

> This study was conducted in cooperation with the United States Department of Transportation, Federal Highway Administration. The objective of this study is to identify the key variables necessary in estimating the impact of regular washing of steel bridges on the paint and service life, recommend methods for recording data in order to most effectively estimate the benefits of bridge washing, and to develop a framework for assessing the impact of bridge washing on paint life. A literature review was conducted to learn more about the mechanisms of corrosion. Then a nationwide survey was sent out to state transportation agencies. A follow-up survey was conducted in order to obtain more detailed information about certain washing programs. It was concluded that little information on the effects of bridge washing exists and it is only deemed beneficial based on anecdotal assumptions. An experiment is proposed for [Washington State Department of Transportation] that will provide hard data to make a decision.

Additional Resources

"Risk-Based Maintenance Optimization of Deteriorating Bridges," Duygu Saydam and Dan M. Frangopol, *Journal of Structural Engineering*, Vol. 141, Issue 4, April 2015.
Citation at http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001038
From the abstract:

> Risk-based performance measures integrate probability of component or system failure with the consequences of this event. In this paper, a novel risk-based maintenance optimization methodology for deteriorating bridges to find the optimum maintenance options and their timing is proposed. Finding the optimum maintenance types and schedule for different components of bridges is formulated as a multicriteria

optimization in which the lifetime maximum value of expected losses associated with failure and the lifetime total expected maintenance cost are considered as the conflicting objectives. The risk-based maintenance approach accounts for different deterioration levels of bridge components and consequences of both component failure and system failure. The methodology is illustrated on a bridge superstructure. The effects of considered life span of the structure and availability of maintenance options on optimum solutions are also investigated.

"Performance Life Cost-Based Maintenance Strategy Optimization for Reinforced Concrete Girder Bridges," Jinsong Zhu and Boqi Liu, *Journal of Bridge Engineering*, Vol. 18, Issue 2, pages 172-178, February 2013.
Citation at http://dx.doi.org/10.1061/(ASCE)BE.1943-5592.0000344
From the abstract:

> This paper presents a maintenance strategy optimization method for RC girder bridges by considering the performance indicators, service life and life cycle maintenance cost, as criteria. The condition and reliability indices are defined as performance indicators. The deteriorated processes of performance indicators with and without maintenance actions are described as multilinear models. The life cycle maintenance planning optimization of deteriorating bridges is formulated as a multiobjective problem to be solved by an improved nondominated sorting genetic algorithm with controlled elitism. The condition index, reliability index, service life, and life cycle maintenance cost of the bridge are considered as four separate objective functions. A simply supported RC girder bridge is analyzed as an application example to demonstrate the usefulness of the proposed procedure.

"Life-Cycle Cost Assessment of Maintenance Strategies for RC Structures in Chloride Environments," John A. Mullard and Mark G. Stewart, *Journal of Bridge Engineering*, Vol. 17, Issue 2, pages 353-362, March 2012.
Citation at http://dx.doi.org/10.1061/(ASCE)BE.1943-5592.0000248
From the abstract:

> Corrosion of the reinforcing steel can cause cover cracking and eventual spalling of reinforced concrete (RC) surfaces, resulting in costly and disruptive repairs. The present paper will compare the effect of maintenance and repair strategies on the timing, extent, and cost of remediation actions over the service life of a RC structure in a chloride environment. The paper presents a probabilistic reliability analysis, which is used to predict the likelihood and extent of corrosion-induced cracking to RC structures. A spatial time-dependent reliability model has been developed where concrete properties, concrete cover, and the surface chloride concentrations are treated as random fields. This allows for the calculation of the probability that a given extent of damage will occur for any time period. Maintenance strategies and repair efficiencies are incorporated in a Monte-Carlo event-based simulation analysis, allowing a comparison in terms of cost and number of repairs over the service life of a RC structure. Thus, the expected timing and extent of repairs can be predicted for various design parameters, inspection intervals, repair thresholds, maintenance strategies, and efficiency of repairs. Results are presented for a RC bridge deck subject to a marine environment. The life-cycle cost (LCC) analysis considers repair and user delay costs. User delay costs can be up to ten times higher than the cost of repair itself. The statistical variability of predicted LCCs can be large, with coefficients of variation exceeding one.

"Integrated Multiple-Element Bridge Management System," Hatem Elbehairy, Tarek Hegazy and Khaled A. Soudki, *Journal of Bridge Engineering*, Vol. 14, Issue 3, pages 179-187, May/June 2009.
Citation at http://trid.trb.org/view/2009/C/888033
From the abstract:

> This paper presents the development of a comprehensive bridge management system that optimizes repair decisions considering multiple bridge elements and large networks of bridges. The strength of the system stems from its integration of project-level decisions of the best repair strategies to use on the elements of each bridge, and network-level decisions of the most beneficial repair year for each bridge. These decisions,

however, represent complex optimization problems that traditional optimization techniques are often unable to solve. To handle such a large problem, the proposed system uniquely segments the problem into smaller sequential optimizations that are solved using the genetic algorithms technique. The system uses a year-by-year optimization formulation to maximize the benefit/cost ratio of the repairs, and to maximize the overall network condition. The paper provides a description of the multiple-element system, its life-cycle formulation, and its related models for deterioration analysis and repair cost estimation. System implementation and an example application are then presented to demonstrate the practicality of the system and its performance on different sizes of bridge networks.

Deterioration Models

National Research and Guidance

Consequences of Delayed Maintenance (Phase I), NCHRP Project 14-20.
Abstract at http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2717

Note: After reviewing the findings of Phase I of this project, the project panel expressed concerns about many aspects of the proposed work and made the determination to discontinue work on the project. Related work will be conducted under NCHRP Project 14-20A; see page 36 of this report for more information about the NCHRP project in progress.

From the abstract:

> The objectives of Phase I of National Cooperative Highway Research Program (NCHRP) project 14-20 are: 1) to summarize the literature on analytical tools for bridge and pavement asset management, the known costs of delayed maintenance, and the risks associated with delaying maintenance; 2) to develop prototype tools to quantify the costs of delayed maintenance actions on pavement and bridges; 3) to illustrate the application of the prototype tools to estimate the cost of delayed maintenance on pavement and bridges; and 4) to summarize other consequences of delayed maintenance not readily incorporated into the prototype tools.

Related Resource:

> **Consequences of Delayed Maintenance**, NCHRP Project 14-20, Interim Report, Cambridge Systematics, Inc., September 2011.
> http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP14-20_InterimReport.pdf
> A discussion of models used to forecast deterioration begins on page 34 of the PDF. The authors describe two approaches to modeling:
>
> - *The Delphi method*. This method involves structured communication among a panel of experts. As the authors indicate:
>
> > DOT staff with significant experience applying maintenance actions and observing the impact of those actions on infrastructure conditions can apply the Delphi method to combine their knowledge into a single, commonly agreed-upon, model for predicting future conditions. Similarly, they could apply the Delphi method to select proper maintenance actions based on their knowledge of the long term costs and benefits of potential actions. There are no specific analytical models for applying this method, but often agencies collect and analyze structured data using an asset management systems to aid in the decision-making process.
>
> - *A data-driven method*. This method uses "historical data to develop statistical relationships between condition and maintenance actions, or between maintenance actions and agency and user costs to forecast future performance and costs." The relationships identified in the analysis are

combined with cost optimization techniques to select a maintenance treatment that minimizes long-term maintenance costs.

The authors note that "bridge management systems often employ the Delphi method to predict future condition, and the data-driven method, typically minimizing long-term costs, to select proper maintenance actions." Among the models considered in this report:

- Pontis (state-specific implementation of the AASHTO software now known as AASHTOWare Bridge Management).
- National Bridge Investment Analysis System (FHWA).
- Bridge Needs Analysis Model (New York State DOT).
- Project Level Analysis Tool (Florida DOT).
- Multi-Objective Optimization System. (This is the product of NCHRP Report 590 (see the citation below). The MOOS model's approach is similar to the one used by Pontis and NBIAS.

The report's recommendations for model use appear on page 37 of the PDF:

> The state of the practice is best represented by the modeling approach used by Pontis and NBIAS. There have been several improvements to this approach, including, for example, those made in the MOOS and PLAT model. However, the NCHRP 14-20 research team recommends using an approach based on NBIAS because the tool includes many national defaults needed for the analysis, and because data required to use the NBIAS models are readily available for all states through the NBI files.
>
> However, it is not recommended that NBIAS be used directly. The current structure of the system is not designed to project the costs of delayed maintenance as defined for this project. Instead, it is recommended that key components of NBIAS be transformed into a prototype model that can be used with any NBI file to estimate the cost of delayed bridge maintenance. These key components are element deterioration models, an optimal maintenance policy, and the agency and user costs associated with each maintenance action.

NCHRP Report 590: Multi-Objective Optimization for Bridge Management Systems, Vandana Patidar, Samuel Labi, Kumares C. Sinha and Paul Thompson, 2007.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_590.pdf
Referred to as a "preservation model" or "optimization model," the product of this research is referenced in the citation above. From the foreword:

> Currently available bridge management system (BMS) tools compute an optimal solution based on the objective of least long-term cost. Bridge managers are finding that their constituents require bridge conditions to be substantially better than a least long-term cost solution would provide. Research was needed to develop a multi-objective optimization model.
>
> To address this need, two distinct BMS optimization models were developed: a network-level model and a bridge-level model. The network-level model provides a decision-making tool that optimizes bridge actions for multiple performance criteria. These performance criteria could be cost, condition, risk, highway bridge replacement and rehabilitation (HBRR) program eligibility, bridge health index, or others. The bridge-level model evaluates the effect of bridge action alternatives on life-cycle cost and other performance criteria for the purpose of selecting projects that are consistent with the network goals.

