Emerging Challenges, Best Practices, and Research Needs in Sustainable Winter Road Operations

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Outline

1. Life cycle sustainability of WRM operations
2. Benefits & emerging challenges in WRM operations
3. Risks to motor vehicles, infrastructure & environment
4. Societal considerations & performance measures
Outline (cont’d)

5. Source control approach to environmental sustainability
6. Reactive approach to environmental sustainability
7. Selection and development of “greener” products
8. A look to the future
1. Life cycle sustainability of WRM operations

Infrastructure Voluntary Evaluation Sustainability Tool: [www.sustainablehighways.org](http://www.sustainablehighways.org), w/ a segment on WM: standard practices, RWIS, SMP, MDSS, etc.

(Los Angeles World Airports, 2010)

ISO 14044: 2006, EM- LCA – Requirements & Guidelines
LCA framework for pavement decision support at the project level
Integrated LCCA/LCA of concrete bridge decks

Vehicle Emissions Model  Construction Equipment Emissions Model  Traffic Delay Model

LCA Model Parameters
User Input & System Definition

Life Cycle Assessment Model

LCC Model Parameters
Unit Costs

Life Cycle Cost Model

Agency Costs  Social Costs

Total Life Cycle Costs

Life Cycle Inventory & Environmental Sustainability Indicators
- Resource Depletion
- Energy Use
- Global Warming Potential

Social Cost Factors
- Pollution Damage Costs
- User Costs:
  - Vehicle Operation
  - User Delay Costs
  - Traffic Crash Risk

Agency Cost Factors
- Construction Material Costs
- Distribution of Materials & Equipment Costs
- Labor & Equipment Costs
- End-of-Life Costs

(Kendall et al., 2008, ASCE Journal of Infrastructure Systems, 14(3), 214-222)
Interconnected components & S.E. perspective
Life cycle of salt and other deicers

www.witnerservices.net

www.clf.org

www.missoulianews.bigskypress.com

www.syracuse.com

www.modot.org

Photo courtesy of M. Mills

www.ci.bellevue.wa.us
Q1. Life cycle sustainability of WRM operations

What are the research needs before we can fully account for the life cycle sustainability of WRM operations?
2a. Benefits in WRM operations

• Fewer accidents
• Improved mobility
• Reduced travel costs & reduced fuel use
• Sustained economic productivity, continued emergency services, ...
Highway winter operations in U.S.

- > 70% roads, 70% population
- Highways: 2.3 $bln/yr + 5 $bln/yr

**Statewide study: MnDOT current practices**

- (4,600 crashes) = 29% avoided
- $10.9M in travel time savings
- $48.4M in user fuel savings
- Total $227M saved, b/c of 6.2
- *Intangible costs & benefits*


Safety evaluation of WRM best practices

• Safety Performance Functions (SPF) to predict average crash frequency for base conditions
• Crash Modification Factors (CMFs) to account for effect of site-specific design features
• Observational before-after study using Empirical Bayes (EB) approach

\[ N_{expected} = w \times N_{predicted} + \frac{(1 - w) \times N_{observed}}{1 + k \times \left( \sum_{all \ study \ years} N_{predicted} \right)} \]

\[ w = \frac{1}{1 + k \times \left( \sum_{all \ study \ years} N_{predicted} \right)} \]
**Safety Analysis of FAST**

FAST systems contributed to crash reductions of:

- 2% on multilane rural highways
- 16 – 70% on urban interstates
- 31 – 57% on rural interstates
- 19 – 40% on interchange ramps
- Unclear for rural two-lane roads

Cost-Benefit Analysis Toolkit

Select the technology you are interested in.

After you conduct an assessment for your first technology, you will be given an option to print the results and compare them against other technologies.

