Pavement-related research at the MIT Concrete Sustainability Hub

Jeremy Gregory

Georgia Concrete Pavement Workshop
May 1, 2017
The US is not sufficiently investing in its ailing road system

The U.S. road system is in poor condition

Significant funding is required to fix the system

Insufficient investments are being made

$170 billion in annual capital investment needed to improve road system (source: FHWA)

- The Highway Trust Fund is nearly bankrupt
- Funding for roads will remain constrained for the foreseeable future
Governments are being forced to do more with less

Governments Look for New Ways to Pay for Roads and Bridges

The New York Times
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
FHWA has issued new performance management rules due to MAP-21

Revised asset management plan requirements:
• Condition and targets of pavements & bridges
• Asset management objectives and measures
• Performance gap analysis
• Risk analysis
• Life-cycle planning
• Financial plan
• Developing investment strategies

April 2018: state DOTs must submit initial asset management plans
There are questions about pavements’ impact on the environment

Climate change and air quality

Urban heat islands

https://climate.nasa.gov/resources/global-warming/

https://www.epa.gov/heat-islands/learn-about-heat-islands
CSHub research supports sustainable infrastructure design decisions

Sustainable infrastructure achieved by:

Increasing performance

Analyze and balance trade-offs

Reducing environmental impacts

Reducing cost

Design process

LCA

LCCA
CShub Mission
Develop breakthroughs that will lead to more sustainable and durable infrastructure, buildings, and homes

CShub Strategy
1. Provide scientific basis for informed decisions
2. Demonstrate the benefits of a life-cycle perspective
3. Transfer research into practice
CShub approach is holistic and multidisciplinary

Science

Engineering

Economics

Environment
CShub pavement research goals

1. Drive the pervasive use of life-cycle costing and life-cycle assessment for:
   – Pavement design
   – Pavement type selection
   – Maintenance decisions
   – Asset management

2. Improve the robustness of pavement-related decision-making
CSHub pavement research approach

Science
- Durability
- Albedo

Engineering
- Pavement-vehicle interaction

Economics
- Life cycle cost analysis
- Inter-industry competition
- Network allocation

Environment
- Life cycle assessment
- Network PVI

Projects

Networks
CSHub pavement research approach

Science
- Durability
- Albedo

Engineering
- Pavement-vehicle interaction

Economics
- Life cycle cost analysis
- Inter-industry competition

Environment
- Life cycle assessment
- Network allocation
- Network PVI
Key findings from CSHub network analyses

- Viable competition is an opportunity
- PVI data can be used in network pavement management
- Diversity of MRR alternatives is a means to enhance network performance
Does the presence of competition between material substitutes impact pavement material prices?

Statistical analyses of Oman BidTabs* data using these parameters:

- Quantity
- Annual spending
- Number of bidders
- Share of AC/PCC bids
- Use of AC & PCC on job
- Share of spending on AC vs. PCC

*2005-2015, 47 states, 298k pay items, 164k jobs
Viable competition is an opportunity

Statistical analysis results for *concrete* initial prices

<table>
<thead>
<tr>
<th>WHAT MATTERS?</th>
<th>PRICE</th>
<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume of concrete on job</td>
<td>![green向下箭头]</td>
<td>$$ $$</td>
</tr>
<tr>
<td>5-year rolling average: Spending on bids per state-year</td>
<td>![红色向上箭头]</td>
<td>$$ $$</td>
</tr>
<tr>
<td>5-year rolling average: Share of spending on concrete</td>
<td>![green向下箭头]</td>
<td>$$ $$</td>
</tr>
<tr>
<td>Mass of asphalt also on job</td>
<td>![红色向上箭头]</td>
<td>$$-$$ $$</td>
</tr>
<tr>
<td>Concrete percent of bid</td>
<td>![红色向上箭头]</td>
<td>$$ $$</td>
</tr>
<tr>
<td>Count of bidders on jobs</td>
<td>![green向下箭头]</td>
<td>$$ $$</td>
</tr>
</tbody>
</table>
Viable competition is an opportunity