State Research

Colorado

Deterioration and Cost Information for Bridge Management, George Hearn, Colorado Department of Transportation, May 2012.
http://www.coloradodot.info/programs/research/pdfs/2012/pontis.pdf/view
From the abstract:

> This study applies contract bid tabulations and element-level condition records to develop element-level actions, costs for actions, transition probabilities for models of deterioration of bridge elements, and transition probabilities for improvements to elements due to actions. The information on actions, costs, and transition probabilities is input to a Pontis [bridge management system] bridge database. The study uses transition probabilities for element deterioration to compute the number of years to possible loss of safety in bridges, and to compute the number of years for inspection intervals. It examines variations in costs of actions and deterioration of elements among Colorado Department of Transportation (CDOT) regions. A set of software applications was developed to handle bid tabulations, compute costs of actions, compute transition probabilities, and mediate the steps needed for movement of data into and out of Pontis BMS.

An implementation plan is included with suggestions regarding merging the Pontis bridge database with Colorado DOT's OnSys bridge database, developing procedures for element-level tracking of repair and rehabilitation work on in-service bridges and developing tools outside of Pontis for decision support for bridge projects.

Florida

Enhancement of the FDOT's Project Level and Network Level Bridge Management Analysis Tools, John O. Sobanjo and Paul D. Thompson, Florida Department of Transportation, February 2011.
http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_MNT/FDOT_BDK83_977-01_rpt..pdf
Researchers developed improved deterioration and action effectiveness models for Pontis and Florida DOT's Project Level Analysis Tool. PLAT is an Excel-based model designed to work with Pontis using life-cycle analysis to aid in decision-making. The Network Analysis Tool uses PLAT results to develop systemwide estimates of funding needs and performance expectations. In another aspect of the project, researchers validated cost models for Pontis, PLAT and NAT.

Indiana

Research in Progress: Models to Support Bridge Management, Purdue University and Indiana Department of Transportation, expected completion date: December 2015.
Citation at http://trid.trb.org/view/2014/P/1363039
From the abstract:

> The research product will be a set of deterioration models for bridge deck, superstructure, substructure and the entire bridge. Separate models will be provided on the basis of highway functional class, bridge material type and the climate region. Improved deterioration models will provide information for the decisions made by INDOT regarding bridge investments.

Michigan

"Instituting a Successful Approach to Bridge Management in Michigan," Dave Juntunen, Michigan Department of Transportation, *National Bridge Management, Inspection and Preservation Conference*, November 2011.
https://pavementvideo.s3.amazonaws.com/2011_Bridge_National/PDF/Instituting%20a%20Successful%20Approach%20to%20Bridge%20Management%20in%20Michigan%20-%20Dave%20Juntunen.pdf
This conference presentation describes Michigan DOT's Bridge Condition Forecast System and highlights key aspects of the system, which:

- Evaluates different mix of fixes (preventive maintenance, rehabilitation and replacement).
- Compares different yearly budgets.
- Uses average cost per deck area.
- Deteriorates population of bridges using transition probabilities.
- Allows user to set "Preservation Path" to identify the bridges that will be worked on and the desired end result.

Related Resource:

Best Practices in Bridge Management Decision-Making, NCHRP Project 20-68A, U.S. Domestic Scan Program, Scan 07-05, November 2009.
http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-68A_07-05.pdf
This domestic scan project focused on state DOT practices to identify, prioritize and execute programs to manage highway bridges. Michigan DOT was among the 21 state DOTs participating in the scan. Page 109 of the PDF describes Michigan DOT's spreadsheet-based Bridge Condition Forecast System:

> Michigan uses spreadsheet-based procedures to forecast network conditions that may result from various maintenance strategies. The spreadsheet is called the Bridge Condition Forecast System (BCFS). The inputs to BCFS are an annual budget and estimated costs for bridge replacement, bridge rehabilitation, and bridge preventive maintenance. Costs are expressed as unit cost per bridge deck area.
>
> BCFS contains Markov-chain deterioration models for NBI condition ratings. Of the two chains, one is for untreated, continuing deterioration and the other is for the outcomes of projects to improve bridge conditions (see Figure 8.5 on page 76). BCFS provides a network-level analysis. An output of BCFS is a measure of future network performance.

Minnesota

Determining Economic Strategies for Repair and Replacement of Low Slump Overlays of Bridge Decks, Justin M. Zimmerman, Steven A. Olson and Arturo E. Schultz, Minnesota Department of Transportation, May 2007.
http://www.lrrb.org/PDF/200714.pdf
From the abstract:

> In the interest of providing tools for the cost-effective maintenance of an aging inventory of bridges, a method for comparing feasible repair/replacement sequences for low-slump concrete overlays for bridge decks is developed. The method relies on a technique for computing deterioration curves using inspection data from the National Bridge Inventory. Over twenty years of inspection data for bridge decks in Minnesota, which were overlaid with low-slump concrete overlays placed between 1974 and 1981, were used. The deterioration curves were assumed dependent on several material and geometric variables identified by means of a literature review, and the statistical significance of these parameters on deterioration rates was examined. These variables include span length, average daily traffic, and superstructure material type, and piecewise linear deterioration curves were constructed for various subgroups with similar deterioration characteristics. Present value cost analysis was used to price the available options by identifying the sequence of repairs that has the least cost while maintaining a specified performance measure. The present value analysis considers the costs and timing of repair/replacement sequences, inflation, and the discount rate.

Nebraska

Life-Cycle Assessment of Nebraska Bridges, Afshin Hatami and George Morcous, Nebraska Department of Roads, May 2013.
http://www.transportation.nebraska.gov/mat-n-tests/research/BridgeOther/Final%20Report%20M312.pdf
From the abstract:

> Life-cycle cost analysis (LCCA) is a necessary component in bridge management systems (BMSs) for assessing investment decisions and identifying the most cost-effective improvement alternatives. The LCCA helps to identify the lowest cost alternative that accomplishes project objectives by providing critical information for the overall decision-making process. The main objective of this project is to perform LCCA for different maintenance strategies using the developed deterioration models and updated cost data for Nebraska bridges. Deterministic and probabilistic LCCA using RealCost software for deck overlay decisions, expansion joint replacement decisions, and deck widening versus deck replacement decisions are presented. For deck overlay decision, silica fume overlay, epoxy polymer overlay, and polyester overlay are compared against bare deck with respect to life cycle cost for variable structural life. In expansion joint replacement decisions, two alternatives are compared: relocating abutment expansion joints at the grade beam; and replacing abutment expansion joints at the same place. Deck widening is compared with deck replacement in five different bridges.

Related Resource:

> **Developing Deterioration Models for Nebraska Bridges**, Afshin Hatami and George Morcous, Nebraska Department of Roads, July 2011.
> http://ntl.bts.gov/lib/45000/45600/45686/Morcous_M302_FINAL.pdf
> From the abstract:
>
> > The objective of this project is to develop deterioration models for Nebraska bridges that are based on the condition ratings of bridge components (i.e. deck, superstructure, and substructure) obtained from bridge inspections since 1998 up to 2010. The impact of governing deterioration factors, such as structure type, deck type, wearing surface, deck protection, ADT, ADTT, and highway district, is considered in developing these models. Recently, NDOR decided to adopt "Pontis", the BMS supported by the AASHTO, to avoid the frequent updates of NBMS, which is costly and time-consuming. Pontis requires the use of a specific type of deterioration models (i.e. transition probability matrices), which are not available for Nebraska bridges. Therefore, another objective of this project is to develop Pontis deterioration models using the inventory and condition data readily available in the NBMS database. Procedures for updating the developed model will be also presented.

North Carolina

Research in Progress: Guidelines for Prioritization of Bridge Replacement, Rehabilitation and Preservation Projects, North Carolina Department of Transportation, expected completion date: July 2017.
Abstract at
https://connect.ncdot.gov/projects/planning/Lists/RNASrchProj/DispForm.aspx?ID=903&ContentTypeId=0x01001325D1791E74A54986A389F4973812BF
From the project summary:

> The project will leverage research on the current law, prior NCDOT practice, and best practices for quantifying criteria related to structural condition, safety, vulnerability, accessibility/congestion, user costs, and other criteria to devise formulas for performance metrics to build the prioritization index (or, potentially, individual indices for Statewide Mobility, Regional Impact, and Division Needs categories of projects). The proposed research principally follows recommended practice outlined in NCHRP Report 590 for establishing prioritization indices through decision-analysis guided by practitioner input to locally calibrate the index to the preferences, goals/objectives, risk attitudes, and needs of the State. The developed indices will provide a data-driven and objective means of quantitatively computing relative priority of specific bridge projects from performance metrics that can be derived largely from design, functional, geographic, traffic, and condition

data readily available in the existing asset management programs. In addition to producing a recommended revision to the current bridge Priority Replacement Index (PRI), the research project will also develop prioritization indices associated with bridge rehabilitation projects and preservation actions, as well as the first culvert priority replacement index.

Determination of Bridge Deterioration Models and Bridge User Costs for the NCDOT Bridge Management System, Tara L. Cavalline, Matthew J. Whelan, Brett Q. Tempest, Raka Goyal and Joshua D. Ramsey, North Carolina Department of Transportation, October 2015.
https://connect.ncdot.gov/projects/planning/Pages/ProjDetails.aspx?ProjectID=2014-07
Excerpts from the abstract:

> In support of data-driven planning, NCDOT's bridge management system (BMS) stores inventory data, including bridge characteristics, inspection data, and rating information, and uses deterioration models and economic models to predict outcomes and to provide network-level and project-level decisions. The objectives of this project were to provide NCDOT with revised, updated deterioration models and user cost tables for use in the BMS software.
>
> ….
>
> Additionally, a unique statistical regression methodology applying survival analysis techniques to better address characteristics of the historical condition rating data was developed and resulted in probabilistic deterioration models for bridge components and culverts that provide significantly improved predictive accuracy and precision over prior deterministic models. These models include transition probability matrices that account for the effects of design, geographic, and functional characteristics on deterioration rates over different condition ratings. These models were found to provide significantly improved prediction accuracy and precision over typical planning horizons used in network analysis. However, while this advanced model was found to best fit the historical condition rating data and provide unique insight on factors influencing deterioration over the life-cycle of each bridge component, it was also discovered that a simplified implementation of the probabilistic deterioration model was able to achieve similar performance without rigorously incorporating the effects of external factors on deterioration rates. To aid in implementation and technology transfer, a software application was developed to facilitate routine updating of both the deterministic and probabilistic deterioration models. Preliminary work to evaluate the relative impact of individual maintenance activities on element condition ratings was performed, including the development of histograms of condition rating changes from prior actions to aid in development of action effectiveness models.

