Sustainability Practices in Highway Winter Operations: A Renewed Perspective

Xianming Shi, Ph.D., P.E.
Webinar for CESTiCC and Pavinar
Feb. 3, 2015
1. Benefits & emerging challenges in highway winter operations
2. Sustainability practices in the use of traction materials
3. Strategic approach and management practices
4. Technologies enabling the reduced usage of snow/ice control materials
5. Selection & development of “greener” products
6. Concluding Remarks
7. A look to the future
1. Benefits of highway winter operations

- Fewer accidents
- Improved mobility
- Reduced travel costs & reduced fuel use
- Sustained economic productivity, continued emergency services, ...
1a. Winter maintenance operations in the U.S.

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

**Minnesota DOT 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 benefits**

---

**References**

1b. Emerging challenges

1c. Principles of sustainability applied to WM operations

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

- Strategic (annual) Operations
- Materials Usage & Innovation
- Levels of Service & Economics
- Performance Measurement and Continuous Improvement
- Operational Practices & Equipment Selection/Innovation
- Enhanced Weather Forecasts
- Tactical (per-storm) Operations
- Staffing and Training
1d. Life cycle of salt & other deicers
Water quality implications & toxicological effects

- Based on 250 lb/l-m application rate

(adapted from Winston et al., 2012)

Deicer impacts on vehicles, bridges & pavements

2. 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**
3. Strategic approach and management practices

Source control

- To ensure the implementation of best practices
- To minimize the materials usage (or loss) & associated environmental footprint


3a. Manage level-of-service (LOS) expectations

- **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”

---

3b. 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
3c. Monitoring & records-keeping

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

Iowa DOT salt usage dashboard

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

<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>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Ames</td>
<td>3,057</td>
<td>1,163.4</td>
<td>1,710.4</td>
<td>☑ 68.0%</td>
<td>☑ 38.1%</td>
</tr>
<tr>
<td></td>
<td>Marshalltown</td>
<td>1,871</td>
<td>829.6</td>
<td>1,081.7</td>
<td>☑ 76.7%</td>
<td>☑ 44.3%</td>
</tr>
<tr>
<td></td>
<td>Tama</td>
<td>1,315</td>
<td>717.8</td>
<td>642.5</td>
<td>☑ 111.7%</td>
<td>☑ 54.6%</td>
</tr>
<tr>
<td></td>
<td>Grundy Center</td>
<td>1,714</td>
<td>459.8</td>
<td>689.1</td>
<td>☑ 66.7%</td>
<td>☑ 26.8%</td>
</tr>
<tr>
<td></td>
<td>Iowa Falls</td>
<td>1,796</td>
<td>512.4</td>
<td>820.6</td>
<td>☑ 62.5%</td>
<td>☑ 28.5%</td>
</tr>
<tr>
<td></td>
<td>Grundy Center</td>
<td>2,179</td>
<td>726.3</td>
<td>1,133.7</td>
<td>☑ 64.1%</td>
<td>☑ 33.3%</td>
</tr>
<tr>
<td></td>
<td>Williams</td>
<td>1,573</td>
<td>558.3</td>
<td>771.6</td>
<td>☑ 72.4%</td>
<td>☑ 35.5%</td>
</tr>
<tr>
<td></td>
<td>Fort Dodge</td>
<td>840</td>
<td>156.0</td>
<td>449.4</td>
<td>☑ 34.7%</td>
<td>☑ 18.6%</td>
</tr>
<tr>
<td></td>
<td>Gowrie</td>
<td>1,005</td>
<td>459.3</td>
<td>488.1</td>
<td>☑ 94.1%</td>
<td>☑ 45.7%</td>
</tr>
<tr>
<td></td>
<td>Jefferson</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boone</td>
<td>551614</td>
<td>1,263</td>
<td>688.2</td>
<td>☑ 120.0%</td>
<td>☑ 54.5%</td>
</tr>
<tr>
<td></td>
<td>Malcom</td>
<td>551802</td>
<td>1,185</td>
<td>628.4</td>
<td>☑ 93.2%</td>
<td>☑ 53.0%</td>
</tr>
<tr>
<td></td>
<td>Grinnell</td>
<td>551803</td>
<td>1,106</td>
<td>488.5</td>
<td>☑ 85.9%</td>
<td>☑ 44.2%</td>
</tr>
<tr>
<td></td>
<td>Newton</td>
<td>551804</td>
<td>2,370</td>
<td>921.3</td>
<td>☑ 88.1%</td>
<td>☑ 38.9%</td>
</tr>
<tr>
<td></td>
<td>Altoona</td>
<td>551806</td>
<td>1,261</td>
<td>542.6</td>
<td>☑ 132.0%</td>
<td>☑ 43.0%</td>
</tr>
<tr>
<td></td>
<td>Des Moines North</td>
<td>551807</td>
<td>2,778</td>
<td>972.4</td>
<td>☑ 96.1%</td>
<td>☑ 35.0%</td>
</tr>
<tr>
<td></td>
<td>Grimes</td>
<td>551808</td>
<td>3,750</td>
<td>1,264.8</td>
<td>☑ 77.3%</td>
<td>☑ 33.7%</td>
</tr>
<tr>
<td></td>
<td>Carlisle</td>
<td>551809</td>
<td>1,603</td>
<td>542.7</td>
<td>☑ 126.3%</td>
<td>☑ 33.9%</td>
</tr>
</tbody>
</table>
• Improves performance monitoring, accountability, decision-making