### Statistical analysis results for *asphalt* initial prices

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<th>SIGNIFICANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-year rolling average: Spending on bids per state-year</td>
<td>↑</td>
<td>$$$</td>
</tr>
<tr>
<td>5-year rolling average: Mass of asphalt per state-year</td>
<td>↓</td>
<td>$$$</td>
</tr>
<tr>
<td>Count of bidders on jobs</td>
<td>↓</td>
<td>$$$-$$$$</td>
</tr>
<tr>
<td>Mass of asphalt on job</td>
<td>↓</td>
<td>$$$-$$$$</td>
</tr>
<tr>
<td><strong>Share of spending on concrete per state-year</strong></td>
<td>↓</td>
<td>$$$-$$$$</td>
</tr>
<tr>
<td>Asphalt percent of bid</td>
<td>↑</td>
<td>$$</td>
</tr>
<tr>
<td>Instability of Share of spending on concrete per state-year</td>
<td>↑</td>
<td>$$</td>
</tr>
<tr>
<td><strong>Volume of concrete also on job</strong></td>
<td>↑</td>
<td>$$</td>
</tr>
</tbody>
</table>
CSHub calculates excess fuel consumption of vehicles due to pavement design and maintenance.

Pavement-vehicle interaction (PVI)

- Pavement Deflection
- Pavement Roughness

Deflection & Roughness → Excess Fuel Consumption (EFC) → Economic & Environmental Impacts
Quantifying PVI in network analyses
Excess fuel consumption from PVI is significant

Estimate of extra fuel consumption from PVI in US pavement test sections

Total of ~700 million gallons of excess fuel per year
PVI data can be used in network pavement management

Excess fuel consumption due to PVI for cars & trucks on interstates in Virginia in 2013

Fuel Consumption (gallon/mile)
- 86 - 4,209
- 4,209 - 6,797
- 6,797 - 11,691
- 11,691 - 19,722
- 19,722 - 31,262

Assumed speed = 100 km/h = 62.6 mph; assumed temperature = 16 C/61 F
EFC analyses connect pavements and air quality

2013 Data

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Annual Caltrans Footprint (CARB)</th>
<th>Annual PVI Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excess Fuel (liter)</td>
<td>21 Million</td>
<td>2.5%</td>
</tr>
<tr>
<td>CO$_2$ (ton)</td>
<td>197 Million</td>
<td>1.9%</td>
</tr>
<tr>
<td>NO$_x$ (ton)</td>
<td>323 Thousand</td>
<td>0.5%</td>
</tr>
<tr>
<td>PM$_{2.5}$ (ton)</td>
<td>6 Thousand</td>
<td>4.4%</td>
</tr>
<tr>
<td>PM$_{10}$ (ton)</td>
<td>7 Thousand</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

EFC impacts include GHG and other air quality emissions

Impact Category

Fuel Consumption (liter/km) 104- 3,074 3,074- 12,055 12,055- 36,472 36,472- 104,351 104,351- 694,955
Goal of MIT pavement management research is to develop an allocation support tool that considers:

- Support project-level decisions
- Uncertainty & risk
  - Pavement deterioration
  - Immediate & future price of actions
- Real-world scale problems
  - Large-scale pavement networks
  - 50 year analysis period
  - Diverse set of maintenance, rehabilitation, & reconstruction (MRR) alternatives

We want to efficiently maintain and improve a pavement network.
Objective: find allocation policy that maximizes expected performance or minimizes cost.
## Key elements of the allocation model

<table>
<thead>
<tr>
<th>Conventional models</th>
<th>MIT model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short analysis periods (~5 yr)</td>
<td>Long analysis period (30+ yr)</td>
</tr>
<tr>
<td>Prescriptive decision rules</td>
<td>Dynamic decision rules</td>
</tr>
<tr>
<td>Deterministic data &amp; analysis</td>
<td>Risk analysis including uncertainty in prices &amp; deterioration</td>
</tr>
</tbody>
</table>
Example with VA interstate network
Expected roadway expenditures over 50 year analysis period

Low expenditures per unit area
Medium expenditures per unit area
High expenditures per unit area