Additional Resources

AASHTOWare Bridge Management (BrM) Software, Version 5.2, AASHTO, March 2013.
http://aashtowarebridge.com/wp-content/uploads/2012/09/5_2-whitepaper-march2013.pdf
AASHTOWare Bridge Management, or BrM (formerly Pontis), is a bridge management system owned and licensed by AASHTO. This software is used by transportation agencies for a range of purposes, including bridge inventory and inspection data storage, deterioration modeling, project planning, and network budget and performance analysis. This white paper describes the features of Version 5.2 of BrM, which will include enhanced deterioration models that use a "new approach based on realistic deterioration models." Also included will be new life-cycle cost analysis tools and project planning modules.

Related Resources:

> **AASHTOWare Bridge Management Review**, undated.
> http://www.dot.state.oh.us/Divisions/Engineering/Structures/Steering%20Committee%20Resources/BrM%20Overview%20for%20SCOJD%20120814%20(1).pptx
> This presentation provides a detailed discussion of Version 5.2.2 of BrM. The new version's enhanced deterioration modeling will implement new deterioration model logic, described as a "Weibull approach to

include time factor," and will allow for multipath deterioration. Slide 27 of the presentation highlights benefits of this new approach to modeling:

- 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.

An example of deterioration modeling and multiobjective analysis appears on slide 28. As the slide's notes indicate, in this example of a railing repair on the approach of a bridge, "the impact can be seen on all components of the bridge, the elements of the bridge, as well as forecasting the overall benefit to the bridge health into the future."

Deterioration Modeling Demo, AASHTOWare Bridge Management, AASHTO, November 2014.
https://www.youtube.com/watch?v=WiHNP4qWKtk&feature=youtu.be
This 14-minute demonstration of deterioration modeling enhancements being developed for implementation with AASHTOWare BrM Version 5.2.2 is available on YouTube. Links to this and other BrM webinars are available at http://aashtowarebridge.com/?page_id=32. The Deterioration Modeling Demo webinar can also be downloaded using this link: http://aashtowarebridge.com/downloads/deterioration_modeling_webinar.zip.

"Adaptive Optimisation Methods in System-Level Bridge Management," Haotian Liu and Samer Madanat, *Structure and Infrastructure Engineering*, Vol. 11, Issue 7, pages 884-896, July 2015.
Citation at http://dx.doi.org/10.1080/15732479.2014.920038
From the abstract:

> In infrastructure management, the slow accumulation of facility condition data and incomplete understanding of the deterioration process can lead to inaccurate deterioration models and subsequently, suboptimal maintenance, rehabilitation and reconstruction decisions and increased system costs. State-of-the-art bridge management systems (such as Pontis) address this problem by successively updating deterioration models over time, by using a class of adaptive control methods known as the certainty-equivalent control (CEC). In this paper, [the authors] demonstrate that CEC does not necessarily guarantee improvement in deterioration model accuracy or savings in system costs for realistic heterogeneous bridge systems undergoing non-Markovian deterioration. [They] further apply an alternative, the open-loop feedback control (OLFC), and demonstrate its superiority to CEC in a simulation study, in which [they] consider a planning agency managing a system of facilities with limited prior knowledge of the deterioration models over a designated planning horizon. [The authors] show that OLFC improves model accuracy and reduces system costs. [They] focus [their] discussion on bridge decks, the component of bridge structures that undergoes the fastest deterioration, but the methodology presented in this paper is applicable to all bridge components.

"Project- and Network-Level Bridge Deck Degradation Models via Neural Networks Trained on Empirical Data," Emily Winn, Rigoberto Burgueno and Syed Waqar Haider, *TRB 92nd Annual Meeting Compendium of Papers DVD*, Paper #13-4989, 2013.
Citation at http://trid.trb.org/view/2013/C/1242916
From the abstract:

> The national bridge inventory (NBI) database offers a wealth of information but its complexity due to non-linear variable relationships, subjectivity from visual inspections, and missing data limit its full utilization for developing performance prediction models. This paper documents how a careful preparation of the NBI database and use of a basic artificial neural network, a multi-layer perceptron (MLP), can be effective for developing bridge deck degradation models. Development of an MLP model for deck surface condition rating and its assessment with statistical metrics are presented, along with its use to create deterioration curves over the life of a deck. An approach for generalizing the neural network model for a population of bridges is also presented. The MLP model had a predictive capability of 83% when allowed a variance equal to bridge inspectors. The generalized MLP degradation curve is more resilient to errors in the data and provides a more

detailed degradation profile than Markov models. Simple MLPs can thus allow for an efficient project and network levels degradation modeling of bridge elements based on empirical historical data.

Methodology of Homogeneous and Non-Homogeneous Markov Chains for Modelling Bridge Element Deterioration, Gongkang Fu and Dinesh Devaraj, Michigan Department of Transportation, August 2008.
http://www.michigan.gov/documents/mdot/MDOT_Research_Report_RC1520_257991_7.pdf
From the abstract:

> Bridge management is an important activity of transportation agencies in the US and in many other countries. A critical aspect of bridge management is to reliably predict the deterioration of bridge structures, so that appropriate or optimal actions can be selected to reduce or minimize the deterioration rate and maximize the effect of spending for replacement or maintenance, repair, and rehabilitation (MR&R). In the US, Pontis is the most popular bridge management system used among the state transportation agencies. Its deterioration model uses the Markov Chain, with a statistical regression to estimate the required transition probabilities. This is the core part of deterioration prediction in Pontis. This report focuses on the Markov Chain model used in Pontis, which is vital to the understanding and implementation of the Pontis software. Emphasis has been made on the limitations of Pontis methodology, and establishing a new method for transition probability estimation. This is because predicting deterioration is the basis for decision-making with respect to MR&R.

Appendix A

Revised Iowa DOT Bridge Condition Index

Similar to the FHWA Sufficiency Rating, but modified to be more sensitive to minor changes.

S_1

Superstructure

If Item 59 is N or	9	then A =	0
	8		2
	7		4
	6		7
	5		10
	4		13
	3		16
	≤ 2	then A =	20

Substructure

If Item 60 is N or	9	then B =	0
	8		2
	7		4
	6		7
	5		10
	4		13
	3		16
	≤ 2	then B =	20

Deck

If Item 58 is N or	9	then	C = 0
	8		1
	7		2
	6		4
	5		6
	4		9
	3		12
	≤ 2	then C=	15

Culvert

If Item 62 is N or	9	then	D = 0
	8		4
	7		8
	6		16
	5		32
	4		40
	3		48
	≤ 2	then D =	55

Load capacity reduction (English Tons or Rating Factor)

$E = (36 – \text{Item } 66)^{1.5} \times 0.2778 \times 0.5$; Always ≥ 0, not > 55: English Tons

$E = \{(1 – \text{Item } 66)*36\}^{1.5} \times 0.2778 \times 0.5$; Always ≥ 0, not > 55: If item 63 is 6, 7, 8, D, E, or F, use this formula.

$$\mathbf{S_1 = 55 - (A+B+C+D+E)} \quad \text{Always} \geq 0$$

S_2

Underclearance

If Item 69 is N or	9	then	A = 0
	8		1
	7		2
	6		4
	5		6
	4		8
	≤ 3	then A =	10

Waterway

If Item 71 is N or	9	then	B = 0
	8		1
	7		2
	6		3
	5		4
	4		5
	≤ 3	then B =	6

Roadway width If Item 43B = 19 or Item 51 = 0, then C = 0

(Item 51/Item 28)	≤14	then	C = 14
	>14 & ≤15	then	C = 10
	>15 & ≤16	then	C = 6
	>16 & ≤17	then	C = 2
	>17	then	C = 0

$$S_2 = 30 - (A+B+C)$$ Always ≥ 0

S_3

Essentiality for public use

K = (S1 + S2)/85

A = (Item 29(ADT) x Item 19(Detour length) x 15)/(200,000 x K)

NHS Highway

If item 104(Highway System) > 0 then B = 5

Else B = 0

S3 = 15 – (A + B) Always ≥ 0

S_4

Structure Type reduction

If Fracture Critical A = 2: If item 92A is Y__, then it is F.C.

If Fracture Critical and Fatigue Vulnerable A = 5: If item 92C is Y__, then it is Fatigue Vulnerable.

Channel Protection

If Item 61 is N or	9	then	B = 0
	8		1
	7		2
	6		3
	5		4
	4		5
	≤3	then	B = 6

S4 = A + B

Priority Ranking = S_1+ S_2+ S_3 - S_4

Appendix B

NEW JERSEY DEPARTMENT OF TRANSPORTATION

BRIDGE PREVENTIVE MAINTENANCE PROGRAM

REVISION III
JANUARY 2015

I. BACKGROUND

An October 8, 2004 memo announced that Highway Bridge Program funds may be obligated for preventive maintenance on Federal-aid highway bridges (other than bridges on roads classified as local roads or rural minor collectors) under Section 309 of the National Highway System Designation Act of 1995 (codified as 23 U.S.C. 116(d)). Under subsection (d) to 23 U.S.C. 116, a preventive maintenance activity shall be eligible for Federal assistance under this title if the State demonstrates to the satisfaction of the Secretary that the activity is a cost-effective means of extending the useful life of a Federal-aid highway.

