NCHRP 14-20A
Consequences of Delayed Maintenance of Highway Assets
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Topics

1. Research Objectives
2. Research Approach
3. Procedure to Quantify the Consequences of Delayed Maintenance
4. Step-by-Step Example for Pavements
5. Summary of the Main Research Contributions
Research Objectives

To provide a set of procedures to quantify the consequences of delayed maintenance to the highway infrastructure.

The ultimate goal is to integrate the procedures developed for individual asset groups into the asset management process to support better maintenance funding decisions and improve the communication across management levels.
What is Delayed Maintenance?

Delayed maintenance is defined as the work needed to preserve the highway system, but postponed in the agency maintenance program.

This definition applies to all the highway asset groups. However, each asset group has unique characteristics in terms of maintenance policies, condition assessment, deterioration rates, service life, and life-cycle costs.
Research Approach

Task 1: Information review and on-line surveys
Task 2: Focused phone interviews with selected DOTs
Task 3: Perform delayed maintenance scenarios

The methods and analytical tools described in the procedures can be adapted to the agency preservation policies, maintenance resources, and performance standards.
Main Steps of the Procedure to Quantify the Consequences of Delayed Maintenance

**Step 1:** Define the asset preservation policy

**Step 2:** Determine maintenance and budget needs for the asset group

**Step 3:** Conduct delayed maintenance scenarios analyses

Pavements, Bridges, Culverts, Guardrails, Lighting, Pavement Markings, and Signs.
Framework to Integrate the Delayed Maintenance Procedures into the Asset Management Process
Step-by-Step Example for Pavements
Step 1
Define the Asset Preservation Policy

1.1 Identify the types of maintenance for the asset group
1.2 Establish performance objectives for the asset group
1.3 Formulate decision criteria for maintenance activities
## 1.1 Identify the Types of Maintenance

**Asphalt Pavements**
- Chip seals
- Cold in-place recycling
- Cold milling
- Crack filling or sealing
- Fog seal
- Hot in-place recycling
- Microsurfacing
- Patching
- Profile milling
- Thin asphalt overlays
- Scrub seals
- Slurry seals
- Ultra-thin asphalt overlay
- Ultra-thin bonded wearing course
- Ultra-thin concrete overlay

**Concrete Pavements**
- Crack sealing
- Diamond grinding
- Diamond grooving
- Dowel bar retrofit
- Full-depth concrete patching
- Joint resealing
- Partial-depth concrete patching
- Thin asphalt overlay
- Ultra-thin bonded wearing course

*AASHTO 2007, Peshkin et al. 2011*
1.2 Establish Performance Objectives

- Maximum International Roughness Index (IRI) of the pavement network
- Minimum pavement condition of the pavement network
- Minimum Present Serviceability Index (PSI) of the pavement network
- Minimum Remaining Service Life (RSL) of the pavement network
- Minimum percent of the pavement network in good condition
- Maximum percent of the pavement network in poor condition
- Minimum Skid Number (SN) of the pavement network
- Minimum International Friction Index (IFI) of the pavement network
1.3 Formulate Decision Criteria for Maintenance Activities

Pre-schedule maintenance based on time-intervals

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Treatment</th>
<th>Recommended Year of Initial Treatment</th>
<th>Treatment Timing Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 to 3</td>
<td>2 to 6 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 to 3</td>
<td>1 to 2 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 to 6</td>
<td>1 to 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 to 6</td>
<td>3 to 5 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 to 7</td>
<td>4 to 7 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 to 5</td>
<td>4 to 7 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 to 6</td>
<td>7 to 10 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 to 8</td>
<td>7 to 10 years</td>
</tr>
<tr>
<td>Bituminous-surfacd</td>
<td>Crack Sealing</td>
<td>1 to 3</td>
<td>2 to 6 years</td>
</tr>
<tr>
<td></td>
<td>Fog Seals</td>
<td>0 to 3</td>
<td>1 to 2 years</td>
</tr>
<tr>
<td></td>
<td>Scrub Seals</td>
<td>1 to 6</td>
<td>1 to 3 years</td>
</tr>
<tr>
<td></td>
<td>Slurry Seals</td>
<td>2 to 6</td>
<td>3 to 5 years</td>
</tr>
<tr>
<td></td>
<td>Microsurfacing</td>
<td>3 to 7</td>
<td>4 to 7 years</td>
</tr>
<tr>
<td></td>
<td>Chip Seals</td>
<td>2 to 5</td>
<td>4 to 7 years</td>
</tr>
<tr>
<td></td>
<td>Ultrathin Friction Course</td>
<td>2 to 6</td>
<td>7 to 10 years</td>
</tr>
<tr>
<td></td>
<td>Thin Overlays</td>
<td>5 to 8</td>
<td>7 to 10 years</td>
</tr>
<tr>
<td></td>
<td>Joint and Crack Sealing</td>
<td>4 to 10</td>
<td>7 to 8 years</td>
</tr>
<tr>
<td></td>
<td>Diamond Grinding</td>
<td>5 to 10</td>
<td>5 to 10 years</td>
</tr>
</tbody>
</table>