**Practices**
- Anti-Icing
- Deicing
- Slurries
- Contracted versus state owned trucks
- Prewetting at the spreader

**Equipment**
- Carbide blades

**Operations**
- Maintenance Decision Support Systems (MDSS)
2b. Emerging challenges in WRM operations

- Increased traffic volumes
- Higher customer demands
- Funding, staffing and technology constraints

- Safety
- Effectiveness
- Mobility / Productivity
- Level of Service
- Customer Satisfaction
- Minimized Corrosion
- Environmental Stewardship


**WHAT:** deliver the right type & amount of materials in the right location at the right time

**WHY:**
- effectiveness & efficiency of winter operations
- material usage, $$\$, environmental footprint

**HOW** to balance LOS vs. sustainability: best practice *in technology & management domains*

Q2. Benefits and emerging challenges in WRM operations

How do we balance different priorities and address tradeoffs in a systematic and defensible framework?
3a. Risks to motor vehicles and transportation infrastructure

3b. Risks to the natural environment: air, water, soil, vegetation, wildlife, & human health

Based on 250 lb/l-m application rate (adapted from Winston et al., 2012)


Q3. Risks to motor vehicles, infrastructure & environment

How do we quantify the risks (and the benefits) with varying road weather scenarios and site-specific constraints, especially when they are long-lasting and intangible?
4a. Societal considerations

- Traffic crash risk
- User delay costs
- Vehicle operations
- Environmental damage & costs
- Continued emergency services
- Just-in-time delivery services
- Traveler decision / traveler information
- Political and cultural priorities/constraints
Managing user expectation for LOS

- **Customer feedback** from driving public: to reassess defined performance measures & LOS guidelines
- e.g., surveys and focus groups of Idaho residents
- Generally “Satisfied” with ITD’s winter maintenance and 3 out of 4 respondents indicated they feel “Safe” on Idaho’s highways
  - Most respondents had “No Concern” w/ “Plowing” & “Gravel/Sand”

Connected vehicles: Concept for WRM

Road geometry
Local road conditions
Road weather information
Upstream speed and road condition data
Geo-referenced historical crash data

GPS

Vehicle speed and trajectory
Driver age
Driver experience
Driver risk behavior

RWIS

High Risk Roadway

Low Risk Roadway
4b. Performance measures

- Mobility, accessibility, reliability, safety
- Measured as: time to bare pavement, return to speed limit, friction, visual inspection, winter mobility index
Iowa DOT salt usage dashboard

- Allocates salt to garages based on weather conditions & policy usage requirements
- Creates a salt budget for each garage

### Garage Salt Use Summary

<table>
<thead>
<tr>
<th>CC</th>
<th>Garage</th>
<th>Allocation (Tons)</th>
<th>Salt Used (Tons)</th>
<th>Salt Target (Tons)</th>
<th>% Target Used</th>
<th>% Allocation Used</th>
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<tbody>
<tr>
<td>D1</td>
<td>Ames</td>
<td>3,057</td>
<td>1,163.4</td>
<td>1,710.4</td>
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<td>Marshalltown</td>
<td>1,871</td>
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<td>Tama</td>
<td>1,315</td>
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<td>Grundy Center</td>
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<td>1,796</td>
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<td>Williams</td>
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<td>726.3</td>
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<td>Fort Dodge</td>
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<td>558.3</td>
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<td>449.4</td>
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<tr>
<td></td>
<td>Boone</td>
<td>1,263</td>
<td>688.2</td>
<td>573.5</td>
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<td>Malcom</td>
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<td>628.4</td>
<td>674.4</td>
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<td>Grinnell</td>
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<td>488.5</td>
<td>568.9</td>
<td>✅ 85.9%</td>
<td>✅ 44.2%</td>
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<tr>
<td></td>
<td>Newton</td>
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<td>921.3</td>
<td>1,045.9</td>
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<td></td>
<td>Altoona</td>
<td>1,261</td>
<td>542.6</td>
<td>410.9</td>
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<td>✅ 43.0%</td>
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<tr>
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<td>Des Moines North</td>
<td>2,778</td>
<td>972.4</td>
<td>1,012.0</td>
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<tr>
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<td>3,750</td>
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<td>1,636.0</td>
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<td>✅ 33.7%</td>
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<tr>
<td></td>
<td>Carlisle</td>
<td>1,603</td>
<td>542.7</td>
<td>429.6</td>
<td>✅ 126.3%</td>
<td>✅ 33.9%</td>
</tr>
</tbody>
</table>