II. DEFINITIONS

Preventive Maintenance: The American Association of State Highway and Transportation Officials (AASHTO) definition of preventive maintenance is "a planned strategy of cost-effective treatments applied to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without substantially increasing structural capacity)." Preventive bridge maintenance is a planned strategy of cost-effective treatments applied at the proper time to preserve and extend the useful life of a bridge.

III. NJDOT BRIDGE PREVENTIVE MAINTENANCE PROGRAM

The Bridge Preventive Maintenance Program is intended to extend the life of bridges in good-standing condition by applying cost-effective preventive maintenance treatments. Preventive Maintenance will be performed at the optimal time or specified intervals to help preserve bridge conditions throughout its service life or to extend the service life of the bridges. Ride improvement and preventive maintenance of serviceability are key elements of the program. Preventive Maintenance treatments include reducing the amount of water infiltrating the bridge, protecting the bridge elements, slowing the rate of deterioration, and correcting surface deficiencies. Safety improvements are also performed where necessary on structures.

Often, a bridge with numerous visual defects is encountered that is difficult to determine the priority for a plan of repairs. Usually a bridge deteriorates from the top (deck) down. The deck is the first element of a bridge that is impacted by traffic. It also is in the worst environment due to deicing chemicals and temperature variations. The deck acts as a roof over the other elements of the bridge and as such protects the superstructure (beams or girders) and substructure (piers and abutments). A deck that remains dry on the bottom side with no (or very minor) cracks can protect the rest of the bridge indefinitely from most top-down deterioration.

One of the most predominate causes of bridge failure nationwide is the loss of substructure stability due to scour or streambed migration. The undermining of footings/foundations is caused by water action eroding away the supporting soil. Usually this undermining can be detected visually, and corrected relatively easily, if caught in its early stages. This

Preventive Maintenance document addresses the various above-mentioned issues in the same way a bridge usually deteriorates: from the top down.

Projects that address major deficiencies in structures, or increase the capacity of a facility are not addressed in the Preventive Maintenance Program.

IV. BRIDGE PREVENTIVE MAINTENANCE PROGRAM EXPECTATIONS

Preventive maintenance activities will concentrate on treating bridges with fair to good National Bridge Inventory condition ratings and showing no more than minor distress. The Bridge Preventive Maintenance Program helps to reduce repair efforts in the long term and system-wide. Projects may be undertaken without geometric enhancements, significant reconstruction or considerable upgrades. Preventive Maintenance techniques and strategies selected will be easily constructible in order to minimize traffic disruption and will provide relief from intensive or frequent repair activity. Projects will not degrade any safety or geometric aspects of the facility. This program applies to projects on both Interstate and Federal Aid Non-Interstate routes.

The overall goals of this program are as follows:

- Maintain bridges in a safe and serviceable condition for the motoring public
- Correct minor surface and/or minor structural defects
- Correct minor deficiencies prior to structure falling into disrepair and in need of complete rehabilitation
- Extend the remaining service life of existing bridges
- Replacement of failed protective coatings on structural steel and bridge appurtenances
- Make efficient use of limited resources
- Utilize Federal participation with State funds on bridge preventive maintenance projects and bridge painting projects
- Allow the NJDOT to better manage overall bridge network conditions
- Create shovel-ready projects for Federal-aid program obligation

V. PROCESS AND PROJECT SELECTION

The National Bridge Inventory inspection reports and the respective bridge condition ratings along with the New Jersey Department of Transportation's Bridge Management System will be used as the basis for a systematic project selection for preventive maintenance treatments to bridges. Deck condition surveys may be needed for further evaluation of deck conditions and for determining the deck repair strategy.

To fulfill the purpose of the Bridge Preventive Maintenance program, bridges will be prioritized using evaluation criteria established in the Bridge Management System to select projects. Additional review and prioritization will be finalized by field visits to the proposed bridges.

A systematic approach to the selection of bridges begins with a highway corridor or section of highway grouping several bridges into one geographical area. This minimizes mobilization costs, traffic safety costs, as well as inconvenience to the motoring public. Bridges with deck ratings between “5” and “9” are identified for bridge preventive maintenance repairs, with priority given to structures coded “5”, “6”, or “7.” Various element condition ratings of the bridge deck, joint, and substructure are also selected.

Candidate structures for preventive maintenance are selected and programmed by applying approved criteria to the New Jersey Department of Transportation’s database of the State’s bridges. The agency’s interim bridge management program identifies bridges classified in good structural condition that have deficiencies in the deck, deck joints, bridge deck drainage, the superstructure, or the substructure. The deck joints category targets deficient fixed or expansion joints, with the aim of preventing safety issues caused by loose armoring plates or contamination of the superstructure and substructure elements caused by water and chlorides leaking through the joint seals.

For bridges with substructure deterioration, New Jersey Department of Transportation focuses on repairing spalls on common substructure elements. In the deck and superstructure category, the agency concentrates on maintaining the bridge’s primary elements in good condition to preserve the structural integrity of the bridge. In the area of bridge deck drainage, New Jersey Department of Transportation addresses water drainage and safety concerns caused by ponding and excessive runoff from restricted drain openings. If a candidate bridge qualifies for preventive maintenance work in numerous categories, New Jersey Department of Transportation considers either rehabilitating or replacing the structure, as the scope of work would be beyond the Bridge Preventive Maintenance Program.

The New Jersey Department of Transportation’s Bridge Management System (BMS) Element 515 (Steel Protective Coating) condition states shall be utilized to prioritize structures in need of painting. For bridges with an Element 515 condition state “3” or “4,” a failed protective coating evident on greater than twenty percent of the structural steel, and/or lead presence, a Society of Protective Coatings (SSPC) SP-10 near-white blast shall be applied to the entire structure. A three coat paint system shall then be applied to the structure utilizing a zinc primer, intermediate coat, and finish coat. For bridges with a BMS Element 515 condition state “2” or “3,” a failed protective coating evident on less than twenty percent of the structural steel, and no lead presence, an SSPC SP-3 power-tool clean shall be applied to the entire structure. A spot prime and two full coat paint system shall then be applied to the structure. For bridges with a BMS Element 515 condition state “1,” “2,” or “3,” and a failed protective coating evident only beneath joints, an SSPC SP-3 power-tool clean shall be applied to beam ends of the structural steel. A spot prime and two full coat paint system shall then be applied to the beam ends. Bridge painting operations must be contained and ventilated to trap, collect, and dispose of blasting waste and paint overspray. Utilities must be protected during painting operations.

The New Jersey Department of Transportation will ensure that all work for Bridge Preventive Maintenance projects and Bridge Painting projects meet all governing, regulatory permit requirements and the work is determined as eligible work under bridge maintenance exemptions with the permitting agencies.

VI. PREVENTIVE MAINTENANCE PROCEDURES

These activities depend on a top-down approach, with the overall goal of keeping water away from sensitive elements of the bridge, thus enhancing its long-term performance. Although the deck is designed to carry traffic loads, it also protects the components below from water, like the roof on a house. Decks must be kept watertight and clean to perform this protective function. When decks have separate wearing surfaces, those surfaces must be kept watertight to protect and preserve the underlying deck. Similarly, joints allowing each deck span to move independently must be kept watertight, or water will reach the beams, bearings, or substructure concrete below, causing deterioration. Drainage systems, designed to carry surface water safely off the deck and away from the bridge, must be kept clean to ensure water flow. Plugged drainage systems allow water to pond on the deck, where it will eventually attack critical bridge elements.

Most of these activities can be readily performed and are cost-effective investments. However, as with all highway-related work, the practitioner must ensure that preventive maintenance and painting procedures contemplated for use are consistent with environmental standards and safety codes within the jurisdiction, and obtain any required permits before commencing work.

Bridge Preventive Maintenance procedures are as follows:

- **Bridge Cleaning:** Remove all salt, dirt, and grit from the deck and supporting members, bearings, pedestals, capbeams, bridge seats, and substructure concrete. Unplug and clean the drainage system (scuppers, open joint troughs, and downspouts) on the bridge. Clean debris and vegetation from around the structure and approaches. The intent of this item is to remove de-icing salt to prevent corrosion, remove debris to enable elements to function properly, and ensure proper drainage on and around the bridge. Cycle: Every two years.
- **Repair and/or Replace Joints:** Repair or replace deteriorated, decayed, damaged, and missing sections of joint systems, including surrounding concrete. Perform this work on all types of joint systems, as required. Proper operation of the joint system will allow for efficient water flow off structure, prevent icing conditions in the winter months, and create an overall safer environment for the traveling public. Failure to periodically and properly maintain bridge deck joints can result in damaged end diaphragms, damaged beam ends, damaged bridge bearings, damaged seats and caps, accelerated deterioration of the substructure and embankment erosion problems at the abutments. Cycle: Every ten years.
- **Repair Concrete Deck and Sidewalk:** Where delaminations and potholes have formed in the deck and sidewalk, the damaged and hollowed portions of structural

concrete deck will be removed to a depth below the rebar. The rebar will be cleaned and the hole filled with a rapid curing deck patch material. This step prevents spalling and delamination from spreading across the entire deck and prolongs the life of the deck itself. Concrete deck repairs must be completed prior to application of corrosion inhibitor or any sealants applied to the deck. Cycle: Every ten years.