Source: adapted from Peshkin et al. 2004

Maintenance activities based on condition trigger values

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Class</th>
<th>IRI (in/mi)</th>
<th>Cracking</th>
<th>Rutting (inch)</th>
<th>Faulting (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible, Composite</td>
<td>Interstate</td>
<td>80</td>
<td>0</td>
<td>250</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Primary</td>
<td>100</td>
<td>0</td>
<td>1000</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>125</td>
<td>5</td>
<td>1000</td>
<td>0.25</td>
</tr>
<tr>
<td>Rigid</td>
<td>Interstate</td>
<td>100</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Primary</td>
<td>100</td>
<td>0</td>
<td>N/A</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>125</td>
<td>0</td>
<td>N/A</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Source: O'Toole et al. 2013
Step 2
Determine Maintenance and Budget Needs

2.1 Assess the asset group condition

2.2 Select performance models to forecast the asset group condition and/or remaining life

2.3 Perform the needs analysis
2.1 Asses Pavement Network Condition

Before Treatment

- Very Good: 47.80%
- Good: 35.60%
- Fair: 12.80%
- Poor: 2.20%
- Very Poor: 1.70%

Current Average Condition Index (CI) 65
2.2 Select Performance Models to Forecast Condition

Deterministic Model

Example of family pavement performance curves
To identify maintenance activities needed to meet the established goals over the period of analysis.

This analysis should be based on applying the right treatment, to the right asset, and the right time; in other words, it should reflect applying the “best engineering” practices related to maintenance treatments.
3.1 Formulate delayed asset maintenance scenarios

3.2 Perform the delayed maintenance scenarios analyses

3.3 Determine the impact and report the consequences of delayed maintenance
1. **All needs** includes the agency-preferred maintenance policy with no funding constraints. A baseline budget is estimated from this scenario.

2. **Do nothing** in which no treatments are applied over the analysis period.

3. **Delayed maintenance** by a given number of years that varies for each highway asset group due to their expected service life, decision criteria, and consequences of postponing maintenance activities.

4. **Budget-driven** with limited funds for maintenance activities.
<table>
<thead>
<tr>
<th>Asset Group</th>
<th>Data</th>
<th>Performance Models</th>
<th>Analytical Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavements</td>
<td>Pavement network inventory with condition assessment</td>
<td>Deterministic Probabilistic Bayesian Expert-based model</td>
<td>Pavement Management Systems (PMS)</td>
</tr>
<tr>
<td>Culverts</td>
<td>NBI data on bridge-length culverts with condition assessment</td>
<td>Prediction of culvert rating (0-9) using a probabilistic approach similar to the bridge mode.</td>
<td>Culvert Management Systems (CMS)</td>
</tr>
<tr>
<td>Guardrails</td>
<td>Guardrail System inventory with condition assessment</td>
<td>Transition probability matrices to model the increase/decrease of deficient guardrails.</td>
<td>Spreadsheet based analytical tool</td>
</tr>
<tr>
<td>Lighting</td>
<td>Lighting System inventory with condition assessment</td>
<td>Weibull models for predicting likelihood of lamp or electrical failure. Straight-line loss of service life based on expected life.</td>
<td>Spreadsheet based analytical tool</td>
</tr>
<tr>
<td>Pavement Markings</td>
<td>Pavement Markings inventory with condition assessment</td>
<td>Weibull models for predicting pavement marking retroreflectivity failure.</td>
<td>Spreadsheet based analytical tool</td>
</tr>
<tr>
<td>Signs</td>
<td>Sign System inventory with condition assessment</td>
<td>Transition probability matrices to model the increase/decrease of deficient signs.</td>
<td>Spreadsheet based analytical tool</td>
</tr>
</tbody>
</table>
### 3.2 Delayed Maintenance Scenarios Analyses

#### Summary of Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Total Agency Cost(^{1,2})</th>
<th>Backlog Cost(^{1,2})</th>
<th>Percent Pavements in Very Poor Condition(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All Needs</td>
<td>$325 M</td>
<td>$0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Do Nothing</td>
<td>$0</td>
<td>$593.5 M</td>
<td>45.1</td>
</tr>
<tr>
<td>3</td>
<td>Delayed Maintenance by 2 years</td>
<td>$192 M</td>
<td>$209.7 M</td>
<td>18.6</td>
</tr>
<tr>
<td>4</td>
<td>Budget-driven with limited funds</td>
<td>$181 M</td>
<td>$310.9 M</td>
<td>35.8</td>
</tr>
<tr>
<td></td>
<td>0 percent of baseline budget for maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. At the end of the analysis period.
2. Total cost using a 3 percent interest and inflation rate.