**Statewide Salt Use vs. Target**

- 78% Salt Use vs. Target
- 551614 Boone: 1263 tons, 573.5% use
- 551802 Malcom: 1185 tons, 674.4% use
- 551803 Grinnell: 1106 tons, 568.9% use
- 551804 Newton: 2370 tons, 1045.9% use
- 551806 Altoona: 1261 tons, 410.9% use
- 551807 Des Moines North: 2778 tons, 1012.0% use
- 551808 Grimes: 3750 tons, 1636.0% use
- 551809 Carlisle: 1603 tons, 429.6% use

Annette Dunn, Iowa DOT
Iowa DOT salt usage dashboard (cont’d)

- Improves performance monitoring, accountability, decision-making
- Cost savings & environmental benefits
Q4. Societal considerations and performance measures

What are the research needs before we can develop more holistic and objective performance measures?
5. Source control approach to environmental sustainability

• To ensure the implementation of best practices

• To minimize the materials usage (or loss) & associated environmental footprint


**Source control: proactive strategies/tactics**

- Salt management plans
- Resource planning (zoning, route optimization, fleet/crew sizing, location of RWIS, etc.)
- Staff training & workforce development
- Design/operations of road maintenance yards
- Monitoring and record-keeping
- Roadway and pavement design
- Vegetation management
- Innovative snow fences for drift control
- Weather services
Source control: proactive strategies/tactics (cont’d)

- Operational strategies
- FAST system
- **Pavement innovations**
  - Maintenance decision support systems
  - Pavement sensors & thermal mapping
  - Advanced snowplows & spreaders
  - Equipment maintenance & calibration
  - Material storage & recycling
  - ...

Salt management plans

A statement of policies & objectives

• Identifies: road use, salt vulnerable areas, storage sites & other facilities, snow disposal sites, materials handling, training, ...

- Documentation
- Proposed approaches
- Training
  - Classroom, CBT, field, post-storm debriefing, simulator, etc.
- Management Review

The most effective way to dispose of snow is to let it melt where it accumulates
Roadway design & snow fences for drift control

- Reduce blowing & drifting snow
- Low cost snow storage
- Increased safety
- Reduce need for ice control products
- 25 yr lifespan at $1.40 per ft²

Enhance wildlife habitat, control erosion, improve water quality, reduce spring-time flooding, sequester CO₂
**Improved weather forecasts**

- **Reduce the WM costs:**
  - 11–25% (labor)
  - 4-10% (material)

- **Improved spatial resolution**
  - Greater benefits to service levels


**Operational strategies**

**Toolbox approach**

- Local needs
- Rd weather scenarios
- Local constraints

**Proactive vs. Reactive**

- Anti-icing
- Deicing (*pre-wet* salt, DLA, ...)
- Sanding (*pre-wet* sand, e.g., slurry)
- Mechanical (plowing/blowing)

**Decision support tools (e.g., MDSS)**

Tools that **integrate** road weather forecasts, coded maintenance rules of practice, resource data to provide recommended treatment strategies (FHWA, 2011)

- Cost & material savings, benefit/cost: 1.33 to 8.67
- Less use of vehicles (and staff overtime)
- *Lessons learned*: time needed to refine forecast and get management on board, continued training & exposure


Maintenance Decision Support System
**Smart snowplows and sensors**

**Mobile RWIS**: integrated with AVL/GPS to provide improved real-time knowledge of road & environmental conditions **throughout a network**

- **Surface temperature sensors**
- **Freezing point & ice presence detection sensors**
- **Salinity sensors**
  - Linked w/ automatic spreader controls
  - Enable educated decisions
  - Prevents over-application, saves material & $$$


GPS/AVL: [http://clearroads.org/project/synthesis-on-gpsavl-equiment-used-for-winter-maintenance/](http://clearroads.org/project/synthesis-on-gpsavl-equiment-used-for-winter-maintenance/)

Q5. Source control approach to environmental sustainability

What are the best practices and research needs in source control?
Chlorides are difficult to remove from the environment!