Budget=$67m/yr
Objective: minimize traffic-weighted roughness
Allocation strategy diversifies after 50 years

Fixed budget ($67m)

Current Composition of System

- AC
- PCC

Expected Composition in Year 50

- AC
- PCC
Diversity of MRR alternatives is a means to enhance network performance

Single material network performs worse than a diversified network

($67m budget for scenarios)
Key findings from CSHub network analyses

Viable competition is an opportunity

PVI data can be used in network pavement management

Diversity of MRR alternatives is a means to enhance network performance
Sustainable infrastructure achieved by analyzing and balancing trade-offs $\rightarrow$ optimize!

Seek Sustainable Solutions

Performance

Environmental impacts

Cost
More information available at:
http://cshub.mit.edu/
cshub@mit.edu
Backup slides
LCCA – Life-cycle cost analysis: Method for evaluating total costs of ownership

Transform individual pavement expenditures over time into…

…total life-cycle cost

Present Value
LCA – Life-cycle assessment: Method for quantifying environmental impact

- Materials Production
- Design & Construction
- Use
- End-of-Life

Activity:
- Energy
- Raw Materials

Product:
- Releases to Land
- Air Emissions
- Water Effluents
CShub pavement research approach

- Science
- Engineering
- Economics
- Environment

- Projects
  - Durability
  - Albedo
  - Pavement-vehicle interaction

- Networks
  - Life cycle cost analysis
  - Life cycle assessment
  - Inter-industry competition
  - Network allocation
  - Network PVI
The life-cycle perspective frames CSHub work

Multiple mechanisms for reducing environmental impact and cost

Materials Production
- Use recycled
- Reduce energy
- Improve material performance

Design & Construction
- Use less (i.e., stronger) material
- Create longer-lasting designs

Use
- Reduce vehicle fuel consumption
- Reduce heat island effects

End-of-Life
- Enable material recovery

Prioritizing mechanisms requires a trade-off analysis of performance and life-cycle environmental impacts and costs
Research motivation: Pavement design is iterative; Accelerated feedback → more testing, more improvement
Research motivation: Pavement design is iterative; Accelerated feedback \(\rightarrow\) more testing, more improvement

- Design Proposal & Context
  - Layers
  - Traffic
  - Climate

Analyze Using ME
Design Principles

Develop Lifecycle
Bill of Activities

Evaluate
LCCA / LCA

Adequate Performance

MIT research aims to integrate these activities
LIFE CYCLE COST & ENVIRONMENTAL IMPACT ASSESSMENT

**Key accomplishments**

**Key findings**
C SHub created linkage between design tools and evaluation

Design Proposal & Context
Layers Traffic Climate

Analyze Using ME Design Principles

Develop Lifecycle Bill of Activities

Evaluate LCCA / LCA

Pavement-ME

Performance-to-activity model
- Material quantities
- Construction activities
- Maintenance timing
- Logistics

LCCA
- Magnitude & timing of cash
LCA
- Inputs → Emissions

Final Design

10.0” JPCP w/ 1.25” Dia Dowels
6.0” Agg Subbse
Subgrade

8.0” JPCP w/ 1.25” Dia Dowels
6.0” Agg Subbse
Subgrade

Adequate Performance

N
Y
C SHub created probabilistic life cycle cost and environmental impact models

Uncertainty quantified for:
- Initial & future costs
- Environmental impacts
- Material quantities
- Pavement deterioration
- Excess fuel consumption

- Extraction and production
- Transportation
- Onsite equipment

- Use
  - Excess Fuel Consumption
    - Roughness
    - Deflection
  - Albedo
  - Carbonation
  - Lighting
  - Traffic delay

- Maintenance
  - Materials
  - Construction

- End-of-Life/Rehabilitation

Incorporating use phase is a recent development

- Excavation
- Landfilling
- Recycling
- Transportation

Slide 38
CShub conducted LCCAs & LCAs for a wide range of scenarios

4 Locations

- CO: Dry freeze
- MO: Wet freeze
- AZ: Dry no freeze
- FL: Wet no freeze

3 Traffic Levels

- Rural local street/highway
- Rural state highway
- Urban interstate

Several framing conditions

- Pavement designs
- Maintenance schedules
- Design life
- Analysis period
LIFE CYCLE COST & ENVIRONMENTAL IMPACT ASSESSMENT