- **Repair Concrete Parapet:** Where spalling or motor vehicle damage has occurred to parapet barriers, remove and replace the deteriorated and damaged concrete. This step will prevent the spalling from spreading across the parapet and will protect the area from water and chloride seepage. Cycle: Every ten years.
- **Sealing Concrete Deck:** Apply sealant to concrete deck, curbs, sidewalks, and fascia. Also apply liquid deck sealer where appropriate. This will maintain waterproof integrity of the deck wearing-surface portion to prevent water and chlorides from reaching the reinforcing steel. Cycle: every five years.
- **Sealing Cracks in the Wearing Surface:** Clean out and seal cracks in the wearing surface to protect the underlying structural deck. Also apply liquid joint sealer where appropriate. This will ensure that the wearing surface provides waterproof protection for underlying structural deck and that asphalt-cement-concrete wearing surface achieves full 12-year life. Cycle: Every two years.
- **Crack Sealing on Concrete Decks:** Apply Joint and Crack sealant to longitudinal cracks along prestressed concrete box beam bridge decks to minimize or eliminate water and chlorides entering the structure through these cracks. Concrete cracks that reach the reinforcing steel and have widths larger than 0.007 in., will allow moisture and chlorides to penetrate and cause corrosion. Cycle: Every two years.
- **Crack Sealing on Parapets:** Apply Crack sealant to vertical or transverse cracks to minimize or eliminate water and chlorides entering the structure through these cracks. Cycle: Every two years.
- **Crack Sealing on Substructure:** Apply Crack sealant to vertical cracks on substructure elements using pressure-injection methods. This will minimize or eliminate water and chlorides entering the structure through these cracks, as well as extend the service life of the existing structure. Cycle: Every five years.
- **Substructure Concrete Repair:** Remove and replace delaminated and spalled portions of structural concrete on piers, capbeams, seats, pedestals, and other substructure areas. This restores the structural integrity of the substructure and prolongs the life of the overall bridge structure. If necessary, temporary shoring shall be installed in order to perform repairs near the bearings. All substructure concrete repairs must be completed prior to application of epoxy waterproofing, application of any substructure sealant, or lubrication of bearings. Cycle: Every ten years.
- **Inhibit Corrosion of Rebar:** Apply a corrosion inhibitor to deck, parapets, and substructure concrete. This application will seep into the structure and slow corrosion of rebar. Cycle: Every five years.
- **Lubricating Bearings:** Clean and lubricate all appropriate bearings and pin-and-hanger connections. This item will ensure that bearings function properly to transfer loads from superstructure to substructure, and allow proper movement of the superstructure. Cycle: Every four years.
- **Seal Concrete Substructure:** Apply epoxy waterproofing to capbeams, seats, pedestals, and other substructure elements within drainage paths and splash areas.

This item will maintain waterproof integrity of substructure elements to prevent water and chlorides from penetrating the concrete and reaching the reinforcing steel. This work will be completed on an as-needed basis, only if other work is being performed on the structure.

- **Repair Approach Slabs:** Concrete approach slabs can settle and result in cracked slabs if the settlement becomes severe and allowed to continue. It is very important to determine the cause of the settlement. If erosion is creating an excessive void under the approach slab, mud jacking methods can be used to fill the voids and lift the slab to its original, intended grade. These repairs prevent further damage to structure, such as header damage due to settlement of the approach slabs. This work will be justified by excessive maintenance repair history for specific bridges only.
- **Hot Mix Asphalt Patch:** Where potholes or deteriorated asphalt exists adjacent to a concrete approach slab, or concrete header if no approach slab exists, an asphalt repair strip shall be installed. This item will protect the concrete from further damage and deterioration from being exposed to elements and traffic. This work will be completed on an as-needed basis, only if other work is being performed on the structure.
- **Repair Erosion/Scour:** Repair undermined foundations and/or scoured or eroded stream channels with concrete, grout, stone fill, or rip-rap. This protects the integrity of bridge substructures to ensure they continue to function as intended. This work will be completed on an as-needed basis, only if other work is being performed on the structure.
- **Safety Improvements:** While addressing structural issues on each bridge, safety elements must also be considered. Re-application of faded traffic stripes and symbols should be completed across the span. Due to thermoplastic's inability to strongly bond to concrete, traffic symbols and markings should be inspected yearly. Where missing, reflective traffic delineators on parapet walls, broken or missing RPMs, and approach guiderails shall be re-installed. Where substandard parapet height conditions exist, fence shall be installed to protect pedestrians.

Movable Bridge Preventive Maintenance procedures are as follows:

- **Cleaning and Lubrication of Movable Bridge Lift Cables:** Clean and lubricate each wire rope lift cable (excluding area where wire rope is in contact with sheave assembly when bridge is in the closed position). Vertical lift movable bridges utilize fiber core steel wire ropes; several individual wire ropes are grouped together at each bridge corner, with each grouping of wire ropes attached to the main lifting girder of the lift span at one end and to the bridge counterweight at the other. Cleaning and lubricating wire ropes will facilitate the removal of contaminants and moisture, reduces the friction between individual wire rope strands as they move over each other, and provides corrosion protection to the wire core, interior wire strands, and exterior surfaces. Failure to clean and lubricate lift cables regularly will reduce cable life and operating capacity, increase wear on bridge components, and can eventually result in permanent damage to the lift cables, sheave assemblies, and/or operating machinery. Clean each wire rope (starting at the maximum elevation of the cable, i.e., from the top down) via wire brush and petroleum solvent, allowing time for excess solvent to dry off, followed immediately by the application of lubricant to prevent

flash rusting. Two types of lubricant shall be used; a penetrating lubricant containing a petroleum solvent is to be applied first in order to saturate the wire core followed by a coating lubricant to seal the outside of the cable from moisture. Asphaltic compounds and grease based lubricants are not permitted. Cycle: Every five years.

- **Cleaning and Lubrication of Movable Bridge Sheave Assemblies & Lift Cables:** Clean and lubricate movable bridge sheave assemblies, including wire rope sheave grooves along entire sheave circumference and all wire ropes in direct contact with sheave when bridge is in the closed position. Clean sheave grooves via wire brush, cloth rags, and petroleum solvent and immediately lubricate with coating lubricant. Clean and lubricate wire ropes as per "Cleaning and Lubrication of Movable Bridge Lift Cables" procedure. Complete cleaning and lubrication of sheave grooves and wire ropes will necessitates sheave rotation, i.e. lifting of bridge. Bridge lifts are limited to a maximum time interval of 15 minutes, with sufficient time allowed for vehicular traffic to clear between each lift (as determined by the bridge operator on duty). Failure to regularly clean and lubricate sheave assemblies and lift cables will reduce cable life and operating capacity, increase wear on bridge components, and can eventually result in permanent damage to the lift cables, sheave assemblies, and/or operating machinery. Asphaltic compounds and grease based lubricants are not permitted. Cycle: Every five years.
- **Movable Bridge Pest Control Brush Replacement:** Replace deteriorated, worn, or damaged sections of pest control brushes. Pest control brushes are utilized on movable bridge structures to prevent pests (birds, rodents, etc.) from gaining access to bridge machinery and equipment. Failure to maintain the integrity of pest control brushes will result in the accumulation of corrosive animal waste and debris in and around critical movable bridge components. Brushes are constructed of either nylon or polypropylene filaments, tightly bound by a galvanized steel strip, and held in place by a small aluminum channel. Brushes vary in length, depending on the specific application and location of use, and are intended to be able to seal irregularly shaped gaps in the movable bridge facility. Pest control brushes shall be resistant to chemical attack, high salt environments, and must be suited for high cycle applications. Cycle: Every five years.

Bridge Painting procedures are as follows:

- **SSPC SP-3, Beam Ends:** A power-tool cleaning shall be applied to structures with a BMS Element 515 condition state "1," "2," or "3," and a failed protective coating evident on the beam ends of the structural steel beneath a joint. The ends of non-integral steel beams at a length of 1.5 times the web depth shall be painted to protect the steel directly beneath expansion joints. This treatment should also be applied to other steel members in the drainage path or splash areas of bridges. A spot prime and two coat paint system shall then be applied to the targeted areas. Bearings shall be lubricated and piers/abutments shall have waterproofing epoxy applied after all painting has occurred.
- **SSPC SP-3, Entire Bridge**: A power-tool cleaning shall be applied to structures with a BMS Element 515 condition state "2" or "3," a failed protective coating evident on less than twenty percent of the structural steel, and no lead presence. A spot prime and

two coat paint system shall then be applied to the entire structure. Bearings shall be lubricated and piers/abutments shall have waterproofing epoxy applied after all painting has occurred.

- **SSPC SP-10, Entire Bridge:** A near-white blast shall be applied to structures with a BMS Element 515 condition state "3" or "4," a failed protective coating evident on greater than twenty percent of the structural steel, and/or lead presence. A three coat paint system shall then be applied to the structure utilizing a zinc primer, intermediate coat, and finish coat. Bearings shall be lubricated and piers/abutments shall have waterproofing epoxy applied after all painting has occurred.

