Doing More with Less: Improving Performance-Based Planning to Enable Sustainable Pavement Networks

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February 6, 2020
Iowa Concrete Paving Association Workshop
The US is not sufficiently investing in its ailing road system

21% of the US highways are in poor condition
Governments are being forced to do more with less

The New York Times

Governments Look for New Ways to Pay for Roads and Bridges

Feb 14, 2013

Gas Taxes Fail to Keep Up Because most states do not tie their gasoline tax to inflation, taxes are worth less over time. Increased fuel efficiency also means consumers are using less gas.

Sources: American Petroleum Institute; Tax Policy Center

Combined local, state and federal gasoline tax

Total gas tax revenue
In 2010 dollars

1980 2010

$40 bil.

40 50 60¢/g

20
Infrastructure spending is at an all-time low

More Potholes? This Might Be Why.
Infrastructure spending as a percentage of G.D.P. has fallen to the lowest level in decades.

The New York Times
Public Works Funding Falls as Infrastructure Deteriorates

By BINYAMIN APPELBAUM    AUG. 8, 2017

A water main and sewer renovation project in Somerville, Mass., this month. Public works projects have slowed across the country. Brian Snyder/Reuters

Source: U.S. Census Bureau
Asset management allocation tools are critical to economically-efficient infrastructure.

Use asset management best practices to prioritize projects and improve the condition, security, and safety of assets while minimizing costs over its entire life span.

Solutions to Raise the Grade

Fix the federal Highway Trust Fund by raising the federal motor fuels tax, and explore alternative, long-term funding mechanisms.

Increase investment at all levels of government to reduce the backlog of rehabilitation needs.
FHWA has issued new performance management rules due to MAP-21

FHWA motivation: *improve decision-making* through performance-based planning and programming

Key elements of asset management plans:

- Life cycle planning
- Risk management analysis
- 10-year financial plan
Pavement network performance management process

Set targets

Measure performance

Implement strategies to meet targets

% Good

% Poor

Pavement Management System

Which strategies?
At what cost?

How to allocate funds to obtain best performance at lowest cost?
Many approaches to allocate funds

<table>
<thead>
<tr>
<th>Pavement Segment</th>
<th>Pavement Condition Index</th>
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<tr>
<td>A</td>
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<td>B</td>
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<td>67</td>
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- How to prioritize which segments to repair?
- Will targets be met?
- Which strategies should be used?
  - Many short term fixes?
  - Few long-term fixes?

An optimization modeling approach is required to answer these questions:
Performance-Based Planning
Goal of MIT asset management research: improve allocation decisions

Performance-based planning through Performance-based budget allocation

Objective: prioritize projects that maximize performance and minimize cost
Why is this a challenge?
The scale of the problem for state pavement networks is daunting

Making decisions about …
... which preservation, overlay, or reconstruction activity to apply to
... which segment
at
... what time (now or future)?

Budget Allocation
Allocating limited funds to the set of activities that meet the goals of the network operator

Thousands of pavement lane-miles

Dozens of technologies to maintain or replace pavements

Fixed budget

Future budget and road condition = ?

What is the best plan?
How to Overcome the Challenge?
Practical network allocation involves two interlinked tasks

Segment-level Decision

• What is the best POR strategy for this segment? (This will involve a sequence of POR activities over time)

Network-level Decision (Allocation)

• What set of best POR strategies will give us the best network performance but still be within our budget?
Implementing Two Stage Budget Allocation Algorithms

PMS Data
Current & historical pavement network data

Project Performance
Identify best POR alternatives for each segment

Allocate Resources
Select a set of best POR options for network
Probabilistic treatment path dependence model (PTPD)

Segment level

Monte Carlo:
- treatment A → cost\(_A\) (optimal treatment path)
- treatment B → cost\(_B\)

future cost distribution for each treatment

risk analysis (Markowitz’s E-V)

Treatment path dependence

Network level

risk-based optimization

constraints

Segment 1: A, B
Segment 2: A, C
...

Seg1: A
Seg2: C
...

