Alternative Methods for Deicing

Final Report

CLEAR ROADS

research for winter highway maintenance

Western Transportation Institute

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Alternative Methods for Deicing

Task 6 Final Report

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16. Abstract
The goal of this project was to aid winter maintenance managers in better understanding the performance and impacts of alternative methods for deicing, which may be non-chloride based deicers, blends of deicing products, or methods that reduce the number of applications or application rates of deicers.

To achieve this, a literature review, survey, and follow-up interviews were used to develop case studies and recommendations on automatic vehicle location (AVL), blended liquid deicing products, direct liquid application (DLA), pre-wet, slurry, mechanical snow removal methods (ice breakers, squeegee plow blades, brooms, sweepers, segmented plow blades), methods to reduce chloride use, route optimization, salt alternatives, and using data to make informed decisions (severity indices (WSI, SSI, SWI), MDSS, and dashboards).

Recommendations for implementation and successful use of each case study topic are provided, followed by recommendations on how to do a lot with a little, or how to identify and implement easy and low-cost improvements. This is followed by a section on making larger investments to find improvements. These sections provide examples, identify pros and cons, and review the challenges of going from being good at something to great. Key steps for implementation are identified, and training resources are provided. Research needs and gaps are identified related to alternative methods for deicing.

17. Key Words Deicing, plowing, automatic vehicle location (AVL), blended liquids, direct liquid application (DLA), pre-wet, slurry, ice breakers, squeegee plow blades, brooms, sweepers, segmented plow blades, chloride reduction, route optimization, salt alternatives, severity indices (WSI, SSI, SWI), MDSS, dashboards	**18. Distribution Statement** No restrictions. This document is available to the public through the Clear Roads pooled fund program and the Minnesota Department of Transportation.

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Executive Summary

The goal of this project is to aid winter maintenance managers in better understanding the performance and impacts of alternative methods for deicing, which may be non-chloride based deicers, blends of deicing products, or methods that reduce the number of applications or application rates of deicers. To achieve this an extensive literature search was conducted that found many published reports, journal articles, and conference papers and presentation on these topics. Key documents identified in the literature search include recent best management practices guides and specific reports on related topics. The amount of literature available highlighted the fact the many of these alternative methods for deicing are well known, documented, and tested. But what was lacking were case examples that provide information on what worked and what did not, contacts at agencies who have tried these practices, technologies, products.

A survey was used to identify agencies and organizations that have or are using key practices, technologies, products and to capture more information from them. Survey responses were captured from 91 respondents from six different countries. The survey responses provided feedback on case studies that could be developed to further support winter maintenance operations. Information was then sought specifically for the following Case Studies from the literature, survey responses, and interviews were conducted;

- Automatic Vehicle Location (AVL)
- Blended liquid Deicing Products
- Direct Liquid Applications (DLA)
- Pre-wet and Slurry applications
- Mechanical Snow Removal Methods
    - Ice Breakers
    - Rubber, Squeegee Plow Blades
    - Multi-Segmented Plow Blades
    - Brooms, Sweepers
- Methods to Reduce Chloride Use
- Route Optimization
- Salt Alternatives for Deicing/Anti-icing
- Using Data to Make Informed Decisions
    - WSI/SSI
    - MDSS, Web MDSS
    - Dashboards

For each developed case study, the topic is defined, and information is provided on how it is commonly used, key components, and implementation considerations, as well as examples of implementation, opportunities for future expansion, and additional resources. For some topics, where available, specific in-depth case examples were developed.

Recommendations for implementation and successful use of each case study topic are provided, followed by recommendations on how to do a lot with a little, or how to identify and implement easy, low cost improvements. This is followed by a section on bringing out the big guns or make larger investments to find improvements. Both of these sections provide examples, identify pros and cons of each, review the challenge of going from being good at something to great, key steps for implementation, and training resources are provided.

Research needs and gaps were identified related to alternative methods for deicing, and specifically each case study topic. These range from benefit-cost analysis of specific technologies and equipment, to better understanding of use and functionality of others. These research ideas are intended to be used by Clear Roads to advance practical usable research.

Acknowledgements

The research team would like to thank the Clear Roads Technical Advisory Committee members – James Morin, Joe Bucci, Joe Thompson, John DeCastro, Patti Caswell, Jan Nicolas, Rick Nelson, Tom Peters, Øystein Larsen, and Kai Lysbakken for their active role in this project. A special thank you goes out to Greg Waidley of CTC & Associates. The research team would like to thank all of the survey respondents for their participation in this research effort and extend a special thank you to the individuals and organizations who participated in follow up interviews. Finally, the research team would like to thank Dana May, Carla Little, and Neil Hetherington from the Western Transportation Institute.

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Introduction

Since the 1960's, North America has observed a steady increase in the quantity of road salt purchased and applied to roads by state and local transportation agencies. At the last reporting, the quantity of salt used annually was in the tens of millions of tons and part of a billion-dollar industry. These applications of deicers all serve to provide the driving public and emergency services with safe and passable roads.

Over time, the driving public has increased its expectations of road conditions during winter months, leading to higher level of service expectations on the state and local transportation agencies. As a result, elevated chloride concentrations in ground and surface water have been measured around the country, particularly in the mid-west and east coast.

To address the issue of elevated chloride levels in surface and ground water and the associated environmental impacts it causes, many agencies have been proactively making changes over the last decade in the products they use for deicing or application methods. Transportation agencies continue to look at new and alternative deicing products, but greater benefit may be found in investigating alternative deicing methods to find improvements and efficiencies to reduce the amount of deicer applied. The goal of this project is to aid winter maintenance managers in better understanding the performance and impacts of alternative methods for deicing, which may be non-chloride based deicers, blends of deicing products, or methods that reduce the number of applications or application rates of deicers.

In this document the work completed for this research effort is described in the methodology section, followed by a summary of the survey, the developed case studies, guidance in the form of recommendations for practitioners responsible for winter maintenance, identified research needs, and conclusions. Following the main body of the report the Appendices include detailed information on the literature summary (A), the survey tool and detailed responses (B), winter maintenance equipment used in Norway (C), and additional recommendations for the successful implementation of AVL/GPS (D).

This document is intended to be used as a reference guide for winter maintenance operators and managers and includes resources and contact information provided to allow for direct follow up.

Methodology

This section describes the methods used to develop the literature review, survey, interviews, case studies, and recommendations for this research effort.

Literature Review

A literature review was conducted that focused on alternative methods for deicing, use of non-chloride deicers, blended products, and methods to reduce the number of applications and quantity of material applied. Leveraging past work by this research team and Clear Roads, the literature review focused on more recent efforts, published since 2016. Databases used to gather relevant information, included: Transportation Research Information Database, Google Scholar, ISI Web of Science, Montana State University Library, and similar sources. Research conducted in Canada, Europe, and from other available international sources was reviewed, along with the ongoing research and existing documents published by the departments of transportation (DOTs), Clear Roads, Pacific Northwest Snowfighters (PNS) Association, University Transportation Centers (UTCs), Strategic Highway Research Program (SHRP), Federal Highway Administration (FHWA), National Cooperative Highway Research Program (NCHRP), Airport Cooperative Research Program (ACRP), American Public Works Association (APWA), and American Association of State Highway Transportation Officials (AASHTO), and presented at the Winter Maintenance Peer Exchanges. The developed literature review summary can be found in Appendix A – Literature Review.

Survey

A survey was conducted to document common current practices that use technology, mechanical snow removal, material application methods, practices, and products; as well as newer methods that agencies are testing or interested in learning about. Paper surveys and quick response (QR) codes that linked to the online version of the survey were distributed at the American Public Works Association (APWA) North America Snow Conference on May 19-22, 2019 in Salt Lake City, Utah and at the Western Canada Snow Fighters APWA Conference in Edmonton, Alberta on June 4-6, 2019. In addition, surveys were distributed to Clear Roads State Representatives, Transportation Research Board (TRB) Committees associated with winter maintenance and operations, the APWA Winter Maintenance Committee, members of the World Road Association (PIARC) Winter Maintenance Committee, and members of the Snow and Ice Listserv. A summary of the survey results can be found in the Summary Survey Results section and the survey questionnaire used and detailed survey responses can be found in Appendix B – Survey.

Interviews

Follow-up interviews were conducted to capture additional information for the case studies. Interviews were conducted with the following individuals and organizations on the specified case study topics.

Interviewee, Organization	Case Study Topic
Marc Valenti, Town of Lexington, MA	Blending Liquids
Chase Fester, Minnesota DOT	Blending Liquids
Brandon Beise, North Dakota DOT	Blending Liquids

Allan Johnson, Wisconsin DOT	Blending Liquids
Ryan Ferrin, Utah DOT	Pre-wetting
Rhett Arnell, Utah DOT	Pre-wetting
Stephen McCracken, The Conservation Foundation	Methods to Reduce Chloride Use
John Kawka, former Dupage County, IL DOT	Methods to Reduce Chloride Use
Philip Anderle, former Indiana DOT and Colorado DOT	Mechanical Snow Removal
Ryan Ferrin, Utah DOT	Mechanical Snow Removal
Dennis Bishop, Alaska DOT	Mechanical Snow Removal
Dan Schacher, Alaska DOT	Mechanical Snow Removal
Dan Varilek, South Dakota DOT	Mechanical Snow Removal
Chase Fester, Minnesota DOT	Mechanical Snow Removal
Øystein Larsen, Norwegian Public Roads Administration	Mechanical Snow Removal
Allan Johnson, Wisconsin DOT	Direct Liquid Application
Dave Hundley and Matt Chenowyth, Michigan DOT	Salt Alternatives
Kerry NeSmith, Alabama DOT	Salt Alternatives

Case Studies

Using information captured from the literature search, survey results, and follow up interviews, case studies on the following topics related to alternative methods for deicing were developed and are presented in Case Studies:

- Automatic Vehicle Location (AVL)
- Blended Liquid Deicing Products
- Deicer Application Timing and Rates
- Direct Liquid Application (DLA) Routes
- Pre-wet and Slurry Technology
- Mechanical Snow Removal
    - Rubber, Squeegee blades
    - Multi-segment plow blades
    - Brooms, Sweepers
- Methods to Reduce Chloride Use
- Route and Fleet Optimization
- Salt Alternatives
- Using Data and Reporting to Make Informed Decisions
    - WSI/SSI
    - MDSS, Web MDSS
    - Dashboards

Recommendations

Recommendations were developed for each case study topic, implementation strategies, and training based on information gathered in the literature review, survey responses, interviews, and in the case study development. Recommendations and research needs can be found in body of this report.