Bridge Preventive Maintenance Repair Items		
Activity	***Selection Criteria***	***Cycle***
Bridge Cleaning/Washing	All functional structures, with priority given to highway over highway bridges	Every two years
Repair/Replace Joints	Decks coded "5" or higher, Condition State "3" or lower	Every ten years
Repair Concrete Deck/Sidewalk	Decks coded "5" or higher, Condition State "3" or lower	Every ten years
Repair Concrete Parapet	Decks coded "5" or higher, Condition State "3" or lower	Every ten years
Seal Concrete Deck	Decks coded "5" or higher, Condition State "2" or lower	Every five years
Seal Cracks on Wearing Surface– asphalt overlay	Decks coded "5" or higher, Condition State "2" or lower	Every two years
Seal Cracks on Deck	Decks coded "5" or higher, Condition State "2" or lower – bare concrete decks only	Every two years
Seal Cracks on Parapet	Decks coded "5"or higher, Condition State "2" or lower	Every two years
Seal Cracks on Substructure	Substructure rated "5" or higher, Condition State "2" or lower	Every five years
Substructure Concrete Repair	Substructure rated "5" or higher, Condition State "3" or lower	Every ten years
Corrosion Inhibitor	All functional structures, with priority given to highway over highway bridges	Every five years
Lubricate Bearings	As needed, applied only if other work is being performed on structure	Every four years
Seal Substructure Concrete	As needed, applied only if other work is being performed on structure	As needed
Repair Approach Slabs	As needed, applied only if other work is being performed on structure	As needed
Hot Mix Asphalt Patch	As needed, applied only if other work is being performed on structure	As needed
Repair Erosion/Scour	As needed, applied only if other work is being performed on structure	As needed
Safety Improvements	As needed, applied only if other work is being performed on structure	As needed

Movable Bridge Preventive Maintenance Repair Items		
Activity	***Selection Criteria***	***Cycle***
Cleaning/Lubrication of Movable Bridge Lift Cables	All operational lift drawbridges	Every five years
Cleaning/Lubrication of Movable Bridge Sheave Assembly & Lift Cables	All operational lift drawbridges	Every five years
Movable Bridge Pest Control Brush Replacement	All drawbridges	Every five years
Painting Items		
Activity	***Selection Criteria***	***Cycle***
SSPC SP-3 Power Tool Cleaning; Beam Ends	BMS Element 515 condition state "1," "2," or "3" Failed protective coating evident on beam ends beneath joints	Every five years
SSPC SP-3 Power Tool Cleaning; Entire Bridge	BMS Element 515 condition state "2" or "3" Failed protective coating evident on less than 20% of structural steel	Every ten years
SSPC SP-10 Near White Blast; Entire Bridge	BMS Element 515 condition state "3" or "4" Failed protective coating evident on greater than 20% rust in structural steel	Every twenty years

VII. IMPLEMENTATION

1. Using procedures set forth in Section VI, Engineering staff shall do a cursory review of bridge inspection reports and element level ratings to determine which structures are eligible for preventive maintenance treatments using Federal funding. Bridges selected shall be grouped into one geographical area or highway corridor to minimize mobilization costs.
2. After bridges are selected, staff shall perform a detailed review of bridge inspection reports, maintenance history records, and preventive maintenance cycles.
3. A field inspection to every structure selected shall be performed. The condition of the bridge (superstructure, substructure, and approaches) shall be documented and photographed.
4. Cost estimates for each maintenance activity as listed in Section IV per bridge shall be drafted.
5. Any work needed that is within the scope of New Jersey Department of Transportation's Maintenance Crews shall be forwarded to the appropriate Region for execution.
6. Work beyond the scope of the New Jersey Department of Transportation's Maintenance Crews shall then be compiled into a Bridge Preventive Maintenance Contract and sent out to bid.

7. Work performed by any contractor shall be supervised by an inspector from the New Jersey Department of Transportation's Bridge Maintenance Division.
8. All Bridge Preventive Maintenance work shall be documented and maintained in the Bridge Management System to aid in the periodic re-evaluation of the program.

VIII. COORDINATION

Where applicable, an effort shall be made to coordinate Bridge Preventive Maintenance Contracts with other programs or active contracts. Coordinating bridge preventive maintenance work with movable bridge preventive maintenance work as well as bridge painting work will greatly increase structure life and eliminate duplicate repairs. Priority shall also be given to structures on highways where a roadway resurfacing has recently taken place or is scheduled to take place.

Where movable bridge preventive maintenance procedures are being utilized, preventive maintenance treatments to fixed approach spans and surrounding structures shall also be performed. Such tactics will reduce mobilization and preventive maintenance treatment costs in addition to keeping fixed span structures on causeways and movable bridge approach spans in a state of good repair.

IX. POST-REPAIR PROCEDURES

Once a structure has been treated under the Bridge Preventive Maintenance Program, the extent of the work shall be documented and filed with both the New Jersey Department of Transportation's Structural Evaluation Unit and Bridge Maintenance Unit.

Upon returning to a structure to perform the cyclical procedures listed in Section VI, the effectiveness of the work previously performed can be evaluated. It is expected that the initial cost of repairing a structure will be greater than the cost to perform the same procedures later in the structure's life. It is the objective of this program to bring the structure to a level where it can be maintained regularly and prevent it from falling into a state of disrepair. By using the activities listed in Section VI, this can be accomplished. Overall, the effectiveness of the Bridge Preventive Maintenance Program will be judged by structure condition, with the goal of reducing the number of structures falling into poor condition.

Appendix C

Virginia Department of Transportation

2015 AASHTO SCOM

Using Current Valuation to Direct Maintenance Decisions

Jeff Milton - Bridge Preservation Specialist

Structure and Bridge Division

July 21, 2015

Maintenance Prioritization Process

General Formula for Prioritization:

Rank = a(*IF*) + b (*Condition*) +c(*CE*) + d(*Risk*) +e(*Function*)

Where:

- ***IF*** **= Importance Factor – measuring the importance of the structure**
- ***Risk*** **= Factor measuring the risk to the structure**
- ***Function*** **= Variable ranking the (geometric) functionality of the structure**
- ***Condition*** **= Virginia Health Index – variable measuring condition**
- ***CE*** **= Cost-Effectiveness of Action**

All five variables will have a 0 to 1.0 scale

- **a, b, c, d, e are coefficients that may be selected to suit the particular evaluation being performed**
- **a + b + c + d + e = 1.0**

By separating the five variables users can readily understand why one project has a higher priority than another

Maintenance Prioritization Process

Description of the Variables:

IF = Importance Factor. Measures *relative* importance of the structure to the roadway network

Uses these variables:

- **Traffic**
- **Truck traffic**
- **Proximity to schools, hospitals and emergency facilities**
- **Detour vs. traffic**
- **Functional class of roadway**
- **Predicted future ADT growth**

Maintenance Prioritization Process

Description of the Variables:

Risk = Factor measuring the risk to the structure, with an emphasis on redundancy but also taking into account financial and functional risk of inaction

Maintenance Prioritization Process

Description of the Variables:

IF = Importance Factor (this index is complete but not published outside of VDOT). Measures relative importance of the structure to the roadway network and considers such variables as: traffic, truck traffic, proximity to schools, hospitals and emergency facilities, detour, functional class of roadway, and prediction of future growth. I can provide you with a draft document describing the methodology if you're interested.

Condition = Virginia Health Index, a measurement of the depreciation of the structure, which will serve as our condition index. We have the methodology complete for this number but are still in the process of automating the formula. The VAHI has the additional characteristic of allowing users to estimate the current valuation of a structure, as VAHI*Replacement Cost = Current Valuation.

CE = Cost-Effectiveness of Action. This will be measured using the benefit/cost ratio of various alternatives. Benefit/cost will be measured as: B/C = (Increase in Current Valuation)/(Initial Project Cost). Increase in Current Valuation can be measured as described in the bullet above using the VAHI (each potential intervention will have associated estimates of how much the structure will improve, what we call "transition probabilities", which will allow users to estimate the post-repair condition and value of the structure for various alternatives). This indicator may be a little complicated for large lists, so we'll have to see how this goes. Once the VAHI calculations are published we can roll this out, but it may take some time for people to adopt this on a wide scale basis.

Risk = Factor measuring the risk to the structure, with an emphasis on redundancy but also taking into account financial and functional risk of inaction.

Function = Measurement of the (geometric) functionality of the structure. Currently this variable is defined by Functional Obsolescence, which is a binary indicator (Yes or No). We have developed an index that will measure the degree of geometric adequacy. This will include crash data, lane and shoulder width, speed etc. Also not yet published.

a, b, c, d, e are coefficients that may be selected to suit the particular evaluation being performed. There may be times when one index is more important than another according to the constraints faced by the decision maker.

All five variables will have a 0 to 1.0 scale.

Maintenance Prioritization Process

Description of the Variables:

IF = Importance Factor (this index is complete but not published outside of VDOT). Measures relative importance of the structure to the roadway network and considers such variables as: traffic, truck traffic, proximity to schools, hospitals and emergency facilities, detour, functional class of roadway, and prediction of future growth. I can provide you with a draft document describing the methodology if you're interested.

