Cost-Benefit Analysis of the Pooled-Fund Maintenance Decision Support System: Case Study

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Outline

• Background
• Benefits and costs
• Methodology
• Case study
• Conclusions
Pooled Fund Study (PFS) Partners

- California
- Colorado
- Indiana
- Iowa
- Kansas
- Kentucky
- Minnesota
- Nebraska
- New Hampshire
- New York
- North Dakota
- South Dakota
- Virginia
- Wyoming
- Meridian Environmental Technology
How PFS MDSS is Used

Applications:
1. Real-time assessment of current and future road weather conditions
2. Real-time maintenance recommendations

PFS states’ experiences are generally between these levels

“A Tool”
Use MDSS Application 1
May Use MDSS Application 2

“A Revolution”
Rely on MDSS Application 1
Rely on MDSS Application 2
# MDSS Benefits and Costs

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Agency</th>
<th>Motorist</th>
<th>Society</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reduced materials use</td>
<td></td>
<td>• Reduced motorist delay (through improved LOS)</td>
<td>• Reduced environmental degradation</td>
</tr>
<tr>
<td>• Reduced labor costs</td>
<td></td>
<td>• Improved safety (through improved LOS)</td>
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<tr>
<td>• Reduced equipment &amp; fuel use</td>
<td></td>
<td>• Reduced response time</td>
<td></td>
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<tr>
<td>• Reduced fleet replacement costs</td>
<td></td>
<td>• Reduced clearance time</td>
<td></td>
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<tr>
<td>• Reduced infrastructure damage</td>
<td></td>
<td>• Reduced vehicle corrosion</td>
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<tr>
<td>• …</td>
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<td>• …</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Software and support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Communications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• In-vehicle computer hardware</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Training</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Administration costs</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Additional weather forecast provider costs</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>• Reduced materials use</td>
<td></td>
<td></td>
<td></td>
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<td>• Reduced labor costs</td>
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</tr>
<tr>
<td>• Reduced infrastructure damage</td>
<td></td>
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<tr>
<td>• …</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Points of Comparison (Scenarios)

- **Point 1**: Calibration Point (Base Case)
- **Point 2**: Keep resources same (Same Resource)
- **Point 3**: Keep LOS same (Same Conditions)

The diagram shows a graph with axes for Level of Service and Winter Maintenance Resources, with points 1, 2, and 3 indicating different scenarios. The graph includes a dashed line labeled MDSS Baseline and hypothetical; not to scale.
Methodology

• Simulation module
  – Simulate one or more routes based on winter maintenance data and rules of practice
  – Simulate three scenarios: base case (Point 1), same resource (Point 2), and same conditions (Point 3)

• Baseline data module
  – Various data such as highway route information, traffic volume, crash data, and weather information are incorporated to establish detailed baseline information for each route segment.

• Apply results from simulation to the baseline data module to obtain statewide resource usage and benefits
How to Simulate?

- Actual Weather Event
- MDSS Treatment
- Actual Rules of Practice
  - Resources Used
  - Predicted LOS
- Predicted LOS
- Resources Used
How to Apply Simulation Results to the Baseline Data Module?

- Identification and Classification of Storms
- Identification of storms (8 variables)
  - Air temperature range (warm, cold, cool…)
  - Pavement temperature trend
  - Duration
  - Precipitation accumulation
  - Precipitation rate
  - Average wind speed in storm
  - Average wind speed after storm
  - Condensation
Storm Classification

• Large number of storms were identified
• Classification method: K-Means Cluster Analysis
  – A simple procedure to classify a given dataset through a certain number of clusters (assume $k$ clusters)
  – Aims at minimizing an objective function

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^j - C_j \right\|^2$$

$J = \text{Squared Euclidean distance}$

$i$: data point; $j$: cluster center
How to Calculate Motorist Benefits? - Safety and Speed Adjustment Factors

• Crash rate and speed are affected by and vary with different pavement conditions
• Adjustment factors for crash rate and speed reduction were identified through literature review (> 30 past studies)
• Around 15 types of pavement conditions were used
New Hampshire Case

- I-93 from Manchester to Massachusetts state line
- Simulation period (Jan. 1998 – Dec. 2005), totally 7 winter seasons
- Weather observations from Concord and Manchester, NH
NH: Baseline Data Inputs

- 723 highway segments, 3,304 centerline miles
- AADT: 1998-2007 (10 years)
- Weather data: 13 weather stations (150 winter seasons, 7,500 storm events)
## NH: Tangible Costs

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Costs ($/year)</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Software and operations costs</td>
<td>$32,878</td>
<td>1 computer/route; 15 min of MDSS installation time.</td>
</tr>
<tr>
<td>2</td>
<td>Communications costs (for MDC)</td>
<td>$50,800</td>
<td>$40/month; 5 months/winter season</td>
</tr>
<tr>
<td>3</td>
<td>In-vehicle computer hardware investment (Capital and maintenance of MDC)</td>
<td>$152,400</td>
<td>254 MDCs; $2,000/MDC; Used for 5 years; Maintenance cost is 10% of the capital cost per year.</td>
</tr>
<tr>
<td>4</td>
<td>Training</td>
<td>$30,226</td>
<td>One training session/year for each garage; Each garage maintained 2 routes; Training costs for trainer and maintenance personnel.</td>
</tr>
<tr>
<td>5</td>
<td>Additional weather forecast provider costs</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Administrative costs</td>
<td>$66,576</td>
<td>25% of direct costs.</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>$332,879</strong></td>
<td></td>
</tr>
</tbody>
</table>
New Hampshire: Expect Great Return on MDSS Investment!