• Cost savings & environmental benefits
3d. Performance measures

• Mobility, accessibility, reliability, safety

• Example: time to bare lane

• Measured as: return to speed, friction, visual inspection, winter mobility index

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Successfully Treated</td>
</tr>
<tr>
<td>0.00-0.30</td>
<td>Significantly Accelerated Grip Recovery</td>
</tr>
<tr>
<td>0.31-0.49</td>
<td>Some Success at Grip Recovery</td>
</tr>
<tr>
<td>0.50-0.69</td>
<td>Very Little Success at Deicing</td>
</tr>
<tr>
<td>0.70-1.00</td>
<td>Limited Maintenance or No Deicer Success</td>
</tr>
<tr>
<td></td>
<td>Observation Data/Parameter Missing or Temperature is Below Threshold</td>
</tr>
</tbody>
</table>

NCHRP 14-34 Guide for Performance Measures in Snow and Ice Control Operations
3e. 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)
- Mechanical (plowing/blowing)

“...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
3f. Effective Application Rates for Anti-icing and Deicing

### Deicing Application Rate Guidelines

#### 24’ of pavement (typical two-lane road)

---

**MN Snow and Ice Control Field Handbook for Snowplow Operators**

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

<table>
<thead>
<tr>
<th>Pavement Temp. (°F) and Trend (↑↓)</th>
<th>Weather Condition</th>
<th>Maintenance Actions</th>
<th>Lbs/lane-mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Salt Prewetted/Pretreated With Salt Brine</td>
<td>Salt Prewetted/Pretreated With Other Blends</td>
</tr>
<tr>
<td>&gt;30° ↑</td>
<td>Snow</td>
<td>Plow, treat intersections only</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>80-160</td>
</tr>
<tr>
<td>30° ↓</td>
<td>Snow</td>
<td>Plow &amp; apply chemical</td>
<td>80-160</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>150-200</td>
</tr>
<tr>
<td>25 - 30° ↑</td>
<td>Snow</td>
<td>Plow &amp; apply chemical</td>
<td>120-160</td>
</tr>
<tr>
<td></td>
<td>Frz. Rain</td>
<td>Apply chemical</td>
<td>150-200</td>
</tr>
</tbody>
</table>
4. Technologies enabling reduced usage of snow/ice control materials

- *Drift control/roadway design and snow fences*
- *Improved weather forecasts*
- *Software applications for WM (zoning, route optimization, CBA toolkit, MDSS)*
- *Smart snowplows and sensors*
- *Advanced snowplows, spreaders, and blades*
4a. Drift control/roadway design & snow fences

- Reduce blowing & drifting snow
- Low cost snow storage
- Increased safety
- Reduce need for ice control product
- 25 yr lifespan at $1.40 per ft$^2$

Wildlife habitat, control erosion, improve water quality, reduce spring-time flooding, sequester CO$_2$

≥8 ft
4b. Improved weather forecasts

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

- Improved spatial resolution = greater benefits to service levels


4c. Software applications for winter operations

- *Optimization of facility sites and plow routes*
- *Cost-benefit analysis toolkit*
- *Decision support tools*
- AASHTO Computer based training (CBT)
- ...
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)
Cost & material savings, benefit/cost: 1.33 to 8.67, less use of vehicles