Key accomplishments

–

Key findings
Key findings from CSHub LCA/LCCA research

- Life cycle matters
- PVI matters
- Context matters
- Risk matters
Life cycle matters
Future costs can be significant

Total life cycle costs for a state highway in Florida

Future maintenance and rehabilitation costs 53%
Initial construction costs 47%

Flexible pavement design developed by Applied Research Associates (ARA), Inc.: AADTT 1k/day; 4 lanes; Wet-no-freeze-FL; FDOT-based rehabilitation schedule; Analysis period = 50 years.
Life cycle matters
Use phase can be a significant fraction of pavement environmental impact

Life cycle greenhouse gas (GHG) emissions of an urban interstate pavement in Missouri

Flexible pavement design developed by Applied Research Associates (ARA), Inc.: AADTT 8k/day; 6 lanes; Wet-freeze-MO; MEPDG-based rehabilitation schedule.
**PVI matters**

Excess fuel consumption is largest contributor to use phase impacts

Use-phase GHG emissions by source for an urban interstate pavement in Missouri

- **EFC: roughness** 40%
- **EFC: deflection** 53%
- **Other**: 7%
- **Other**: carbonation & lighting

*Other: carbonation & lighting*
Context matters
Costs vary with location, traffic level, & pavement design

- **Interstate, rigid design**
  - Rehab costs: 2%
  - Initial costs: 98%

- **Interstate, flexible design**
  - Rehab costs: 21%
  - Initial costs: 79%

- **Local highway, rigid design**
  - Rehab costs: 11%
  - Initial costs: 89%

- **State highway, flexible design**
  - Rehab costs: 53%
  - Initial costs: 47%
Context matters

*GHG emissions* vary with location, traffic level, & pavement design

- **Initial** = Materials & construction
- **Rehab** = Maintenance & rehabilitation
- **EoL** = end-of-life

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**Interstate, rigid design**

- **EoL** = 7%
- **Rehab** = 0%
- **Use** = 57%
- **Initial** = 36%

**Interstate, flexible design**

- **EoL** = 8%
- **Rehab** = 16%
- **Use** = 42%
- **Initial** = 34%

**Local highway, rigid design**

- **EoL** = 11%
- **Rehab** = 1%
- **Use** = 31%

**State highway, flexible design**

- **EoL** = 8%
- **Rehab** = 25%
- **Use** = 35%

Risk matters
Higher uncertainty means higher risk

Difference between alternatives depends on risk profiles
Risk of exceeding a particular cost can be calculated

Risk matters
Higher uncertainty means higher risk

Difference between alternatives depends on risk profiles
Risk of exceeding a particular cost can be calculated

Risk of exceeding a particular cost can be calculated

Risk of exceeding a particular cost can be calculated
CShub created probabilistic cost estimates for entire life-cycle

Agency:
- Unit-price of inputs
- Quantity of inputs

Agency:
- Quantity of inputs
- Future construction prices
- Maintenance timing

User:
- Traffic delays & fuel loss
CShub created effective long-term, probabilistic price projections

- Must be built from significant sets of data
- Must be viewed as probabilistic in nature

Source: USGS
CSHub models are probabilistic

Probabilistic models incorporate uncertainty. The figure shows a range of cost outcomes for two competing project alternatives. Source: FHWA
The future is worth considering

Prices change differently for different materials

Asphalt
Ave. annual price change = 1.3%

Concrete
Ave. annual price change = -0.2%

Lumber
Ave. annual price change = -0.8%
The future is worth considering
Effective price projections are plausible

**Concrete** (Constituent Based)

**Asphalt** (Constituent Based)
CShub forecasts have been shown to be more effective than current assumptions.

Testing the effectiveness of the model for the state of Colorado.

Real price projections outperform conventional assumptions of no real price change.