Summary Survey Results

Below is summary of survey results. The survey questionnaire and detailed survey responses and analysis can be found in Appendix B – Survey.

The research team conducted an online survey of winter operations practitioners and stakeholders in May and June of 2019. The survey was designed to collect information about common snow and ice operations, including methods, products, and equipment. Overall, 91 survey responses were collected from six countries, 28 US states, and two Canadian provinces. The following is a summary of the survey responses.

Deicing, pre-wetting, and anti-icing were the most common application methods used. About half of the survey respondents indicated they used DLA.

A variety of responses were provided for the equipment used to apply sand and solid material. Responses ranged from specific application methods and manufacturer names to generalized responses (e.g., sander).

For pre-wetting, the most commonly reported equipment used was a saddle tank, ranging in capacity from 100 to 400 gallons.

Several types of equipment were used to apply liquids, including tanker trucks, standard plows with tanks, and tow plows. Some respondents indicated that they use in-house built equipment. Liquid tank capacity ranged from 1000 to 6000 gallons.

Front plows and wing plows were used by a large number of respondents to mechanically remove snow. Other reported mechanical snow removal methods that were less common included underbelly plows, tow plows, and rotary plows.

AVL/GPS was the most common technology used by respondents on their equipment, followed by ground speed controllers and mobile mounted sensors. Pavement temperature followed by air temperature were the mostly commonly used mobile sensors. Road Weather Information System (RWIS) was the most commonly listed “other” technology used in snow and ice control operations.

Snow and ice control products reported in the survey responses included:

- Solid salt was most commonly reported with application rates ranging from 100 to 800 lbs/l-m, or an average application rate of 280 lbs/lane mile (l-m).
- Blends of salt/sand were the next most commonly reported product used. Blends ranged from 10:90 to 33:67, but most common was a 50:50 blend of salt:sand. Application rates ranged from 100 to 1000 lbs/l-m, or an average application rate of 350 lbs/l-m.
  A subgroup of respondents specifically mentioned that their deicer and or salt/sand application rates vary depending on factors like ground speed, road width, storm conditions, and temperature.

- Pre-wet products typically involved solid salt wet with salt brine and applied at a range of 100 to 500 lbs/l-m, or an average application rate of 275 lbs/l-m. The volume of liquid added ranged from 4 to 30 gals/ton, or an average of 12 gals/ton of liquid added to solid material for pre-wetting.
- Salt brine was the most commonly reported anti-icer used with application rates ranging from 15 to 200 gals/l-m, followed by magnesium chloride brine used at application rates of 15 to 200 gals/l-m. The average liquid application rate was about 40 gals/l-m. Many respondents indicated that they use blends with agriculturally derived products and/or corrosion inhibitors.

More than half of survey respondents indicated that they have changed or modified their application rates of solids, liquids, and/or pre-wet in the last five years. Respondents who discussed decreasing application rates mentioned using anti-icing and pre-wetting to achieve this. To a lesser extent, respondents mentioned using storm data, variable application rates, and improving equipment calibration in order to reduce material usage. One DOT mentioned an increase in application rates in the last five years due to changes in the level of service (LOS) policy to wet roads and a change in product type from pre-wet to salt.

Just under half of survey respondents indicated that they have changed products used for winter maintenance operations in the last five years, with many switching to using more liquids, blending of liquids, and or changes in pre-wet materials.

In those cases in which states provided more than one response to the survey, responses were highly variable. This may indicate that decisions are made at the local level (garage/shed) based on local conditions.

The survey also sought information on methods, equipment, technology, practices, or products that respondents and their agencies were testing or interested in learning about. A summary of responses is provided below.

- Technology: Respondents showed interest in developing a better understanding of material application rates, AVL/GPS, route optimization, MDSS, and stationary and mobile sensors.
- Mechanical Snow Removal: Respondents showed interest in snow plow technologies, including belly brooms on plows, finger plows, and underbelly plows. Various snow plow blades were also mentioned, including segmented blades, composite blades, and plow blades that could reduce the removal of raised pavement markers.
  Survey respondents indicated that they are testing the following new equipment: snow plows with loader-mounted rotary plows, trucks with augers, new bits to reduce material and labor costs, and improved pre-wet systems, specifically the SnowLion DW30R and the Raiko Icebreaker T-15.
- Material Application Methods: Respondents showed interest in anti-icing equipment, slurry generators, and v-box spreaders.
  One respondent indicated interest in testing pre-treatment [anti-icing] for sidewalks, bike lanes, and roadways.

- Products: Respondents showed interest in salt alternatives or methods to reduce the use of chloride-based deicing products, including calcium magnesium acetate (CMA), organics, Ice Slicer (*Note that this is complex chloride-based product), brines (*Note that brine usually refers to a chloride based liquid anti-icing product), and pre-wet methods.
- Practices: Respondents showed interest in direct liquid application (DLA), pre-wetting, application timing and rates, and equipment calibration.

Case Studies

Automatic Vehicle Location (AVL)

Automatic vehicle location (AVL) uses global positioning systems (GPS) or signpost beacons to track the real-time location of a vehicle. GPS uses earth orbiting satellites to determine the location of a receiver. Signpost beacons use short-range radio, beam emission, or optical scanners to track the location of a vehicle when it passes the beacon. AVL data can be wirelessly transmitted to a central location or control center for fleet management. AVL data is widely used in many maintenance programs.

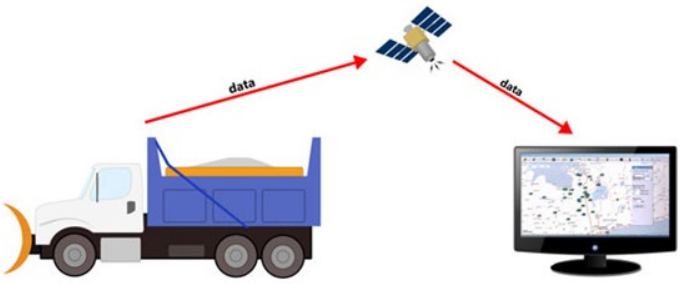


Figure 1. Source: https://www.cdot.gov/

As shown in Figure 1, AVL can be used alone to provide location information for all agency vehicles. This could allow an agency to track snow plow progress along a route using geographic information systems (GIS) mapping software as well as optimize snow plow routes or divert nearest snow plows to an event or incident. AVL can also be used in coordination with other mobile mounted sensors in order to track snow plow progress as well as track material usage, report plow up/plow down, determine efficient material application rates, etc. Geographic data from an AVL can provide information to the public on which routes have been maintained.

Current Usage
Common
Key Components
• GPS Receiver or Signpost Beacons • Wireless Data Transmitter • Computer • Staff Training
Implementation Considerations
• An agency should consider how they will use AVL data, which will determine which type of AVL would be most useful and which types of additional technologies may be necessary. • While some snow plow drivers have expressed concerns surrounding the use of AVL and feeling watched or monitored, these initial concerns often diminish quickly once they see how an agency and the driver themselves can benefit from the captured information. An agency should consider addressing these concerns upfront with drivers during training for the new equipment. • AVL can be integrated into a winter maintenance program for a variety of uses including improved real-time data for monitoring and both internal and external communications. • AVL can be useful for ensuring effective use of agency resources. • AVL and GPS have aided DOTs in tort liability cases. • AVL and GPS require a high level of data processing, management, and storage. Considering bringing IT and database management staff into the project at the beginning.

Examples of Implementation

Idaho Transportation Department

The Idaho Transportation Department (ITD) stated that they have been using storm data from their AVL system to find the greatest efficiency in application rates. The application rates were then modified to find the most efficient rate that still provides the same level of service. This averaging of 25 to 50 % higher rates than 5 years ago is due to changes in LOS guidelines and products used.

Contact: Ryan Crabtree, ryan.crabtree@itd.idaho.gov

Pennsylvania Department of Transportation

During the 2014-2015 winter season, PennDOT pilot tested AVL systems on 119 snow plows. PennDOT now has over 2,200 AVL equipped snow plows. Data from AVL equipped snow plows is used to track snow plow route coverage, review material usage, and to optimize dispatch of snow plows to areas that need additional service. Additionally, PennDOT uses the AVL data in coordination with real-time weather information to determine material

application rates. The public is able to view the location of PennDOT's snow plows on their Where's My Plow website and on the State's 511 website.

Ontario Ministry of Transportation

During the winter season of 2015-2016, the Ontario Ministry of Transportation completely outsourced their winter maintenance program to five vendors. As a part of the vendor contract, the Ontario Ministry of Transportation requires all contractors to have AVL installed on all of their equipment and must report AVL data at 10-second intervals. This data is used to provide performance reports to the Ministry, which are periodically audited, and locational data is provided to their 511 website which includes a track-my-plow map. The Ontario Ministry of Transportation found that understanding how the AVL data will be used and providing clear deliverables helped to create buy-in from contractors and managers and worked to improve performance metric evaluation.