20-year analysis period
The procedure to quantify the consequences of delayed maintenance of highway assets involves comparing changes in:

- Asset condition
- Remaining service life
- Agency costs in terms of:
  - Budget needs
  - Backlogged costs
  - Asset value
How to Report the Consequences of Delayed Maintenance?
Impact on Pavement Condition

- Scenario 1 - All Needs
- Scenario 2 - Do Nothing
- Scenario 3 - Delayed maintenance by 2 yrs
- Scenario 4 - 0% of Maintenance Budget Needs

Condition Index vs Year

2015 ... 2016 ... 2017 ... 2018 ... 2019 ... 2020 ... 2021 ... 2022 ... 2023 ... 2024 ... 2025 ... 2026 ... 2027 ... 2028 ... 2029 ... 2030 ... 2031 ... 2032 ... 2033 ... 2034
Pavement Network Condition
At the End of 20 Years

Scenario 1
All Needs
- Very Good: 10%
- Fair: 1%
- Poor: 0%
- Good: 89%

Scenario 2
Do Nothing
- Very Good: 0%
- Fair: 16.6%
- Poor: 38.2%
- Very Poor: 45.1%

Scenario 3
Delayed Maintenance by 2 Years
- Very Good: 16.3%
- Fair: 0%
- Poor: 0.8%
- Good: 64.3%
- Very Poor: 18.6%

Scenario 4.b
0% of Maintenance Budget
- Very Good: 1.6%
- Fair: 12.3%
- Poor: 2%
- Good: 48.3%
- Very Poor: 35.8%
Remaining Service Life

Remaining Life at the End of Analysis (year 2034)

- <2 years
- 2-5 years
- 5-10 years
- 10-15 years
- 15-20 years
- >20 years

- Before Treatment
- Scenario 2 - Do Nothing
- Scenario 1 - All Needs
- Scenario 3 - Delayed Maintenance by 2 Years
- Scenario 4 - 0% of Maintenance Budget Needs

20-year analysis period
Backlogged Cost

Scenario 1
All Needs

Scenario 4
0% of Maintenance Budget Needs
Pavement Network Value

Scenario 1. - All Needs

$ Millions

Network Value (US $ million)

Sustainability Ratio

Scenario 4 - 0% of Maintenance Budget Needs

$ Millions

Network Value (US $ million)

Sustainability Ratio
# Summary of Performance Measures for Strategic and Network Level Reports

<table>
<thead>
<tr>
<th>Performance Measure Report Category</th>
<th>Pavement</th>
<th>Bridge</th>
<th>Culvert</th>
<th>Guardrail</th>
<th>Lighting</th>
<th>Pavement Marking</th>
<th>Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset condition</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Remaining service life</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Agency costs</td>
<td>✓</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Asset value</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sustainability ratio</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Sustainability and user’s costs</strong> 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety (e.g. Accident costs)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobility (e.g. Travel time, operating costs)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental (e.g. CO\textsubscript{2} emissions)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Reports may include user costs or sustainability performance measures only if data and analytical tools are available to estimate these parameters.
1. The procedures describe preservation policies, maintenance practices, inventory data, condition assessment methods, analytical tools for analyses, and reports to assist agencies in quantifying the consequences of delayed maintenance.

2. The procedures have been prepared in a practical, adaptable, and easy-to-follow format with focus on implementation. Therefore, the procedures can be implemented using agency-specific analysis tools from existing management systems.
Recommendations for Implementation

1. Make the decision to proceed with the implementation
2. Integrate the preservation policies into an overall asset management process
3. Periodic update of the asset group inventory, condition assessment, and service life data. The procedures rely on up-to-date records with reliable maintenance and inspection data to develop or calibrate performance models
4. Select appropriate analytical tools to perform the needs and scenario analyses
5. Select reports to facilitate the interpretation of the results from the scenario analyses
Acknowledgments

We are thankful to the National Cooperative Highway Research Program for the opportunity to work on the NCHRP 14-20-A research project.

We also want to acknowledge the Project Coordinator Dr. Amir Hanna for his advice along this project, the panel members, and the DOTs and cities for their valuable input on maintenance practices.
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Thank You!

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