- Current Practice
- CShub Forecasting Model

Increasing Performance
There are several opportunities for future research

• Improve models for estimating initial construction cost

• Incorporate life-cycle cost considerations into asset management programs
Deflection matters
In some contexts, deflection causes the majority of fuel lost to PVI

Example:
Use-phase GHG emissions by source for an urban interstate pavement in Missouri

*Other: carbonation & lighting
Roughness matters
In some contexts, however, roughness causes most of the fuel lost to PVI

*Other: carbonation & lighting

Example:
Use-phase GHG emissions by source for an urban interstate pavement in Colorado

- Fuel loss: roughness 61%
- Fuel loss: deflection 31%
- Other* 8%
- Use
Large opportunities to improve exist
Pavement design optimization saves GHGs & $

Optimizing design represents a clear win-win
There are several opportunities for future research

• Develop context-specific models of albedo

• Explore impacts of using recycled content in pavement materials

• Identify opportunities to reduce impact using optimized designs
Opportunities for collaboration

Design Proposal & Context
Layers
Traffic
Climate

Analyze Using ME Design Principles

Develop Lifecycle Bill of Activities

Evaluate LCCA / LCA

Adequate Performance
N
Y

Final Design

Theme of collaborative projects: Integration of LCCA and LCA into pavement and asset management decisions
Potential collaborative research topics

• LCCA
  – Integrating probabilistic LCCA and ME design
  – Improving cost estimation methods
• LCA
  – Integrating probabilistic LCA and ME design
  – Improving data and models used in LCA
• PVI
  – Network-level assessments of excess fuel consumption due to PVI
Case study: wet no-freeze state HW in Florida

<table>
<thead>
<tr>
<th>Flexible</th>
<th>Rigid</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5” AC Surface</td>
<td>9” JPCP</td>
</tr>
<tr>
<td>3.5” AC Binder</td>
<td></td>
</tr>
<tr>
<td>6” Lime Rock Base</td>
<td>6” Lime Rock Base</td>
</tr>
<tr>
<td>Subgrade</td>
<td>Subgrade</td>
</tr>
</tbody>
</table>

**Parameter** | **Value**
---|---
AADTT two Directions | 1,000 vehicles/day
Number of Total Lanes-two Directions | 4
AADTT Linear Annual Increase | 3%
Climate | Wet No Freeze – FL
Soil Type | A-2-4

**FDOT Rehabilitation Schedule**
- Year 14: 2” Mill, 2.5” AC overlay
- Year 28: 2” Mill, 2.5” AC overlay
- Year 40: 2” Mill, 2.5” AC overlay
- Year 50: end of life

**MEPDG Rehabilitation Schedule**
- Year 20: 2” Mill, 2.5” AC overlay
- Year 37: 2” Mill, 2.5” AC overlay
- Year 50: end of life

**Functional Unit:**
1 center-lane mile over a 50-year analysis period
Case study: wet freeze urban interstate HW in Missouri

**Flexible**
- 2” Asphalt Surface
- 3” Asphalt Inter.
- MO : 8.5” Base
  MEPDG: 7” Base
- 24” rock base material

**Rigid**
- 11.0” JPCP w/ 1½ in Dia Dowels
- 6.0” Agg Subbse
- Subgrade

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADTT two Directions</td>
<td>8,000 vehicles/day</td>
</tr>
<tr>
<td>Number of Total Lanes-two Directions</td>
<td>6</td>
</tr>
<tr>
<td>AADTT Linear Annual Increase</td>
<td>3%</td>
</tr>
<tr>
<td>Climate</td>
<td>Wet Freeze - MO</td>
</tr>
<tr>
<td>Soil Type</td>
<td>A-7-6</td>
</tr>
</tbody>
</table>

**MODOT Rehabilitation Schedule**
- Year 25: 2” Mill, 2” AC overlay
- Year 35: 2” Mill, 2” AC overlay
- Year 50: end of life

**MEPDG Rehabilitation Schedule**
- Year 12: 2” Mill, 2” AC overlay
- Year 33: 2” Mill, 3” AC overlay
- Year 50: end of life