- **Dilution + controlled storage/release** (via detention, retention or evaporation ponds; wetlands and shallow marshes)
  - To mix larger volumes of stormwater to reduce peak [Cl\(^-\)]
  - Route the runoff away from sensitive receiving waters
- **Infiltration** (e.g., via infiltration trenches/basins, vegetated swales and filter strips) vs. *groundwater contamination*
- **Phytoremediation** (plant uptake)
- **Chloride capture on filter media**
Combined use of various BMPs to provide flow control

(Strecker, 2014)
Q6. Reactive approach to environmental sustainability

What are the best practices and research needs in reactive approach?
7. Selection and development of “greener” products

### Multi-criteria collaborative decision making

<table>
<thead>
<tr>
<th>Normalized Data</th>
<th>Cost per Lane Mile</th>
<th>Average Performance</th>
<th>Infrastructure Impacts</th>
<th>Environmental Impacts</th>
<th>Composite Index</th>
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</thead>
<tbody>
<tr>
<td>AF Salt</td>
<td>73</td>
<td>59</td>
<td>27</td>
<td>65</td>
<td></td>
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<tr>
<td>BLKFT Salt</td>
<td>86</td>
<td>57</td>
<td>27</td>
<td>55</td>
<td></td>
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<tr>
<td>Firth Salt</td>
<td>83</td>
<td>49</td>
<td>27</td>
<td>53</td>
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<tr>
<td>Boise Salt</td>
<td>86</td>
<td>49</td>
<td>27</td>
<td>54</td>
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<tr>
<td>Regular Salt</td>
<td>100</td>
<td>73±3</td>
<td>43</td>
<td>51±1</td>
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<td>AF Slicer</td>
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<td>27</td>
<td>54</td>
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<tr>
<td>Ice Slicer BLKFT</td>
<td>79</td>
<td>56</td>
<td>27</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Ice Slicer Malad</td>
<td>79</td>
<td>49</td>
<td>27</td>
<td>52</td>
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<tr>
<td>BLKFT Brine</td>
<td>26</td>
<td>62</td>
<td>68</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Pocatello Brine</td>
<td>96</td>
<td>6</td>
<td>68</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Regular Brine</td>
<td>11±13</td>
<td>60</td>
<td>68</td>
<td>50±10</td>
<td></td>
</tr>
<tr>
<td>30% MgCl₂ Boise</td>
<td>0</td>
<td>61</td>
<td>82</td>
<td>22</td>
<td>41</td>
</tr>
<tr>
<td>Max</td>
<td>100</td>
<td>86</td>
<td>82</td>
<td>68</td>
<td>65</td>
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<tr>
<td>Min</td>
<td>0</td>
<td>2</td>
<td>49</td>
<td>22</td>
<td>41</td>
</tr>
</tbody>
</table>


Ice Melt vs. Time 20°F

- Mix 28
- Mix 29
- Mix 30
- Mix 31
- Mix 35
- Mix 36
- Mix 3
- Mix 22
- Mix 13Z

Mix 80:20 NaCl:Boost

Time (min)

mL brine/g deicer
Freeze-thaw weight loss of PCC following the SHRP H205.8 test

Percent Weight loss (%) vs. Treatment:
- 23%NaCl
- 30% MgCl2
- DI Water
- Mix 3A
- Mix 22A
- Mix 3
- Mix 22
- Mix 3B
- Mix 22B
- Mix 3C

Data indicates significant weight loss for Mix 3 and Mix 22, with Mix 3 showing the highest loss.
Q7. “Green” anti-icing and deicing products

What are the best practices and research needs in “green” products for snow/ice control?