Lessons learned: time needed to refine forecast and get management on board, continued training & exposure

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)
Maintenance Decision Support System
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)

---


4d. 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-equipment-used-for-winter-maintenance/](http://clearroads.org/project/synthesis-on-gpsavl-equipment-used-for-winter-maintenance/)
Real-time road condition information

- Used to time treatments & determine which treatments to use
- Benefits:
  - LOS
  - Cost savings
  - Aid in maintenance response
  - Efficiency
- Benefit/cost ratio: 1.4 to 11
Pavement Sensors & Thermal Mapping

- Monitoring, planning, treatment strategies, forecasting
- Invasive & non-invasive
• Monitoring, planning, treatment strategy, prevent over-application

• **Colorado DOT**
  
  o Non-contract friction measurements
  
  o Provide good short/long-term assessment of product performance
4e. 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


5. 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 /Vehicle Impacts</th>
<th>Environmental Impacts</th>
<th>Composite Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF Salt</td>
<td>73</td>
<td>59</td>
<td>27</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>BLKFT Salt</td>
<td>86</td>
<td>57</td>
<td>27</td>
<td></td>
<td>55</td>
</tr>
<tr>
<td>Firth Salt</td>
<td>83</td>
<td>49</td>
<td>27</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Boise Salt</td>
<td>86</td>
<td>49</td>
<td>27</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Regular Salt</td>
<td>100</td>
<td>53</td>
<td>43</td>
<td></td>
<td>51±1</td>
</tr>
<tr>
<td>AF Slicer</td>
<td>84</td>
<td>50</td>
<td>27</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Ice Slicer BLKFT</td>
<td>79</td>
<td>56</td>
<td>27</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>Ice Slicer Malad</td>
<td>79</td>
<td>49</td>
<td>27</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>BLKFT Brine</td>
<td>26</td>
<td>62</td>
<td>68</td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>Pocatello Brine</td>
<td>96</td>
<td>6</td>
<td>60</td>
<td></td>
<td>45</td>
</tr>
<tr>
<td>Regular Brine</td>
<td>11±13</td>
<td>60</td>
<td>68</td>
<td></td>
<td>50±10</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>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>2</td>
<td>49</td>
<td>22</td>
<td>41</td>
</tr>
</tbody>
</table>

Ice Melting Performance at 60 min at 30°F

- Mix 3
- Mix 4
- Mix 6
- Mix 13
- Mix 16
- Mix 19
- Mix 20
- Mix 22
- Mix 27

23% NaCl

ml brine/g deicer
Ice Melting Performance at 60 min at 15°F

<table>
<thead>
<tr>
<th>ml brine /g deicer</th>
<th>23% NaCl</th>
<th>Mix 3</th>
<th>Mix 4</th>
<th>Mix 6</th>
<th>Mix 12</th>
<th>Mix 13</th>
<th>Mix 16</th>
<th>Mix 19</th>
<th>Mix 20</th>
<th>Mix 22</th>
<th>Mix 27</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.1</td>
<td>1.6</td>
<td>1.5</td>
<td>1.6</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Mix 23</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Freeze-thaw weight loss of PCC following the SHRP H205.8 test

Percent Weight loss (%)
6. Concluding remarks

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

7. 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

---

Connected vehicles: Concept for WM

- 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
Questions?

Xianming Shi, PhD, PE
Associate Professor, Civil & Environmental Engineering
Washington State University
Sloan 101, PO Box 642910
Pullman, WA 99164-2910
Phone: 1-509-335-7088
xianming.shi@wsu.edu
Additional Slides for Q&A
Anti-icing

Preventing the formation or development of bonded snow & ice by timely applications of a chemical freezing-point depressant
Plowing

The physical removal of snow from the road using a snowplow.
Deicing

Breaking the bond between snow & ice and the pavement surface through applications of a chemical freezing-point depressant
Sanding

The application of sand, cinders, ash, etc. to improve friction on the roadway
Winter Maintenance Products