Norway Public Road Administration (NPRA)

All winter maintenance operations are contracted out in Norway. To ensure that all contractors have AVL/GPS on their equipment, Norway requires it in the contracting phase and has an additional requirement on specific data reporting and the data format from the contractor. The data captured by the AVL/GPS units is used to assess the contractor's performance. To support this effort the NPRA has someone on staff who reviews the data to ensure compliance by the contractors.

Opportunities for Future Expansion

AVL equipped snow plows could be used in coordination with other mobile mounted sensors in order to obtain data on real-time road and weather conditions. Locational information from AVL equipped snow plows could be integrated with a state's 511 or traveler information systems to alert the public on the location of snow plows and which routes have been serviced, as well as integrated with privately developed applications such as CAV, WAZE, or iCone, for example.

AVL could be used in coordination with cameras to capture photos of road conditions during snow plow service and transmit them in real-time to a state 511 website or other traveler information systems. Minnesota Department of Transportation (MnDOT) installed AVL equipped cameras in 226 snow plows during the 2015-2016 winter season. When the cameras were tested MnDOT acknowledged there was room for improvement in respect to driver concerns, ease of use, and camera limitations in capturing falling snow, However, overall, the cameras provided benefits to both staff and the traveling public.

Additional Resources

- Utilization of AVL/GPS Technology: Case Studies
  - http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.16-01_Final.pdf
- Clear Roads Technology: Automatic Vehicle Location Website
  - https://clearroads.org/avl/
- State of the Practice of Automated Vehicle Location for Winter Maintenance Operations
  - https://www.researchgate.net/publication/228947437_State_of_the_Practice_of_Automatic_Vehicle_Location_for_Winter_Maintenance_Operations
- Evaluation of the GPS/AVL Systems for Snow and Ice Operations Resource Management
  - https://rosap.ntl.bts.gov/view/dot/32513
- Installing Snow plow Cameras and Integrating Images into MnDOT's Traveler Information System
  - http://dot.state.mn.us/research/reports/2017/201741.pdf

Data Management or Governance Resources

- Data Governance
  - https://www.fhwa.dot.gov/datagov/
- Creating Data Management Plans (DMPs)
  - https://ntl.bts.gov/public-access/creating-data-management-plans
- GIS in Transportation, Data Governance & Data Management, Case Studies of Select Transportation Agencies.
  - https://www.gis.fhwa.dot.gov/reports/GIS_Data_Governance_and_Data_Management_Case_Studies.pdf

Blended Liquid Deicing Products

Liquid deicers consist of solid granular deicers dissolved into a solution. Liquid deicers, or brines, are often applied before or at the beginning of a storm (Figure 2). This practice is known as anti-icing (also see the case study on Direct Liquid Application Routes). Liquid deicers are primarily used to prevent snow and ice from bonding to the pavement, but they can also be used as deicers to burn through packed snow and ice. Use of liquid deicers can reduce the amount of deicing materials used, aid in quicker recovery of the road surface, and reduce person and equipment hours. Data has shown that the use of liquids can reduce solid materials usage by up to 50%. Agencies can purchase liquid deicers, make their own brines, and/or created their own blended product on site. Sodium chloride brines are the most commonly used liquid deicer, followed by use of magnesium chloride and calcium chloride-based products. Blends of these chloride-based brines are often used to:

Figure 2. Anti-Icing Vehicle Source: C. Fester MnDOT

- enhance performance, allowing the products to work at colder temperatures
- reduce corrosion rates
- enhance melting capacity, longevity on the road surface.

Chloride based brines are often blended by deicing vendors using proprietary protected products. When blended in house, what is added and the blending ratios used can be controlled, but then quality control and testing must be conducted to ensure the blended product will perform.

Commonly blended materials include a sodium or magnesium chloride base brine with:

- agricultural byproducts – beet juice, by- or co-products of organic processing, etc.
- corrosion inhibitors
- cold temperature enhancement – $MgCl_2$, $CaCl_2$, potassium acetate, sodium formate, glycol/glycerin, etc.

Current Usage
Very Common
Key Components
• Liquid Material Storage Tanks • Blending Systems • Tanker Trucks, Slide-in Sprayer Units, Trailer Sprayer Units • Staff Training
Implementation Considerations
• Liquid deicers can be tailored to storm conditions. • Surface temperature is important when choosing a liquid deicing product. • Blending allows for products to work at colder temperatures, reduce corrosion rates, and enhance product performance. • Use of liquid materials has been linked to material use reductions and cost savings.

Common blending rates (by percent (%)) and products include:

- 80/20 – salt brine/agricultural by-product
- 90 to 75/10 to 25 - salt brine/beet juice product
- 90/10 – salt brine/magnesium chloride
- 90 to 80/10 to 20 – salt brine/calcium chloride and corrosion inhibitor.

Please note that these rates provide general guidance and each blend will perform slightly differently. Users are encouraged to play with blending rates and products, as this is equal parts art and science.

Examples of Implementation

Case Study Town of Lexington, Massachusetts

The town of Lexington, MA began its liquids program with anti-icing in 2011-2012 using salt brine. They quickly realized through training and conference attendance that they could benefit from using blended liquids instead of straight salt brine. Their initial blend was a 70% salt brine and 30% of commercially available product composed of 10% molasses and 28% magnesium chloride (70/30). The addition of the new product to the salt brine gave the staff more confidence in the liquid performance with the thought that it would reduce potential to cause icing events. They quickly began playing with blending ratios and landed on a range of 80/20 to 75/25 depending on temperatures and conditions. To simplify things for the staff they used the same liquid blend for anti-icing, Direct Liquid Application Routes, or Pre-Wet and Slurry Technology.

After a few years of experience with this blend, they selected a 100% organic based additive to blend with the salt brine they made in-house. Due to the temperate/moderate temperatures they experience, they felt that they did not need the magnesium chloride, which helps the blend to function at colder temperatures. They blended salt brine with the 100% organic additive initially at the 80/20 blend ratio recommended by the manufacturer, but quickly realized they preferred the performance of the blended liquid at a ratio range of 85/15 to 90/10. While these lighter blends slightly reduced the potential corrosion protection, they were sufficient to provide the residual effects of the product on the pavement. In the last few years, they switched to another 100% organic product due to tighter control on quality, local distribution, and good performance.

Overall, the town of Lexington, MA has seen their liquids program grow from 20,000 gallon to 260,000 gallons used over a five-year period. They make their own salt brine and blend their own liquids. Initially, the start of the liquids and blending program was overwhelming for staff. They attribute this in part to pushing too hard initially and not providing sufficient knowledge and training. They basically had to rebuild the program after the first year due to a lack of confidence from the staff. Now, to support new staff and share information to avoid past issues, they use a 1-day, 8-hour, liquids training course developed by the Massachusetts LTAP and based on the APWA liquids series 101-401 that reaches hundreds of local and state winter maintenance operators each year. They feel that in the training it is key for staff to hear about success and failures from folks they know and trust.

Contact: Marc Valenti, mvalenti@lexingtonma.gov

Case Study: Minnesota Department of Transportation, District 7

MnDOT District 7 has had luck using a blend of salt brine, calcium chloride brine, and organic additives. They found that using the calcium chloride brine provides a residual effect of product remaining on the pavement surface that dries fairly quickly, preventing blowing snow and ice from sticking to the road. [Note that both commercially available calcium chloride brines that they indicated they use have corrosion inhibitors added by the manufacturer.] Another reason they chose the calcium chloride brine is that they store large quantities of salt brine outside in tanks and have found that adding about 10% calcium chloride to the salt brine prevents freezing (Figure 3). They will make the blend with a higher concentration of calcium chloride brine if temperatures fall below 10°F. The blended product has performed well at colder temperatures and the use of the liquid has initiated quicker melting. MnDOT also treats salt piles with 4 gallons of calcium chloride per ton to keep them workable in winter.

Figure 3. Liquid deicer storage tanks (3000 gal, 6500 gal, and 10,000 gal capacity) used by MnDOT, District 7. Source: C. Fester, MnDOT.

A cost analysis of the use of the blended liquids shows they are paying $1.30 more per mile to use half the salt they would typically apply, compared to a traditional salt brine or rock salt application. So, while it may cost more, they are using significantly less product overall.

Lessons learned include, when the temperature is forecasted to or drops to 0°F or below, the liquid must be bled out of the outside storage pumps. Even with the addition of the 10% calcium chloride brine to salt brine, they still found their pumps were freezing up. They also cautioned against blending some liquid products as they found calcium chloride brine and magnesium chloride brine when blended can gel up and cause major issues with their applicator.

Contact: Chase Fester, chase.fester@state.mn.us

Case Study: North Dakota Department of Transportation

North Dakota DOT (NDDOT) is using a salt brine blended with a locally sourced sugar beet additive. They make the salt brine and blend in the sugar beet additive as the brine is made or add to storage tanks. Blending ratios are typically 80% salt brine to 20% sugar beet additive (80/20), but as temperatures get warmer, they have used just salt brine, or as temperatures gets colder, they have used up to a 50% salt brine blended with 50% sugar beet additive (50/50).

NDDOT uses the blend to help lower the freezing point of salt brine. Since blending, they do not see salt brine freezing in the storage tanks anymore, and feel they see a residual effect of the product on the pavement.