<table>
<thead>
<tr>
<th>SAVINGS</th>
<th>Resources (ton)</th>
<th>Delay ($M)</th>
<th>Safety ($M)</th>
<th>Total ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Same Conditions</td>
<td>23,644</td>
<td>$1.182</td>
<td>$0.017</td>
<td>$1.168</td>
</tr>
<tr>
<td>Same Resource</td>
<td>442</td>
<td>$0.022</td>
<td>$0.242</td>
<td>$2.622</td>
</tr>
</tbody>
</table>

**MDSS COSTS/YEAR**  $0.333

**BENEFIT/COST**  ~ 8:1

Validation: simulated vs. actual statewide salt usage
149,980 vs. 152,653 tons (1.8% error)
MN: Simulation Inputs

- A supercommuter route on I-94 within the St. Cloud County
- Simulation period (Jan. 2001 – Dec. 2006), totally 5 winter seasons
- Three scenarios:
  - Control
  - Same Salt
  - Same Conditions
MN: Baseline Data Inputs

- Historical Data Inputs for Benefit Analysis
  - 889 highway segments, 11,839 center miles (all routes)
  - AADT: 8 years
  - Crash data: 2000-2006
  - Weather data: 61 weather stations (871 winter seasons)

  - To calculate the number of storms by type per winter for each highway segment
CO: Simulation Inputs

- A highway segment on I-225 (MP 0.00 – 12.00)
- Simulation period: 4 winter seasons (2004-2008)
CO: Baseline Data Inputs

- Historical Data Inputs for Benefit Analysis
  - 613 highway segments, 9,057 centerline miles
  - AADT: 2005-06
  - Crash: 2000 – 01, 2003-04
  - Weather Data: 30 weather stations (431 winter seasons)
All three case studies confirm the benefits of MDSS

<table>
<thead>
<tr>
<th>Case State</th>
<th>Scenario</th>
<th>Benefits</th>
<th>Percent of User Savings (%)</th>
<th>Percent of Agency Savings (%)</th>
<th>Costs</th>
<th>B-C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Hampshire</td>
<td>Same Condition</td>
<td>$2,367,409</td>
<td>50</td>
<td>50</td>
<td>$332,879</td>
<td>7.11</td>
</tr>
<tr>
<td></td>
<td>Same Resources</td>
<td>$2,884,904</td>
<td>99</td>
<td>1</td>
<td>$332,879</td>
<td>8.67</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Same Condition</td>
<td>$3,179,828</td>
<td>51</td>
<td>49</td>
<td>$496,952</td>
<td>6.40</td>
</tr>
<tr>
<td></td>
<td>Same Resources</td>
<td>$1,369,035</td>
<td>187</td>
<td>-87</td>
<td>$496,952</td>
<td>2.75</td>
</tr>
<tr>
<td>Colorado</td>
<td>Same Condition</td>
<td>$3,367,810</td>
<td>49</td>
<td>51</td>
<td>$1,497,985</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>Same Resources</td>
<td>$1,985,069</td>
<td>90</td>
<td>10</td>
<td>$1,497,985</td>
<td>1.33</td>
</tr>
</tbody>
</table>
Conclusions

1. It was perceived that there were three types of benefits and costs associated with the use of MDSS: agency, user (motorists), and society. By using MDSS as a simulator, three benefits including reduced material usage (agency benefit) and improved safety and mobility (motorist benefits) were able to be quantified. The methodology for benefit-cost analysis was developed to analyze these tangible benefits and costs.

2. By comparing the actual material usage and the simulated usage, it was found that they had similar results. This is favorable to validate the reasonability of the simulation-based methodology. The analysis method provided the capability of comparing different implementation scenarios and looking at different maintenance results by using rules of practice and MDSS recommendations.
Conclusions (II)

3. Three case studies collectively showed that the benefits of using MDSS outweighed associated costs. The benefit-cost ratios did not indicate which MDSS scenario was (always) better. However, it is most likely that an agency implementing MDSS would fall somewhere between the *Same Resources* scenario and the *Same Condition* scenario, seeking to achieve both a level of service improvement and a reduction in winter maintenance costs. The case studies also showed that there is a trade-off between agency benefits and user benefits. Increased use of material will achieve more motorist benefits, while increase agency costs, and vise versa.
Questions?

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