8. A look to the future

- Technological and institutional barriers remain!
- Micro-scale road weather forecasting & sensing
- Understanding the ‘dynamic layer’ on the road surface: timing & freq.
- More integrated & automated onboard sensors
- Low-cost, high-reliability FAST system or pavement innovations for ice-prone locations
- A holistic snow/ice control management system
- *Ultimate integration of solutions into the WM toolbox*: continued investment & efforts in R&D + user-needs driven product strategies
Q8. A look to the future

What are the emerging challenges and solutions in the next five to ten years?
Q & A for the workshop

1. What are the research needs before we can fully account for the life cycle sustainability of WRM operations?

2. How do we balance different priorities and address tradeoffs in a systematic and defensible framework?

3. How do we quantify the risks (and the benefits) with varying road weather scenarios and site-specific constraints, especially when they are long-lasting and intangible?

4. What are the research needs before we can develop more holistic and objective performance measures?
Q & A for the workshop (cont’d)

5. What are the best practices and research needs in source control?
6. What are the best practices and research needs in reactive approach?
7. What are the best practices and research needs in “green” products for snow/ice control?
8. What are the emerging challenges and solutions in the next five to ten years?
Questions?

Collaboration?

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Additional Slides for Q & A
Sustainability practices in the use of traction materials

• **Air quality** (PM 10)
• **Water quality** (TMDL/turbidity)
• **More materials, lower LOS**
• Apply at low speed roads, hills, curves, intersections
• **Pre-wetting**
  • *Liquid product or hot water*
  • Reduce bounce & scatter
  • Accelerates breakup of snow/ice and improve longevity on pavement
• Heating sand
• **Cleaning up**
Monitoring & records-keeping

- Determine baseline & identify trends
  - Total length of road
  - Winter severity rating
  - Number of events
  - Material used
  - **Calibration** dates
  - Treatment effectiveness

“…prevent the formation or development of bonded snow & ice by timely applications of a chemical freezing-point depressant”

Or weaken the bond

• ↑LOS, ↓product, abrasives & plowing
• 20 – 65 gal/l-m
• Cost savings +↑mobility/safety
• reducing impacts to the environment, infrastructure, vehicles

• Limitations:
  • Cold temps, rain/sleet, blowing snow, air temp above freezing & rising, high humidity
**Prewetting:** Slurry Technology

- High volume liquid anti-icer to dry salt (30%:70%) ~ 60-90 gal/ton
- 200 lb/l-mi = ~ 9 gal/l-mi
- Oatmeal consistency, salt grains fully saturated
- Slurry auger & at spinner
  - Goes into action quicker, acts immediately, lasts longer on road, out-perform traditional pre-wetting, minimizes bounce & scatter
Slurry Technology

• Lesson Learned
  • ¾ in salt allowed but smaller grains work better
  • Start with a heavier application, followed by smaller
  • Some equipment has worked better than others
    • Pumps, on board crushers, overall equipment design/functionality
## Typical Product Application Rates

<table>
<thead>
<tr>
<th>Product</th>
<th>Use</th>
<th>Application Rate</th>
<th>Pavement Temperature Ranges</th>
<th>Reference</th>
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</thead>
<tbody>
<tr>
<td><strong>NaCl</strong></td>
<td>Deicing</td>
<td>200 to 800 lbs/l-m</td>
<td>32 to 0°F</td>
<td>Levelton Consultants Limited, 2007; Salt Institute, 2007</td>
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<td>Anti-icing</td>
<td>20 to 80 gal/l-m</td>
<td>32 to 10°F</td>
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<td>Pre-wet solid</td>
<td>200 to 800 lbs/l-m</td>
<td>32 to 0°F</td>
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<tr>
<td><strong>MgCl₂ and CaCl₂</strong></td>
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<td>100 to 400 lbs/l-m</td>
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<td>Fischel, 2001</td>
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<td>Anti-icing</td>
<td>30 to 45 gal/l-m</td>
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<td>Fischel, 2001</td>
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<td>Pre-wetting</td>
<td>10 to 12 gal/l-m</td>
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<td>Blackburn et al., 2004</td>
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<tr>
<td><strong>Abrasives</strong></td>
<td>Traction sand</td>
<td>500 to 6000 lbs/l-m</td>
<td>no limits</td>
<td>Levelton Consultants Limited, 2007</td>
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<td></td>
<td>Salt-sand mix</td>
<td>500 to 6000 lbs/l-m</td>
<td>32 to 0°F</td>
<td>Levelton Consultants Limited, 2007</td>
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<td>Pre-wet abrasives</td>
<td>500 to 6000 lbs/l-m</td>
<td>no limits</td>
<td>Levelton Consultants Limited, 2007</td>
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</tbody>
</table>
### Deicing Application Rate Guidelines