Reduced cost and regional availability of organic additives were the initial motivation for blending the salt brine with the sugar beet additive. They purchase the sugar beet additive from a processor that is able to source the material in the state, which makes pickup and delivery easier and therefore less expensive. There are many options for sugar beets additives in North Dakota making this organic product less expensive than commercially available products. The blended brine delivered is costing $1.45 a gallon, or $1.33 a gallon if pickup at the plant.

Contact: Brandon Beise, bbeise@nd.gov

Opportunities for Future Expansion

Agencies can make their own brine which has cost savings benefits while allowing an agency to control the blend, the additives (including sourcing local materials), and amounts needed. Making your own brine will require purchasing of brine-making equipment. According to a Clear Roads Study, brine-making equipment ranged from $1,940 to $21,500 in 2010.

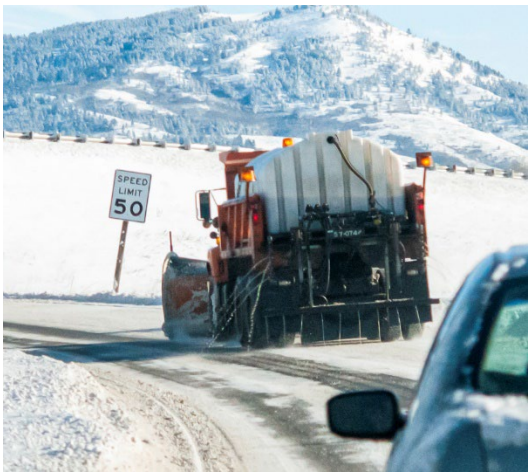
Using locally sourced agricultural by- or co-products can reduce costs compared to purchasing proprietary products that enhance performance of salt brines.

Additional Resources

- Understanding the Effectiveness of Non-Chloride Liquid Agricultural By-Products and Solid Complex Chloride/Mineral Products Used in Snow and Ice Control Operations
  - https://clearroads.org/project/13-02/
- Evaluation and Analysis of Liquid Deicers for Winter Maintenance
  - https://rosap.ntl.bts.gov/view/dot/32841
- Salt Brine Blending to Optimize Deicing and Anti-Icing Performance and Cost Effectiveness
  - http://www.dot.state.mn.us/research/documents/201220.pdf
- Developing Locally Sourced Brine Additive for Anti-Icing
  - https://westerntransportationinstitute.org/wp-content/uploads/2018/03/4W3881_AUTC51006FinalReport04252014.pdf

Deicer Application Timing and Rates

Snow and ice control material application rates and timing can be tailored by an agency in order to effectively treat the roadway while reducing material use. For example, treatment of a roadway during the beginning of a storm event (prior to precipitation) or anti-icing can later facilitate mechanical removal of snow and ice by preventing bonding of snow and ice to the roadway. Or the use of variable application rates, adjusted based on conditions and forecasts, can aid in reducing materials use while still achieving safety and mobility. Application timing and variable application rates are data dependent. Weather forecasting and pavement condition data provided by strategically placed sensors can be used to support the appropriate timing and application rates for an agency.



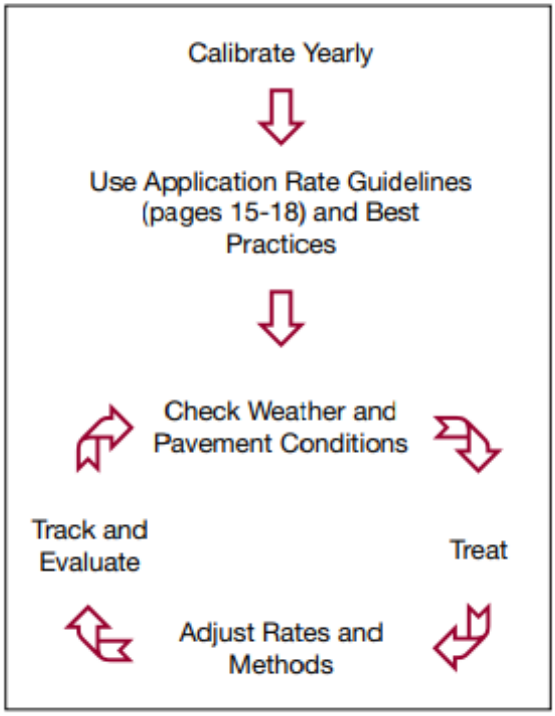
Examples of Implementation

Minnesota Department of Transportation

The Minnesota Department of Transportation has published the Minnesota Snow and Ice Control Field Handbook for Snow plow Operators. This handbook provides guidelines on treatments to use before, during, and after a storm, as well as charts for application rates depending on pavement temperature and weather conditions for both deicers and pre-wet materials. Minnesota has found these application rates to be effective in treating roadways while working to reduce chloride use. It is noted in general that application rates will be highest during the first pass and that rates will decrease with follow-up treatment.

Current Usage
Common
Key Components
• Vehicles with the Capability to Apply Differing Application Rates • Real-Time Storm and Roadway Conditions Data • Materials Management System • Training for Staff
Implementation Considerations
• Compared to using a single application rate for all conditions, variable application rates can drastically reduce materials use. • An agency can start out slow and grow their variable application rates as recommended by the data.

Fine-tuning your program



The length of time that a material application will last depends on five factors including:

- pavement temperature,
- application rates,

Figure 4. Fine tuning your program (From Minnesota Snow and Ice Control Field Handbook for Snow plow Operators)

- precipitation,
- beginning concentration,
- and chemical used.

While the guidebook provides application rate tables for anti-icing and deicing, it is noted that these application rate tables should be used as a starting point to create application rates that can be modified slowly to fit local needs through the use of data and experience (Figure 4). Methods like the use of anti-icing, pre-wetting, equipment calibration, using data and reporting to make informed decisions for chemical use and application, and route optimization are discussed in a short and precise manner as methods to further reduce material use.

Utah Department of Transportation

Utah DOT provides guidance to plow drivers in the truck on application rates and materials to use based on pavement temperature, precipitation type, and amount (Table 1). This table provides guidance for drivers but should be tailored to each location based on site specific conditions and available products.

This guidance provided in Table 1 is tied to the specific winter maintenance products they have on hand to use, as shown in Table 2.

Pavement Temperature Range

Storm Type	**Above 32°F and constant**	**Above 32°F and dropping**	**20°- 32°F**	**5°- 20°F**	**Below 5°F**
Light Snow	Apply nothing – just monitor	100-150 lbs/lane mile	100-150 lbs/lane mile	150-250 lbs/lane mile	Apply no salt
Light to Moderate Snow	Apply nothing – just monitor	100-200 lbs/lane mile	200-250 lbs/lane mile	250-350 lbs/lane mile	Apply no salt
Moderate to Heavy Snow	Apply nothing – just monitor	100-150 lbs/lane mile	200-250 lbs/lane mile	250-500 lbs/lane mile	Apply no salt
Freezing Rain	Apply nothing – just monitor	75-100 lbs/lane mile	150-300 lbs/lane mile	250-500 lbs/lane mile	Apply no salt

Table 1. Summary table provided to Utah DOT plow drivers to use as guidance for application rates during winter maintenance operations.

Table 2. Summary table provided to UDOT staff with application rates, materials, methods, temperatures, and conditions.

<table>
<tr><th colspan="2">Precipitation Type</th><th colspan="2">Rain</th><th colspan="2">Light Snow</th><th colspan="2">Heavy Snow</th><th colspan="2">Frost/Black Ice</th></tr>
<tr><th colspan="2">Application Method</th><th>Anti-icing</th><th>Deicing</th><th>Anti-icing</th><th>Deicing/Pre-wet</th><th>Anti-icing</th><th>Deicing/Pre-wet</th><th>Anti-icing</th><th>Deicing/Pre-wet</th></tr>
<tr><td rowspan="20">Temperature (°F)</td><td>32 & Rising</td><td colspan="8">None</td></tr>
<tr><td>32 & Falling</td><td colspan="2">Salt@100</td><td rowspan="5">Brine@100</td><td rowspan="5">Salt+Brine@100</td><td>Brine@100</td><td>Salt+Brine@100</td><td rowspan="3">Brine@50</td><td rowspan="3">Salt+Brine@50</td></tr>
<tr><td>31</td><td colspan="2" rowspan="15"></td><td rowspan="4">Brine@200</td><td rowspan="4">Salt+Brine@200</td></tr>
<tr><td>30</td></tr>
<tr><td>29</td></tr>
<tr><td>28</td></tr>
<tr><td>27</td><td rowspan="2">Brine@100</td><td rowspan="2">Salt+Brine@100</td></tr>
<tr><td>26</td></tr>
<tr><td>25</td><td rowspan="5">Mag@100</td><td rowspan="5">Salt+Mag@100</td><td rowspan="8">Mag@200</td><td rowspan="8">Salt+Mag@250</td><td rowspan="5">Mag@100</td><td rowspan="5">Salt+Mag@100</td></tr>
<tr><td>24</td></tr>
<tr><td>23</td></tr>
<tr><td>22</td></tr>
<tr><td>21</td></tr>
<tr><td>20</td><td rowspan="5">Mag@200</td><td rowspan="5">Salt+Mag@200</td></tr>
<tr><td>19</td><td rowspan="5">Salt@170</td><td rowspan="5">Salt+Mag@170</td></tr>
<tr><td>18</td></tr>
<tr><td>17</td></tr>
<tr><td>16</td></tr>
<tr><td>15 & Rising</td></tr>
<tr><td>15 & Falling</td><td colspan="6">Plow Only</td><td colspan="2">Apply Abrasives</td></tr>
</table>

[*Note that Brine = liquid NaCl, Salt = granular salt, Mag = magnesium chloride, application rates are provided in pounds per lane mile (lbs/l-m).]