PTPD outperforms conventional Benefit-Cost model

✓ PTPD incorporates uncertainties and treatment path dependence
✓ To achieve a similar performance, B/C model should increase 10% of annual budget

Average TWIRI over 20 years

*B/C: benefit cost ratio model
Case study – Iowa U.S. route system

- Iowa PMS 2017
- 9,550 lane miles
- Pavement type: asphalt, asphalt overlay composite, and concrete
- Initial traffic-length weighted IRI (TWIRI) = 1.65 m/km
- Initial traffic-length weighted PCI (TWPCI) = 76.3
Treatment strategies

Materials
- AC
- PCC

Treatment types
- Short-term: preservation + thin overlay
- Long-term: thick overlay + reconstruction

Segment evaluation period
- 5 years
- 10 years

*AC: asphalt concrete, PCC: Portland cement concrete
Treatment strategies: parameters

- **Evaluation metrics:**
  - Traffic-length weighted IRI (TWIRI): roughness
  - Traffic-length weighted PCI (TWPCI): overall condition
  - Roughness-induced GHG emissions: environmental impact

- **Network analysis period** (planning horizon): 20 years

- **Budget levels:**
  - Critical/medium budget ($135M): Maintaining the same TWPCI after 20 years
  - Other budget levels: $135M +/- $15M in $5M increments
Weighted multi-output neural network model for pavement deterioration created

- Incorporate correlations among outputs
- Output weights can be considered

Inputs:
- Age
- Thicknesses
- Maintenance
- Traffic
- Climate
- Condition

Outputs:
- Roughness
- Faulting
- Cracking
- PCI
Key conclusion: leverage four strategies

- Sufficient budget
- Mix of pavement types
- Mix of short and long-term fixes
- Long evaluation periods
Sufficient budget: increasing budget level improves network performance and reduces GHG emissions

(a). Annual mean TWIRI

(b). Annual mean TWPCI

(c). Total GHG emissions for 20 years
Mix of pavement types: Diverse materials improve network performance and reduce GHG emissions

- AC only strategy: maintain more pavement area, but treatment effects are short.
- PCC only strategy: treatment effects are long, but only maintain the least pavement area.

(a). TWIRI after 20 years
(b). TWPCI after 20 years
(c). Average annual GHG emissions

*AC: asphalt concrete, PCC: Portland cement concrete
Mix of pavement types: Diverse treatment types improve network performance and reduce GHG emissions

- Short-term strategy: maintain more pavement area but last short.
- Long-term strategy: maintain less pavement area but last long.
- GHG emission: short-term and long-term strategies have similar median values but long-term strategy has a larger range.

![Graphs showing performance and emissions over budget](attachment:graphs.png)

- (a). TWIRI after 20 years
- (b). TWPCI after 20 years
- (c). Average annual GHG emissions
Long evaluation periods: Treatment actions with long-term benefits improve network performance and reduce emissions

- Segment analysis period (SAP) represents the period to evaluate benefits of treatments.
- SAP=5: treatments with short-term benefits are preferable. These treatments are cheap, and more pavement areas can be fixed.
- SAP=10: treatments with long-term benefits are preferable.

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Key conclusion: leverage four strategies

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- Mix of short and long-term fixes
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Benefits increase with higher budgets
Treatment strategies: optimal scenario

Materials

Treatment types

Evaluation period

AC
PCC

Reconstruction
Overlay
Preservation

5 years
10 years
Optimal scenario: Evolutionary IRI distribution

IRI distribution for U.S. route network in Iowa

Annual TWIRI

Year: 0
Optimal scenario: Evolutionary GHG emission distribution

GHG distribution for U.S. route network in Iowa

Year: 0

0  25  50  75  100  125  150  175  200(ton)
Data analysis can be challenging

Evolution of many randomly selected segments and their IRI over time

Many segments exhibit a decrease in their IRI over time

What is signal?
What is noise?
Measure pavement roughness using Carbin app

Carbin
Bader Anini  Education
Everyone

⚠️ You don’t have any devices.

Add to Wishlist

Install

Feedback sent back to the User

Measurements begin when driving

Data is shared to web server
Crowdsourced data can support asset management

http://www.fixmyroad.us/

156,391 miles
28 countries
10,002,420 data points
Thank you

cshub@mit.edu
http://cshub.mit.edu/
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Baseline scenario: Evolutionary PCI distribution

PCI distribution for U.S. route network in Iowa

Annual TWPCI

Year: 0