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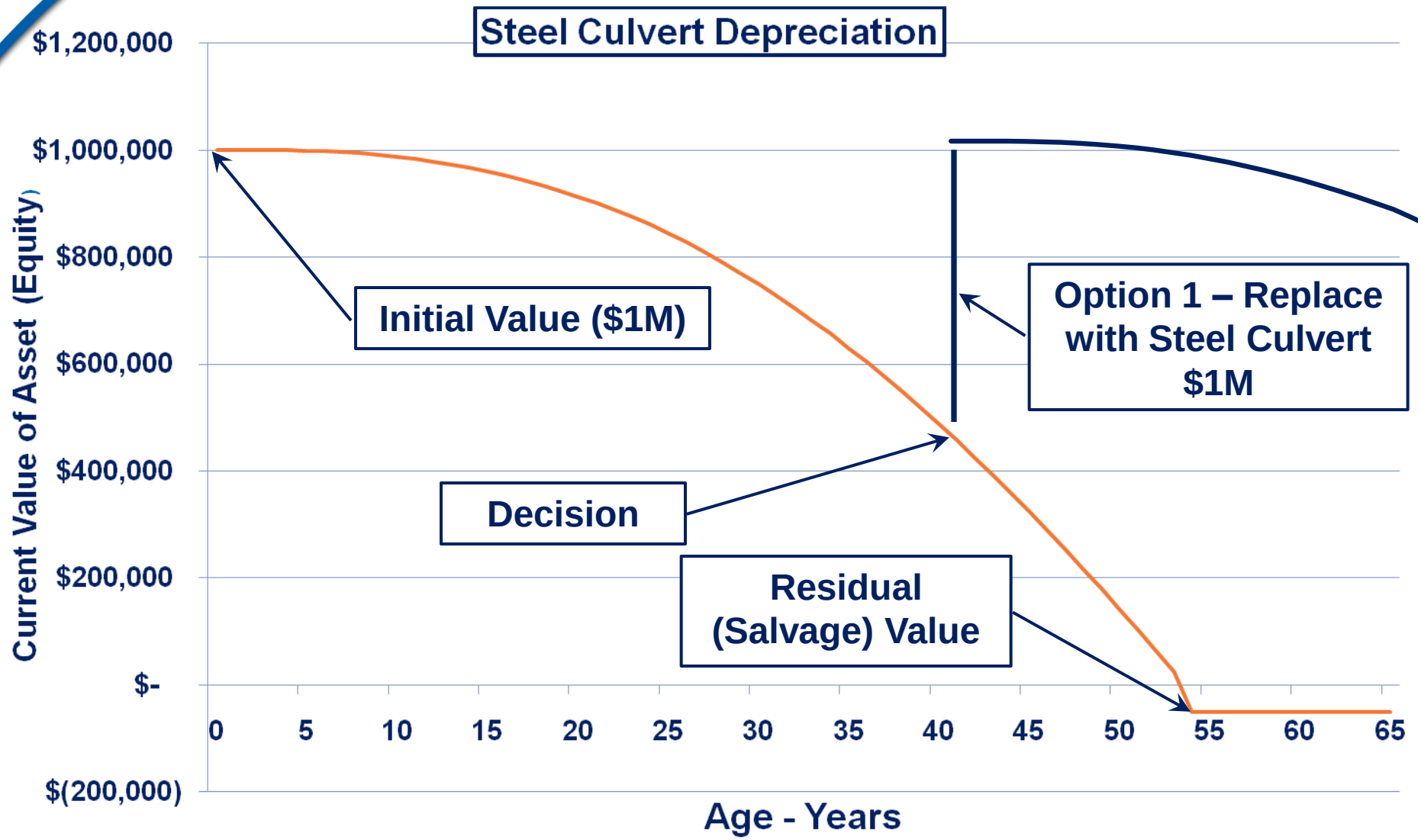
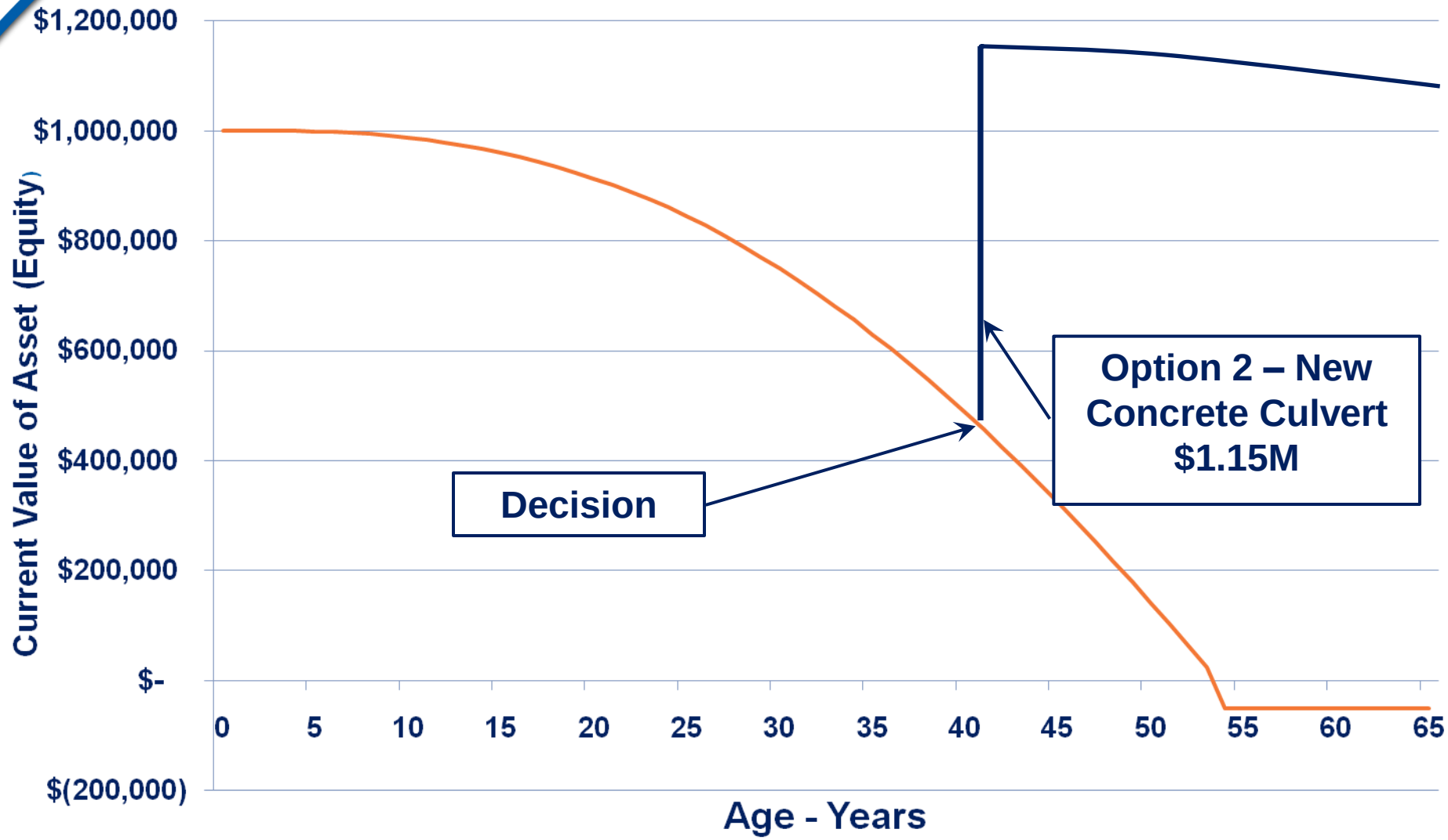
The Benefits of Using Equity as the Basis for Engineering Decisions



The Benefits of Using Equity as the Basis for Engineering Decisions



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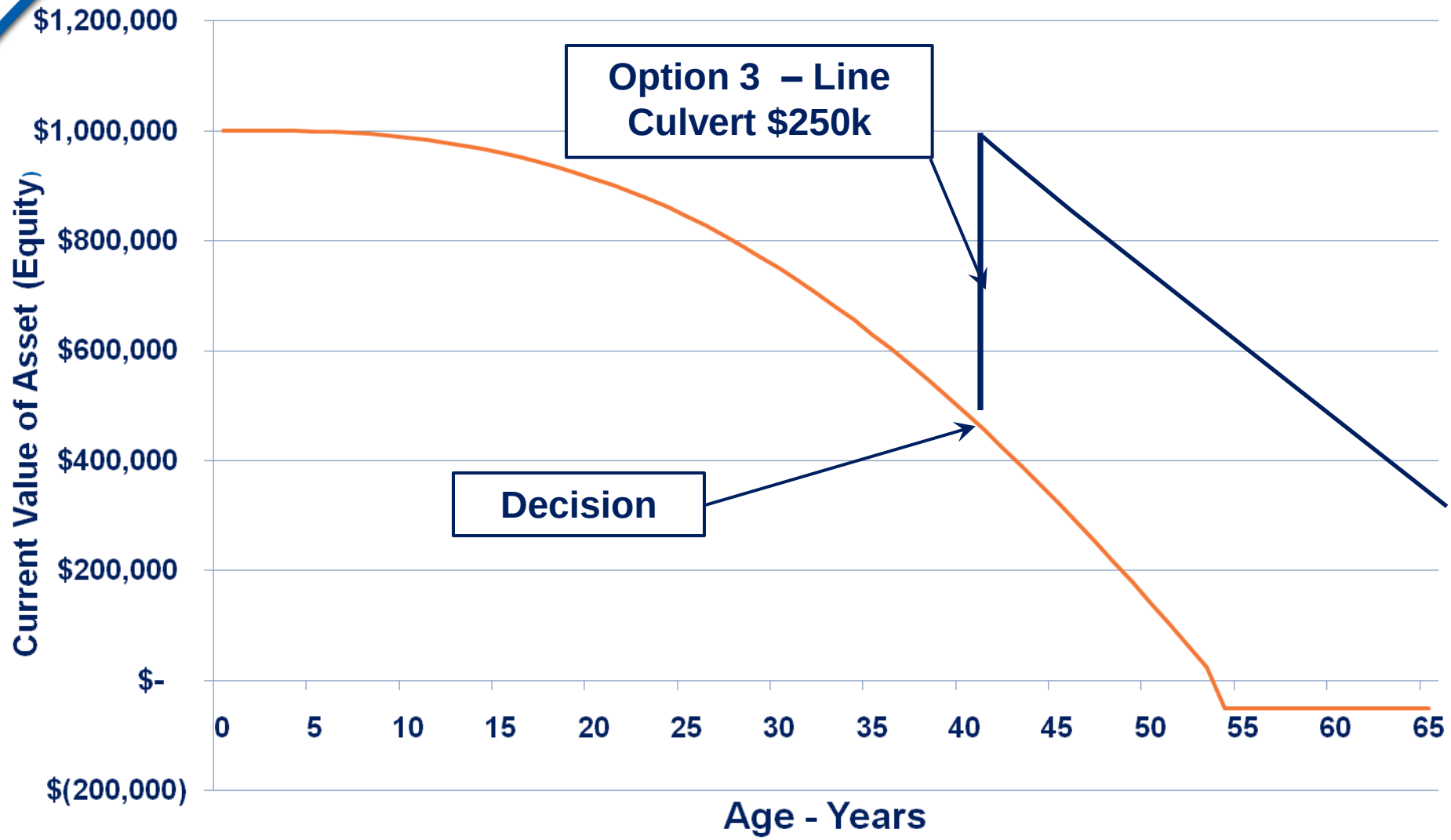