Contact: Rhett Arnell, rarnell@utah.gov

Opportunities for Future Expansion

Through the use of sensor technology, an agency will be able to adjust material application rates in real-time on the road depending on weather and roadway conditions. This technology will allow an agency to calibrate and reduce their material use.

Additional Resources

- Clear Roads: Establishing Effective Salt and Anti-Icing Application Rates
  - http://clearroads.org/wp-content/uploads/dlm_uploads/Summary-Report-of-Task-2-Findings.pdf
- Minnesota Snow and Ice Control Field Handbook for Snow plow Operators
  - http://www.mnltap.umn.edu/publications/handbooks/documents/snowice.pdf

Direct Liquid Application Routes

Direct Liquid Application (DLA) is the practice of applying liquid-only deicers directly to the road surface. DLA is commonly used prior to a storm event for anti-icing, preventing snow and ice from bonding to the roadway, though it can be used both during and after a storm as well. Liquids provide a benefit of reducing material use, as liquids tend to stay on the roadway better than solid materials which can bounce and scatter from the roadway. In addition, liquids can aid in the mechanical cleanup during and post storm, reducing cleanup time and wear on vehicles. DLA Plow Routes use only liquid treatments for anti-icing and deicing if the conditions are appropriate.

In general, the decision to use DLA comes down to three factors:

1) pavement temperature,

2) storm intensity, and

3) moisture content.

DLA tends to be more effective when temperatures are greater than 25°F and when snow fall is at a rate around one inch per hour.

Current Usage
Less Common
Key Components
• Liquid Material Storage Tanks • Tanker Trucks, Slide-in Sprayer Units, Trailer Sprayer Units • Weather Forecast Data
Implementation Considerations
• DLA allows an agency to be proactive in their snow and ice control measures, particularly when used for anti-icing. • DLA tends to work better in storms with dry moisture content; with wetter conditions DLA has the tendency to be diluted. • Surface temperature is important when choosing a liquid deicing product. While sodium chloride liquid deicers are common, sodium chloride is effective to 15 degrees Fahrenheit. Liquid calcium chloride and magnesium chloride have been found to work better at lower temperatures. • Use of DLA has been associated to material use reductions, reductions in cleanup time, and cost savings.

Examples of Implementation

Ohio Department of Transportation

The Ohio Department of Transportation has successfully implemented DLA in the northeast portion of the state. Salt brine was the most common liquid used, though ODOT also uses calcium chloride, AquaSalina, and Beet Heet as additives. ODOT has implemented DLA during and after storms. ODOT has found that DLA is effective for storms where pavement temperature is around 20°F to 25°F and where snow fall is less than 0.5 inches per hour. They found that reapplication of DLA every two hours can prevent the formation of black ice on roadway. ODOT found that DLA improved level of service while reducing post-storm cleanup time and resulted in average cost savings of 30% from use of liquids instead of solids.

Utah Department of Transportation

Utah Department of Transportation (UDOT) began using liquid-only applications as a method to improve pretreating roadways around 2000. UDOT treats the roads with liquids 24 hours before a storm for anti-icing with the goal of being back on the roadway after 30 minutes to check on conditions and treat again as necessary. UDOT has found that DLA sticks to the roadway better and that they are able to monitor treatment effectiveness more efficiently compared to

traditional road salt which can take up to 45 minutes to become effective. On a mountain pass on I-80 UDOT uses DLA both before and during a winter storm in conjunction with plowing. A recent level-of-service study found that this stretch of road outperformed other routes in Utah that were still relying on solid salts. In addition, maintenance crews found added benefits of reduced labor and reductions in material use.

Case Study: Wisconsin Department of Transportation

Wisconsin DOT partnered with six counties to pilot test direct liquid application routes or "mostly liquid applications" during the 2017-2018 winter season. Moving forward they are still using DLA, more so than in the past two winters. They feel they have seen definite success in using DLA. In fact, one county has proven they use 52% less salt under similar conditions when using DLA. They do caution that there are times when liquid only is not appropriate to use and that there is a learning curve for everyone at all levels in the organization from the plow driver to management.

For Wisconsin, DLA routes are faster to clear when the right amount of brine is used, which also happens to be much less salt used overall. They have found that the brine does not last as long on the road. For example, salt brine usually lasts for 2+hours, whereas are rock salt can last around 6 hours. For this reason, route cycle times needed to be adjusted. For this same reason, they note that it is easier to "lose control" of the road conditions if you are not paying attention.

They also found that the amount of brine that needs to be applied on DLA routes exceeds what was capable on older brine distribution on the older trucks. This included the need to apply at higher pressure as pounds per square inch (psi). Because of the higher psi required they needed to upgrade the flow meters because the older flow meters could not handle the required volume or pressure. For some trucks improvements to the electrical system were required to meet the needs of the pumps as well.

The final component that was key to the success of DLA in Wisconsin was ensuring the plow drivers understood when and how to apply brine to match the weather conditions. They feel that good management and oversight helped with the learning curve for the drivers. Their final piece of advice is to know the weather and pavement conditions, which are more critical to be on top of when using DLA. Overall, the savings observed validates the continued use of the DLA in Wisconsin.

Contact: Allan Johnson, allan.johnson@dot.wi.gov

Opportunities for Future Expansion

Using weather forecast data, an agency can tailor the liquid deicer for conditions.

Additional Resources

- Clear Roads: Identifying the Parameters for Effective Implementation of Liquid-Only Plow Routes
  - http://clearroads.org/wp-content/uploads/dlm_uploads/09-02_WisDOT-0092-10-18-Final-Report.pdf
- Clear Roads: Training Video for the Implementation of Liquid-Only Plow Routes
  - http://clearroads.org/wp-content/uploads/dlm_uploads/FinalReport_CR16-06_FINAL.pdf
- Clear Roads: During-Storm Direct Liquid Applications (DLA) A New Tool for Winter Maintenance Toolbox
  - http://clearroads.org/wp-content/uploads/dlm_uploads/09-02_WisDOT-0092-10-18-Quick-Reference-Guide.pdf

Pre-Wet and Slurry Technology

Pre-wetting and slurry are the practice of adding liquid to solid deicers or liquids to abrasive products either at a stockpile or more commonly on the truck, for example at the spreader. Slurry is slightly different from traditional pre-wetting in that a slurry has a higher ratio of liquid added to the solid material, resulting in an oatmeal or slush consistency. The use of pre-wet or slurry can help to:

- minimize the bounce and scatter of material on the roadway, keeping material on road and minimizing loss to the environment.
- accelerate the melting properties of the solid materials therefore improving performance.
- reduce the overall amount of product used by transportation agencies.

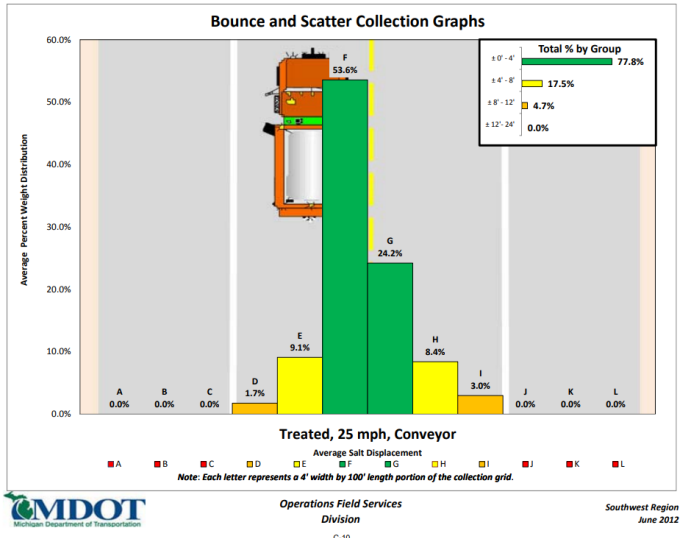


Figure 5. Michigan DOT study of the benefits of prewetting showing reduction of bounce and scatter when prewetting, driving at 25 mph, and using a conveyor to apply the material. (Michigan DOT, 2012)

Any deicing chemical can be used for pre-wetting or slurry, and through the use of this technology an agency can reduce costs through lower material use and reduction in loss of material off the road. Commonly used materials for pre-wetting or slurry:

- Liquids – salt (sodium chloride) brine, magnesium chloride brine, calcium chloride brine, liquid agricultural additives, corrosion inhibitors.
- Solids – rock salt (sodium chloride or a complex chloride), sand, solid magnesium chloride, and calcium chloride.

Commonly used mixing rates:

- Pre-wetting: 4 to 30 gals of liquid added per ton of solid material, with an average of 12 gal/ton
- Slurry: 50 to 90 gals of liquid added per ton of solid material.

Commonly used application rate ranges for pre-wetting or slurry which vary based on conditions:

- 25 to 200 lbs/l-m
- 50 to 250 lbs/l-m
- 100 to 500 lbs/l-m, with an average application rate of 275 lbs/l-m

Current Usage

Common

Key Components

- Onboard or stationary sprayer systems
- Tailgate or side-mounted liquid delivery systems and spreader (zero-velocity spreader, v-box spreader, etc.)
- Onboard sensors (*optional*)
- Staff Training

Implementation Considerations

- Pre-wetting at a maintenance shop requires less upfront equipment, pre-wetting on-board the vehicle allows staff to treat as needed.
- Field research has found that pre-wet materials are as effective as solid materials but required 20% less material.
- Slurry has been observed to melt snow and ice on the roadway quicker and last longer on the roadway compared to typical pre-wet.
- Organic materials like beet juice, and other liquid additives has been used successfully in pre-wet mixtures.
- Anecdotally, the use of slurry technology was found to work quicker, last longer on the road, and outperform traditional pre-wet methods.