**MODOT Rehabilitation Schedule**
- Year 25: Diamond grinding & full depth patching
- Year 50: End of life

**MEPDG Rehabilitation Schedule**
- Year 30: Diamond grinding & full depth patching
- Year 50: 7 years salvage

Functional Unit:
1 center-lane mile over a 50-year analysis period
# Key model inputs

## Objective: Increase Network Performance (eg. Minimizing traffic weighted-IRI)

### Current State of System
- Roughness (IRI)
- Material type
- Age
- Traffic Volume

### Available Actions

**Maintenance**
- Diamond Grinding
- Mill and Fill Rehabilitation
- Thick AC overlays
- PCC white topping Reconstruction
- New JPCP and HMA pavement

### Projection Model of Future Conditions
- Pavement deterioration
- Forecasting and initial-cost models
What Have We Learned?

*A diversified system improves performance at constant cost*

- Risk-based model shows benefit of
  - Considering uncertainty
  - Technology diversification within the system
- Diversity of MRR alternatives is a means to:
  - Improve performance at the same budget
  - Reduce performance risk
- Diversity benefit is robust to many permutations of case context
- Optimal materials mix shifts with context
Example with VA interstate network

Input data

Current Condition of Roadway Facilities
- Average IRI (in/mile)

Current Traffic Volume of System
(AADT x1000)
Diversity of MRR alternatives is a means to enhance network performance

Asphalt only option is affected by high variability in price throughout the lifecycle

($67m budget for scenarios)
Diversity of MRR alternatives is a means to enhance network performance

The inclusion of concrete reduces downside risk at moments of spiraling asphalt prices

($67m budget for scenarios)
Key takeaways

Takeaway 1: Diversity of MRR alternatives increases overall performance

Takeaway 2: The benefit is larger in the risk-aware case

<table>
<thead>
<tr>
<th>Traffic-Weighted IRI (in/mi)</th>
<th>Deterministic</th>
<th>Probabilistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>Asphalt &amp; Concrete</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Asphalt</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Asphalt &amp; Concrete</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>
Case study

Data:
- VA state: 2,778 segments
- Pavement type fraction:
  - AC 65%, Com 24%, PCC 10%

Parameter:
- Network analysis period: 20 years
- Budget: $ 80,352,704 / year
- M&R: 8 alternatives
Optimization Objectives

• MRRBenefits
  – Maximize MRR benefits of the whole network.

• TWIRI (traffic weighted IRI)
  – Minimize the average traffic-weighted IRI of the whole network.

• RSL (remaining service life)
  – Maximize the average traffic-weighted RSL of the whole network.

• GoodCondition
  – Maximize the percentage of pavements in good condition while the percentage of pavements in poor condition should not exceed a threshold value.

• PoorCondition
  – Minimize the percentage of pavements in poor condition while the percentage of pavements in good condition should exceed a threshold value.
Comparing optimization objectives:
Network performance affected by objective

TWIRI > MRRBenefits > GoodCondition > RSL > PoorCondition
Comparing optimization objectives:
Network performance affected by objective

RSL > MRRBenefits > TWIRI > GoodCondition > PoorCondition
Pavement type distribution affected by optimization objective

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>Initial</th>
<th>MRBenefits</th>
<th>TWIRI</th>
<th>RSL</th>
<th>GoodCondition</th>
<th>PoorCondition</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>60%</td>
<td>20%</td>
<td>40%</td>
<td>60%</td>
<td>80%</td>
<td>100%</td>
</tr>
<tr>
<td>Concrete Top Composite</td>
<td>20%</td>
<td>80%</td>
<td>60%</td>
<td>20%</td>
<td>40%</td>
<td>60%</td>
</tr>
<tr>
<td>Concrete Top Composite</td>
<td>10%</td>
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<td>Asphalt Top Composite</td>
<td>10%</td>
<td>90%</td>
<td>80%</td>
<td>10%</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>
Pavement condition distribution affected by optimization objective

GoodCondition > TWIRI > MRRBenefits > PoorCondition > RSL