With Equity Curves Simple Life Cycle Analysis is Practical

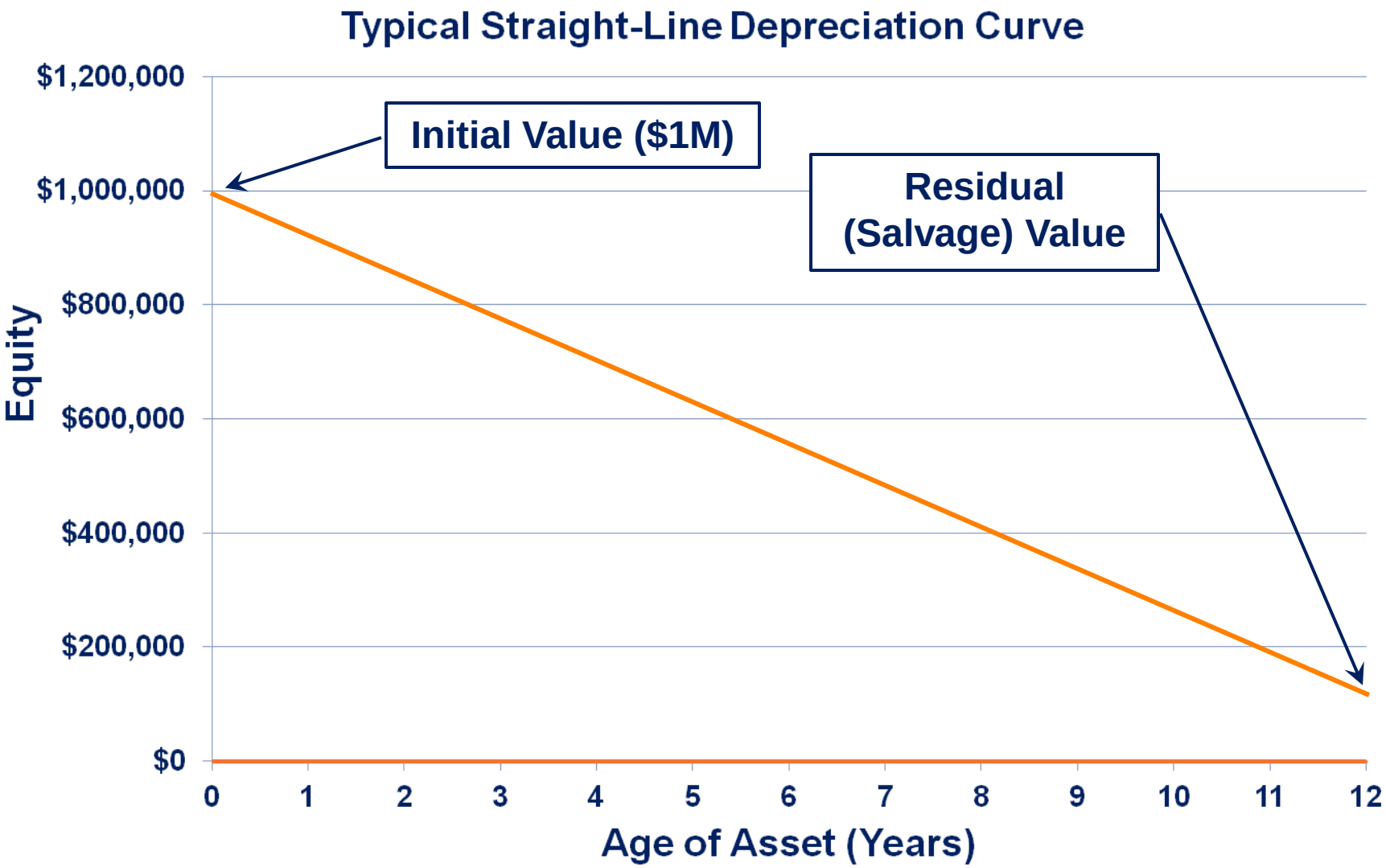
		Initial Costs						
	Name	Initial Construction	Traffic Control	Engineering, Inspection, R/W	Total Initial Cost	Estimated Maintenance Costs Per 10 Year Interval	Replacement Year	Present Value (calculated)
Option 1	Coated Steel	$748,400	$64,500	$187,100	$1,000,000	$4,000	53	-$1,131,192
Option 2	Precast Concrete	$850,240	$87,200	$212,560	$1,150,000	$6,000	110	-$893,554
Option 3	Steel Liner	$190,000	$12,500	$47,500	$250,000	$4,000	30	-$1,380,666

Discount Rate	1.50%

Suggested PE, CEI, R/W Factor	0.25

Steel Liner Option Assumes New Steel Culvert Required in 25 Years

Measuring Equity – Common Practice: Time Based Depreciation



Developing A Measurement of Equity Using Condition

VDOT has a good understanding of the condition of each element of every structure

Element Data Collected During Inspections

Component	Number	Title
Deck	801	Sidewalk
	802	Deck Drains
Superstructure	811	Beam/Girder End
	812	Reinforced Concrete Frame
Substructure	821	Steel Abutment
	822	Steel Wingwall
	823	Reinf.\ Concrete Abutment
	824	Reinf.\ Concrete Wingwall
	825	Timber Abutment
	826	Timber Wingwall
	827	Masonry Abutment
	828	Masonry Wingwall
	829	MSE Abutments
	830	MSE Wingwall
Culverts	831	Concrete Culvert Endwall/Headwall
	832	Concrete Cuvlert Wingwall
	833	Roadway Over Culvert
Joints	841	Asphalt Plug Joint
	842	Elastomeric Concrete Plug Joint
	843	Link Slab
	844	Slab Extension
	845	Joint Effectiveness
Slopes & Channels	851	Unprotected Slope
	852	Protected Slope - Paved
	853	Protected Slope - Riprap
	854	Channel
Protective	881	Wearing Surface - Unprotected Asphalt Wearing Surface
	882	Wearing Surface - Protected Asphalt Wearing Surface
	883	Wearing Surface - Thin Overlay
	884	Wearing surface - Rigid Overlay
	885	Wearing Surface - Other

Element Data Collected During Inspections

Table 1. Bridge Elements.

Element	Units	Element Number					
		Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Deck/Slab							
Deck	SF		13	12	31		60
Open Grid Deck	SF	28					
Concrete Filled Grid Deck	SF	29					
Corrugated or Orthotropic Deck	SF	30					
Slab	SF			38	54		65
Top Flange	SF		15	16			
Superstructure							
Closed Web/Box Girder	LF	102	104	105			106
Girder/Beam	LF	107	109	110	111		112
Stringer	LF	113	115	116	117		118
Truss	LF	120			135		136
Arch	LF	141	143	144	146	145	142
Main Cable	LF	147					
Secondary Cable	EA	148					149
Floor Beam	LF	152	154	155	156		157
Pin, Pin and Hanger Assembly	EA	161					
Gusset Plate	EA	162					
Substructure							
Column	EA	202	204	205	206		203
Column Tower (Trestle)	LF	207			208		
Pier Wall	LF			210	212	213	211
Abutment	LF	219		215	216	217	218
Pile Cap/Footing	LF			220			
Pile	EA	225	226	227	228		229
Pier Cap	LF	231	233	234	235		236
Culvert							
Culvert	LF	240	245	241	242	244	243
Bridge Rail							
Bridge Rail	LF	330*		331	332	334	333
Joint							
Strip Seal	LF	300					
Pourable	LF	301					
Compression	LF	302					
Assembly with Seal (Modular)	LF	303					
Open	LF	304					
Assembly without Seal	LF	305					
Other	LF	306					
Bearing							
Elastomeric	EA	310					
Movable (roller, sliding, etc.)	EA	311					
Enclosed/Concealed	EA	312					
Fixed	EA	313					
Pot	EA	314					
Disk	EA	315					
Other	EA	316					

Virginia Health Index: Example Equation

If a structure has the following characteristics:

- **0 to 100 scale**
- **0 means no health left (failed)**
- **100 for a new (ideal) structure**
- **Example: If a structure has deteriorated 32%, the VAHI = 68 (68 = 100 - 32)**

$$VAHI = \frac{\Sigma\,(VAHI_{Element} * Replacement\ Value_{Element})}{\Sigma\ Replacement\ Value_{Elements}}$$

If Σ Superstructure Value = 0, then deck = 0

If Σ Substructure Value = 0, then deck and superstructure = 0

Equity Determination: Example Equation

Equity = VAHI * Structure Replacement Cost

Example Structure:

VAHI= 78

Replacement Value = $2,000,000

Equity = .78 * 2,000,000 = $1,560,000

Virginia Health Index: Example Calculation #1

Element Name	$VAHI_{Element}$	Element Replacement Value	VAHI * Replacement Value
Columns	63	$25,000	$15,750
Pier Caps	54	$30,000	$16,200
Abutments	75	$60,000	$45,000
Girders	83	$160,000	$132,800
Diahragms	86	$30,000	$25,800
Deck	92	$180,000	$165,600
Joints	65	$30,000	$19,500
Parapet	92	$40,000	$36,800
Sum	**-**	**$555,000**	**$457,450**

VAHI = $457,450 ÷ $555,000 = 82

Virginia Health Index: Example Calculation #2

Element Name	$VAHI_{Element}$	Element Replacement Value	VAHI * Replacement Value
Columns	63	$25,000	$15,750
Pier Caps	54	$30,000	$16,200
Abutments	75	$60,000	$45,000
Girders	83	$160,000	$132,800
Diahragms	86	$30,000	$25,800
Deck	0	$180,000	$0
Joints	0	$30,000	$0
Parapet	0	$40,000	$0
Sum	**-**	**$555,000**	**$235,550**

Note: Replacement Cost of Bridge < ΣElement Replacement Values

VAHI = $235,550 ÷ $555,000 = 42

Equity – Multiple Uses

Equity can be a powerful tool in guiding bridge management

- **Can determine the most cost-effective actions on a given structure**
- **Helpful in selecting which structures should be worked on**
- **Can be used to measure effectiveness of various work programs**
- **Helpful as a measurement of progress**

Virginia Department of Transportation

Thank you for your time and attention

Questions??

2015 Virginia Concrete Conference

VDOT's Experience with Reinforced Concrete and Metal Culverts

Structure and Bridge Division