Commonly used equipment for pre-wetting:

- Spreaders mounted on plows (combination spreaders or v-box spreaders) with saddle tanks,
- Sanders,
- Brine tanks on trucks and or saddle tanks ranging from 100 to 400 gallon capacity.

If an agency does not have pre-wetting equipment for their vehicles there are alternative options:

- Pre-wetting solid salts at the stockpile,
- Pre-wetting the entire truckload of salt using a sprayer system.

The downside to these alternatives is that the pre-wet liquid could leach out over time and the solid salts may not be treated evenly.

Application of a pre-wet slurry requires specialized equipment manufactured by a few companies globally.

Examples of Implementation

Maine Department of Transportation

During the winter season of 2009, MaineDOT installed a rock/salt crusher on one of their slurry trucks for a cost of $1,000. The goal was to crush the solid deicer materials into smaller particle size and combine with a high ratio of liquid (50 gallons per ton). This slurry system was tested over 10 storm events. MaineDOT found that larger particle sizes worked best during colder storm events (less than 20°F) and smaller particle sizes worked best during warmer storm events. Additional testing was planned to determine the best particle size for given storm condition.

Minnesota Department of Transportation

Minnesota DOT has developed a pre-wet spreader system that uses on-vehicle friction sensors to adjust the zero-velocity spreader to deploy materials when slippery spots are detected. This system was found to be reliable with snow plow speeds up to 25 miles per hour.

Ontario Ministry of Transportation

The Ontario Ministry of Transportation has successfully used pre-wetting to reduce material application rates and reduce costs. During the winter season of 2015-2016, the Ontario Ministry of Transportation field tested the performance of dry vs. pre-wet sand for roadway friction improvements. Results found that pre-wet sand was as effective as dry sand but required 20% less material. Ontario already includes pre-wet salt in their winter maintenance toolkit, finding that salt treated with brine is as effective as dry salt but required 30% less material.

City of Cowansville, Quebec

The City of Cowansville, Quebec sprays beet juice on their road salt prior to treating the roads. Pre-treating road salt with beet juice helps the road salt stick to the road better, reducing the amount of material scatter and reducing overall salt usage. Cowansville estimates that pre-treating road salt has resulted in a 30% reduction in salt use while maintaining the same level of service. Beet juice was found to be particularly effective at temperatures less than 25°F (-4°C).

Utah Department of Transportation

Highlighted in the section on Deicer Application Timing and Rates, UDOT provided a detailed table to their plow drivers. on the various pre-wet materials they use, application conditions, and application rates.

Opportunities for Future Expansion

The use of pre-wet or slurry materials can be used in coordination with on-vehicle sensors (such as the example provided by Minnesota DOT above) or other technology like AVL to automatically detect areas applicable or sensitive areas not applicable for pre-wet on-the-fly.

Additional Resources

- Clear Roads: Use of Prewetted Solid Materials for Roadway Anti-Icing
  - http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.17-S2_Jan19.pdf
- Field Investigation of the Effectiveness of Prewetting Strategy for Snow and Ice Control of Transportation Facilities
  - https://ascelibrary.org/doi/10.1061/%28ASCE%29CR.1943-5495.0000101
- Developing Friction Data to Support the Optimal Use of Pre-Wet Deicing Salt for Enhanced Winter Mobility
  - https://cammse.uncc.edu/sites/cammse.uncc.edu/files/media/CAMMSE-UNCC-2018-UTC-Project-Report-16-Shi-Final.pdf
- Field Evaluation and Performance Analysis of Different Pre-Wetting Ratios for Sustainable Salting
  - https://uwspace.uwaterloo.ca/handle/10012/13856
- Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America
  - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.604.6777&rep=rep1&type=pdf
- Winter Operations and Salt, Sand, and Chemical Management
  - https://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/8_0.aspx
- Evaluation of the Monroe Slurry Maker
  - https://rosap.ntl.bts.gov/view/dot/28479

Mechanical Snow Removal

Mechanical snow removal is the plowing or scraping of snow or ice from the roadway. Advances in plow blade technologies are allowing agencies to optimize their mechanical snow removal methods through the use of plow blades that are effective for different conditions or roadway compositions, resulting in cost effective snow and ice removal while reducing damage to the roadway, roadway markings, and other obstacles. Squeegee blades, multi-segmented blades, and brooms are recent innovations in mechanical snow removal. These mechanical methods will be discussed on the following section.

Current Usage
Common
Key Components
• Staff Training
Implementation Considerations
• An understanding of road and weather conditions can help an agency determine the best snow plow blade to effectively mechanically remove snow and ice. • Using a snow plow blade that fits your needs can reduce costs, not only through reduced manhours but also through reducing damage to roadway markings and other obstacles.

Icebreaking

Icebreakers, or penetrating drums, use metal spikes or blades to break the packed snow or ice bonded with the pavement into relatively small pieces (see Figure 7) that can then be plowed off the roadway. Three manufacturers of this technology were identified, with a potential fourth in China. Fairbanks International Airport (FAI) built their own icebreaker specified for use on airport runways, called the Yeti, and won an award for innovative design (Figure 6).

Figure 6. The Yeti icebreaker custom built for use at Fairbank International Airport. Source: http://dot.alaska.gov/comm/pressbox/arch_2015/PR15-2554.shtml# (https://www.youtube.com/watch?v=XJiWOByFMiI)

Their use has identified key lessons learned including:

- Be aware of the down-pressure used to avoid damage to the pavement on very thick icepack.
- Turning should be kept to a minimum when the icebreaker is being used.
- Ideal driving speed is 15-17 mph.
- Use caution when crossing railroads and bridge expansion joints.

Figure 7. Raiko T model IceBreaker. Source: http://team-eagle.ca/equipment/raiko/

Examples of Implementation

Utah Department of Transportation

UDOT pilot testing of the SnowLion DW30R (http://snowlion.us/) (Figure 8) and Raiko Icebreaker T-15 (http://www.raikomachines.com/). They ultimately choose the Raiko.

The Raiko T-15 unit cost around $30,000. They have only used it one time (June of 2019) on the winter closure road Guardsman Pass to open the road up for spring. There were 1-3 inches of icepack on the roadway after the snow had been cleared and the Raiko cut through the icepack pretty well. UDOT likes the Raiko and believes that it saved on salt usage but worries about the damage that it does to the roadways if too much down-pressure is applied. UDOT has only one unit in their fleet and no plans to buy anymore at this time. They feel the Raiko is a valuable tool, but that it should not to be used everywhere – for example, only on very thick icepack while being extremely cognizant of the down-pressure.

Figure 8. The Snow Lion Icebreaker. Source: http://snowlion.us/

Figure 9. The Arctic Shark Icebreaker. Source: http://www.ultramech.com

Case Study: Minnesota Department of Transportation

MnDOT currently has around 15 Raiko units located throughout the state costing roughly $37,000 each. Overall, MnDOT has been very satisfied with the Raiko Ice breaker. MnDOT notes that it is not a magic bullet but that it definitely does aid in helping with compaction on roadways. MnDOT uses the ice breakers whenever they have compaction of a ½ inch or greater, and they prioritize use based on need and conditions. MnDOT has found that the ice breakers can be used on concrete or asphalt bituminous roadways without causing damage to the surface.

MnDOT feels that the use of the ice breaker has allowed districts to reduce their salt usage after an event by helping to cut the compaction. MnDOT would also run motor graders on roads to help aid in cutting compaction as well. By having the ice breaker attached to a plow truck with an underbody blade they are able to cut the majority of the compaction down to a much easier thickness to manage. MnDOT has had the ice breakers in use across the state for a couple of years now and everyone seems to be onboard with their usage. While the ice breakers do not get used every storm, they are out and running during heavier snowfall events that cause compaction.

Contact: Chase Fester, chase.fester@state.mn.us

Case Study: Alaska Department of Transportation

Alaska DOT (AK DOT) has observed more freezing rain and needed to look for new ways to manage the resulting packed snow and ice on the pavement. This led to testing of the Raiko, Arctic Shark (Figure 9), and Snow Lion ice breakers (Figure 8). They currently have two Raikos and one Arctic Shark for a loader and another for a Bobcat. They chose to send back the Snow Lion due to issues with getting parts. In order to make the Raikos functional for AK DOT, they modified the Raiko hardware to enable it to mount on the front of their plow trucks. This was done inhouse in the machine shop in a matter of hours.

Initial highway testing in 2016 of the ice breaking found the ability of the Raiko attachment was mixed, but favorable. In the same time frame, the Fairbanks International Airport designed and built their own wheel loader-mounted prototype penetration drum attachment (Figure 6). It is based on a gang of standard carbide tipped planer drums mounted on an articulating frame.

Adding a trailing plow behind the penetration drum is a common enhancement. Raiko offers an integrated, small trailing plow option on their wheel loader version. A serrated ice cutting blade can be attached to the moldboard of this device. The Raiko equipped plow truck in Alaska utilizes an underbody plow attachment. A trailing plow blade can be useful in clearing away pulverized ice tailings and by utilizing specialized ice cutting blades, can enhance the ice scraping.

The cost of the Raiko was $44,000, while the cost of Artic Shark was $40,000 for a loader mounted, and $21,000 for a skid steer mounted. Alaska DOT uses the skid steer mount for sidewalks and path with fair results.