24’ of pavement (typical two-lane road)

[www.pca.state.mn.us/programs/roadsalt.html](http://www.pca.state.mn.us/programs/roadsalt.html)

MN Snow and Ice Control Field Handbook for Snowplow Operators

<table>
<thead>
<tr>
<th>Pavement Temp. (°F) and Trend (↑ ↓)</th>
<th>Weather Condition</th>
<th>Maintenance Actions</th>
<th>Lbs/lane-mile</th>
<th>Winter Sand (abrasives)</th>
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<td>Salt Prewetted/ Pretreated With Salt Brine</td>
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<td>Dry Salt</td>
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<tr>
<td></td>
<td></td>
<td>Salt Prewetted/ Pretreated With Other Blends</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;30° ↑</td>
<td>Snow</td>
<td>Plow, treat intersections only</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>80-160</td>
<td>70-140</td>
</tr>
<tr>
<td>30° ↓</td>
<td>Snow</td>
<td>Plow &amp; apply chemical</td>
<td>80-160</td>
<td>70-140</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>150-200</td>
<td>130-180</td>
</tr>
<tr>
<td>25 - 30° ↑</td>
<td>Snow</td>
<td>Plow &amp; apply chemical</td>
<td>120-160</td>
<td>100-140</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>150-200</td>
<td>130-180</td>
</tr>
</tbody>
</table>
FAST Systems

- Reduced mobile operations
- Reduced crash frequency & delay
- Less material required

- Challenges
  - Activation frequency
  - System maintenance & training
- Appropriate only at a highly localized level, as a supplement to mobile operations
  - Installation should be site specific

New Hampshire Case Study

- **MDSS Benefits** (per winter season)

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Delay Savings</th>
<th>Crash Savings</th>
<th>Materials Savings</th>
<th>Total Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same Conditions</td>
<td>$5,039</td>
<td>$335,052</td>
<td>$354,661</td>
<td>$694,752</td>
</tr>
<tr>
<td>Same Salt</td>
<td>$72,461</td>
<td>$786,385</td>
<td>$6,624</td>
<td>$865,470</td>
</tr>
</tbody>
</table>

Assume 30% MDSS recommendations were followed.

- Costs per winter season: $332,879
- Benefit-Cost Ratios:
  - **2.1 (Same Conditions); 2.6 (Same Salt)**


Pavement Sensors & Thermal Mapping

- Monitoring, planning, treatment strategies, forecasting
- Invasive & non-invasive
Advanced snowplows and spreaders
Precise Application of Materials

- Tailgate Spreaders & Reverse dumping
- Multipurpose spreaders
- Rear Discharge Spreaders
- Zero velocity spreaders
- Dual spinners
- Modified spinners
- Homemade chutes

Challenges
- Mechanical failure
- Clogging & freezing
- Corrosion
- Frequent calibration


• Monitoring, planning, treatment strategy, prevent over-application
• Colorado DOT
  o Non-contract friction measurements
  o Provide good short/long-term assessment of product performance
A “Supermix” (85% salt brine, 10% De-ice, 5% CaCl$_2$):
anti-icing above 15°F @ 40 gln/ln-mi
pre-wetting above 2°F @ 10 gln/ton