• Sand
• Treated sand (sand + 10% salt (s,l))
• Chlorides – NaCl, MgCl₂, CaCl₂ (s,l), ...
• Agro-based – beet, corn (l), ...
• Acetates & formates (s,l), glycols (l)
## 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>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</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>
</tr>
<tr>
<td></td>
<td>Anti-icing</td>
<td>20 to 80 gal/l-m</td>
<td>32 to 10°F</td>
<td>Levelton Consultants Limited, 2007, Peterson et al. 2010</td>
</tr>
<tr>
<td></td>
<td>Pre-wet solid</td>
<td>200 to 800 lbs/l-m</td>
<td>32 to 0°F</td>
<td>Levelton Consultants Limited, 2007</td>
</tr>
<tr>
<td>MgCl₂ and CaCl₂</td>
<td>Deicing</td>
<td>100 to 400 lbs/l-m</td>
<td></td>
<td>Fischel, 2001</td>
</tr>
<tr>
<td></td>
<td>Anti-icing</td>
<td>30 to 45 gal/l-m</td>
<td></td>
<td>Fischel, 2001</td>
</tr>
<tr>
<td></td>
<td>Pre-wetting</td>
<td>10 to 12 gal/l-m</td>
<td></td>
<td>Blackburn et al., 2004</td>
</tr>
<tr>
<td>Abrasives</td>
<td>Traction sand</td>
<td>500 to 6000 lbs/l-m</td>
<td>no limits</td>
<td>Levelton Consultants Limited, 2007</td>
</tr>
<tr>
<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>
</tr>
<tr>
<td></td>
<td>Pre-wet abrasives</td>
<td>500 to 6000 lbs/l-m</td>
<td>no limits</td>
<td>Levelton Consultants Limited, 2007</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


SAFETY ANALYSIS OF FAST

• FAST systems contributed to crash reductions of:
  o 2% on multilane rural highways
  o 16 – 70% on urban interstates
  o 31 – 57% on rural interstates
  o 19 – 40% on interchange ramps
  o Unclear for rural two-lane roads

Natural environments at risk

1. **Soil**: swelling/compaction, increased conductivity, loss in stability, …

2. **Surface and ground waters**: increased salinity, heavy metals, …

   EPA Cl-thresholds for fish species:

   - 1-hr average of 860 mg/l &
   - 4-d average of 230 mg/l
   - Not to exceed more than once every 3 years
Natural environments at risk

3. Vegetation: increased deicer concentrations in the soil and water...lead to plant injury symptoms & loss of native species...

4. Wildlife (habitat)

5. Human health
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
Identify Potential Waste Material or By-Products

Design of Experiments to Determine Concentrations

Determine Ice Melting Performance, Corrosion to Steel, & Impacts to Concrete

Laboratory Investigation Following SHRP H205.2 NACE TM0169-95, & SHRP H205.8

Field Operational Testing of Highest Performers

Implementation to Maintenance Agencies
Ice Melting Performance 60 min 20°F

<table>
<thead>
<tr>
<th>Mix</th>
<th>ml brine/ml deicer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 36</td>
<td>2.05</td>
</tr>
<tr>
<td>Mix 35</td>
<td>1.95</td>
</tr>
<tr>
<td>Mix 13</td>
<td>1.85</td>
</tr>
<tr>
<td>Mix 13Z</td>
<td>1.75</td>
</tr>
<tr>
<td>Mix 22</td>
<td>1.65</td>
</tr>
<tr>
<td>Mix 3</td>
<td>1.55</td>
</tr>
<tr>
<td>Mix 28</td>
<td>1.45</td>
</tr>
<tr>
<td>Mix 29</td>
<td>1.40</td>
</tr>
<tr>
<td>80:20 NaCl:Boost</td>
<td>1.35</td>
</tr>
<tr>
<td>Mix 30</td>
<td>1.30</td>
</tr>
<tr>
<td>Mix 31</td>
<td>1.25</td>
</tr>
<tr>
<td>Mix 32</td>
<td>1.20</td>
</tr>
<tr>
<td>Mix 33</td>
<td>1.15</td>
</tr>
<tr>
<td>Mix 34</td>
<td>1.10</td>
</tr>
</tbody>
</table>
A “Supermix” (85% salt brine, 10% De-ice, 5% CaCl₂):
anti-icing above 15°F @ 40 gln/ln-mi
pre-wetting above 2°F @ 10 gln/ton