For best performance a Raiko was mounted on plow truck driving at 15 – 17 mph to cut through built up ice. The ice breakers cannot turn, and must be lifted around turns, but do work on super elevation. Alaska uses the ice breakers on ¾ inch or thicker packed snow or ice. At thinner layers there is concern about wear on the pavement. They have also found that the thicker ice fractures better and down to the road surface.

Ice breakers overall work well in the right application. Alaska DOT observed three unique benefits from using ice breakers:

1. Fracture bonded ice and packed snow down the road surface,
2. Create a path for chemical deicers to reach the road surface and break the bond between snow and ice and pavement,
3. And in extreme icing events, create profile or a higher friction driving surface on the ice.

When using ice breakers, the geometry of the metal spikes is key and needs to be maintained through sharpening and eventual replacement of the metal spikes and drum. Alaska made a die set for quicker sharpening of the metal spikes.

Contact: Dan Schacher, daniel.schacher@alaska.gov

Rubber or Squeegee Blades

Squeegees – Squeegee blades are often made of rubber or plastic (Figure 10). This type of blade is useful for removing slush or light snow from a roadway. Squeegee blades offer the benefit of not damaging roadway markings and can be effective on brick or cobblestone. Squeegee blades can also be used in combination with a front cutting-edge snow plow blade to remove excess liquids or snow left behind.

Figure 10. Squeegee Blade Source: http://www.snowengineeringdivision.com/atv-rubber-snow plow-blade-1x6-inch/

There are many rubber plow blades available on the market. From a survey conducted for this project, rubber blades were most often used in combination with a steel blade.

Examples of Implementation

Iowa Department of Transportation and Illinois Department of Transportation

Agencies in the neighboring states of Iowa and Illinois have been using multi-edge snow plow blades with a 3-blade configuration which includes a main plow blade, a scarifying blade to break up hard packed snow, and a squeegee blade to clear slush (Figure 11). Snow plow operators can raise or lower each blade depending on the conditions to best remove snow and ice on the roadway. Field tests of the multi-edge snow plow blades have shown that they are able to clear more snow and ice in a single pass than a traditional snow plow blade. In a field test, the multi-edge snow plow blade was used to remove sand from a roadway. Iowa DOT found that the multi-edge plow blade removed 20 to 25% more material than a traditional plow blade.

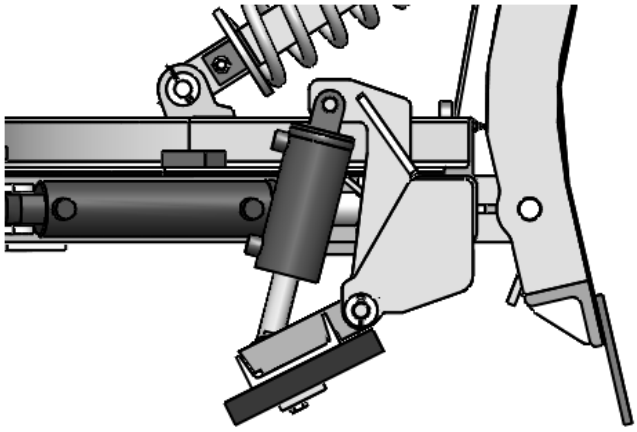


Figure 11. Multi-blade plow system. Source: https://henkemfg.com/multi-blade/

Case Study: South Dakota Department of Transportation

Based on the Clear Roads project Multiple Blade Plow Prototypes, South Dakota DOT (SDDOT) began use of a front mounted plow blade with a carbide tip and squeegee blade mounted behind in 2015 (Figure 12).

Figure 12. SDDOT squeegee blade set-up. Source: SDDOT, D. Varilek.

The cost of the squeegee kit was $1641 (does not include shipping costs). Installation of the first squeegee kit took about 40 hours and this included removing the snow plow jacks, installing the squeegee blade components, mounting and plumbing in the in-cab controls, running control lines to the front bumper, fabricating mountings for the disconnect couplers, and testing the system. The second kit was done in considerably less time. Installation cost was estimated at $800, and the cost of the rubber squeegee blades is about $260, for a total cost of $2700 per truck.

South Dakota DOT estimates that with the use of the squeegee blades, salt application rates were reduced from 150 lbs/l-m to 75 lbs/l-m, saving $150 with each pass on a route. With this salt saving, they estimate a squeegee blade is paid for in 18 passes.

The squeegee blade down pressure is controlled by an air pressure system. With newer plows and the improved air filters on pneumatic systems, they have not had issues with reaching or controlling psi at very cold temperatures. SDDOT noted that they need to be careful with how much down pressure they use. They target 10 – 15 psi on the squeegee blade, and will go as high as 20 psi, but never above this. Too much pressure will cause premature wearing of the rubber squeegee blades. [Note that on most routes, where the squeegee blades are used, they are asphalt with a high friction overlay which can cause more wear to the rubber squeegee blade than a typical asphalt and PCC concrete surface.]

South Dakota currently has six plows with squeegee blades in its fleet, three located in two separate regions. The Rapids City regions noted that routes that have squeegee blades mounted all season (Oct. 1 to May 1) last about one season. Overall, the drivers are really happy with how the rubber squeegee blades perform especially on cleanup duties. Whatever they don't get with the plow blade, the squeegee blade gets. This allows the pavement to dry quicker.

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Case Study: Norway Public Roads Administration

A special type of equipment has been developed that has diagonal slush slats (re: blades) on a trailer that can be towed by a snow plow (Figure 13). So far, only one unit of this equipment exists. The purpose of this equipment is also to remove as much slush and water as possible from the roadway before salt is applied. This device can apply dry salt and pre-wetted salt as well as brine.

Figure 13. Snowplow vehicles with tow behind trailers with slush blades used by the Norwegian Public Road Administration. Source: Tellefsdal/AEBI/SCHMIDT

The trailer has three consecutive slush blades with independently suspended slush elements that stay close to the roadway and remove slush from ruts in the roadway (Figure 14).

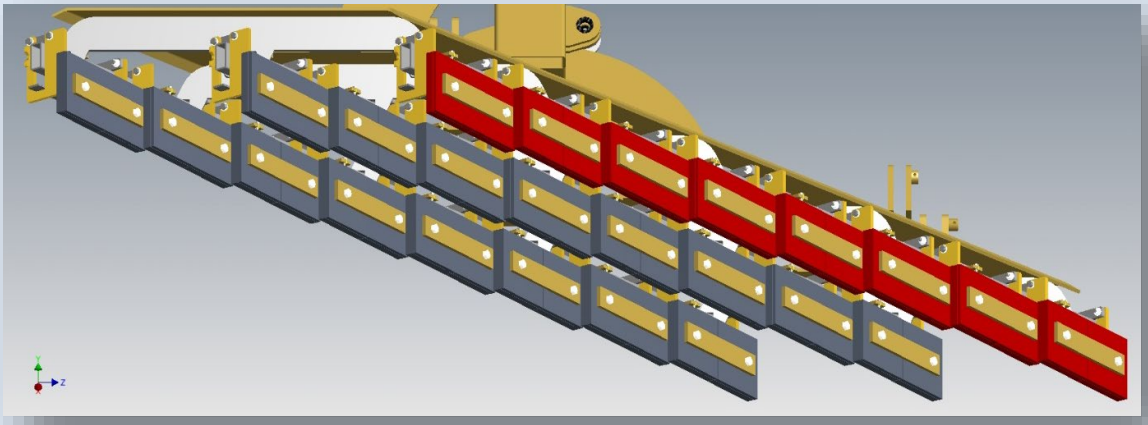

Figure 14. A drawing of the three horizonal and consecutive slush blades developed for testing in Norway. Source: Tellefsdal/AEBI/SCHMIDT

The experience with this equipment is that it provides good mechanical removal of snow, slush, and water from the roadway, and this makes the roadway dry faster and less salt can be used. The equipment has a clearing width of 2.55-3.0 metres (8.4-9.8 ft). Only one unit of this equipment has been made.

The equipment is relatively inexpensive to build, compared to a sweeper, and has low operating costs.

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Case Study: Norway Public Roads Administration

Contractors using Rubber Blades and Driving Speed Guidance

In Norway, the Norwegian Public Roads Administration (NPRA) uses performance-based contracts for winter maintenance, but these contracts also have some requirements for equipment. Snow plows with rubber blades are required on all salted roads. The plows should have six independent sections of rubber blades to enable slush removal from the road surface and the deep ruts in the pavements.

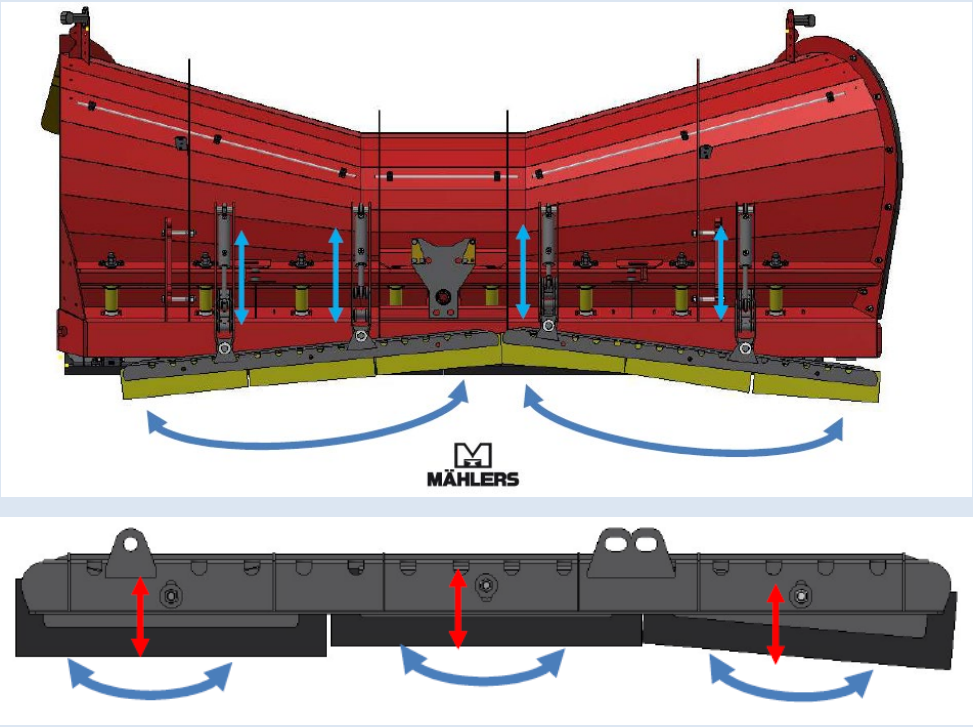

Figure 15. Segmented slush removal rubber blades. Images from http://mahlers.se/en/mahlers/products.html

The placement of extra rubber blades behind the hard plow blades has been shown to be very effective at removing light snow, slush, and water from the road surface. This makes it possible to use less salt during winter maintenance operations. In Norway, rubber blades are only used on salted roads and not on snow covered roads. If rubber blades are used on hardpack snow it may polish the snow surface and make it more slippery.

Figure 16. From left to right, NPRA slush blade, Arctic Machine slush blade, Schmidt segmented slush blade.

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Case Study: Norway Public Roads Administration

Contractors using Rubber Blades and Driving Speed Guidance (Continued)

Driving speed influences the end results when using rubber plow blades. A test with different plowing speed showed that more snow and slush is left behind when you drive faster than 40 km/h (25 miles/h).

Figure 18. Field test, plowing slush with rubber blades at 25 mph; left before, right after showing data collection. Photos provided by NPRA.

Figure 19. Field test, plowing slush with rubber blades at 40 mph; left before, right after showing data collection. Photos provided NPRA.

Figure 19 provides an example of plowing at 40 mph. It shows the connection between snow plow speed and remaining snow/slush in this test when compared to the after plowing at 25 mph which has clear pavement (Figure 18). Figure 17 further reinforces what can be seen in the photos in Figures 18 and 19, as the blue columns show the amount of snow/slush on the road surface before plowing, and the red columns show the amount of snow/slush on the road surface after plowing at 25, 40, and 50 mph (40, 60, 80 km/t, respectively). The rubber blades cleared the pavement best when plowing was done 25 mph. When plows drove at faster speeds less snow/slush was plowed off the road by the rubber plow blades.

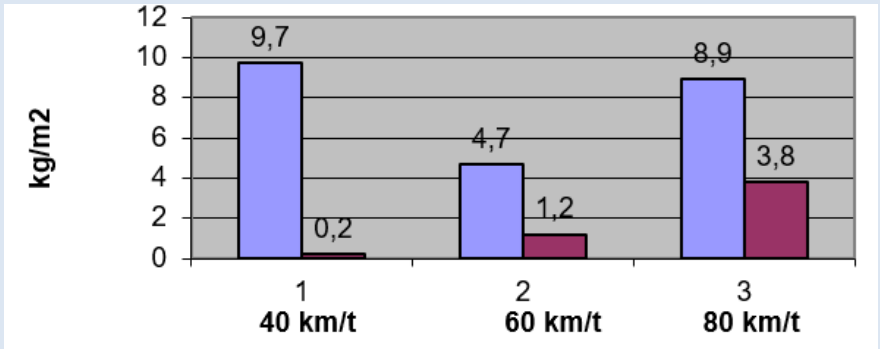

Figure 17. Measured slush on the road before plowing (blue column) and after plowing with rubber blades (red column) at 25, 40, 50 mph (40, 60, 80 km/t, respectively).

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Multi-Segment Plow Blades

Multi-Segmented Plow Blades (or articulated plow blades), provide the benefit of being able to conform to the roadway. This allows not only for better cleaning of the roadway but can reduce damage to roadway markings or other obstacles.

Figure 20. Multi-Segment Cutting Edge Source: https://www.kageinnovation.com/

Examples of Implementation

City of Edina, Minnesota

In 2019 Edina, Minnesota began testing JOMA segmented snow plow blades in four neighborhoods to improve winter maintenance operations and reduce the need for road salts. These blades were found to be effective at removing snow and ice from the roadway and provided the unexpected benefit of being quieter than traditional plow blades. If the blades continue to be effective, the city plans to replace more snow plow blades with the JOMA blades.

Iowa Department of Transportation

The Iowa Department of Transportation tested a flexible-edge blade produced by the Flink Company at their Bedford maintenance garage. This blade was designed with a flexible edge with one-foot sections and a squeegee blade. The blade was designed to adjust to the contours of the roadway surface for more efficient snow and ice removal. Operators found that the flexible edge blade reduced noise and had a more even wear pattern when compared to a traditional plow blade.

Case Study: Alaska Department of Transportation

Alaska Department of Transportation has tested the use of finger plows to remove snow and ice from roadways. Finger plows have several steel "fingers" that are tipped with a carbide cutting edge about 2 inches wide. Each "finger" can move independently from each other, allowing the plow to move over roadway obstructions and follow the contours of the roadway. Finger plows were found to be effective at reducing damage to roadway obstructions and removing snow from rutted pavement, but Alaska DOT found that snow often got stuck between the "fingers" resulting in not enough pressure to cut into ice.

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Brooms/Sweepers

Brooms were originally used for snow removal at airports but recently their use has expanded to remove snow from sidewalks and roadway. Their use has identified key lessons learned including that sweepers do not work as well as plow blades that scrape when storms come in as wet snow or rain, but brooms have shown good results on the roadway through reducing the amount of deicer material needed and reducing the amount of slush left on the roadway.

Figure 21. Broom Source: https://tracklessvehicles.com/

Examples of Implementation

City of River Falls, Wisconsin

The City of River Falls, WI uses two John Deere tractors and one Toro tractor equipped with a broom to clean public sidewalks and trails around municipal buildings. The City has found snow brooms to be effective under typical plowing operation conditions (1-6 inches of snow).

City of Cloquet, Minnesota

The City of Cloquet, MN used 5-foot-wide booms attached to tractors to remove snow on their sidewalk network. The City of Cloquet has 13 miles of priority sidewalks that they maintain during the winter. These include sidewalks around schools and others with high pedestrian traffic. The use of the brooms allowed the City to clear these priority sidewalks with small initial startup costs. The brooms are effective with snowfall up to 3 inches. If snowfall is greater than 4 inches, the City uses a tractor-mounted plow blade to remove the snow then follows up with the broom.

Montana State University Campus Maintenance, Bozeman, Montana

Montana State University (MSU) has four brooms it uses routinely in winter maintenance operations, most of which are 6 feet long and one 7ft broom. Brooms work well in Bozeman, MT because typical snow events are about 2 inches of low density (re: dry) snow, making the brooms an ideal tool for sweeping away the “cold smoke.” In the over 10 years of using brooms, they have found that brooms remove more material than plows, and noted that after sweeping, the pavement dries and goes to bare pavement faster. This allows for less effort - fewer repeat passes on each route, less or no use of deicing chemicals, and reduced risk for users. They feel strongly that the brooms give them an environmental advantage and reduce the number of potential freeze-thaw events, preserving pavement life. They use brooms for dry snow falls up to 6 inches, but for denser (re: wetter) snow only go up to 4 inches. Anything above this they will plow. Maintenance staff require minimal additional training to use the brooms but note that the brooms throw material off the pavement and that driver needs to be cognizant of this. Maintenance of the brooms is limited to typical equipment maintenance and replacement of the broom bristles, which last about 200 miles (or about 15 storms events, with two passes on each route, with each route about 7 miles long), which can be accomplished during the downtime between events. They caution that using a broom after plowing can create a polished snowy surface, decreasing friction and increasing risk.

Case Study: Norway Public Roads Administration
In Norway, sweepers are used only to a minor extent.

At airports there is a long tradition of using sweepers for the removal of snow on runways, but on roads there is only limited experience with this type of equipment.

The Norwegian Public Roads Administration (NPRA) lost its production department in 2003, and since then all maintenance work has been carried out by contractors. Winter maintenance is part of so-called performance-based contracts, where the NPRA defines the required standards for winter maintenance, whereas the contractors themselves decide what equipment to use and implement the necessary measures when this is required to meet the defined standards. This means that NPRA also does not own equipment for this type of work.

Sweepers on roads are currently used in two places in Norway; in Ålesund on the west coast, and in Gjøvik in the inland of Eastern Norway.

Experience from Ålesund
Ålesund is situated in an area that has a typical coastal climate with mild winters and at times heavy snowfalls. In this area, two sweepers have been in use.

This equipment was taken into use in order to reduce the use of salt on a road section past a lake that is used as a source of drinking water. The use of sweepers was included as a specific requirement when the contract was developed. The sweeper is a towed airport sweeper supplied by the Øveraasen company, supplier of equipment to airports. It has brushes as well as equipment for brine application. The sweeper is towed by a lorry (re: truck) with a snow plow in the front. This means snow is plowed off the road, the remaining snow/slush/water is removed by brush and brine is applied all in one operation. The plow has extra rubber blades to remove as much slush as possible before the brush.

The method has worked well, and NPRA's use of salt has been reduced by around 25-30% while the road surface conditions have improved. The reason for this is that the sweeper removes the slush and moisture from the roadway so effectively that less salt is required, and a bare and dry road is achieved faster. Driving speed is around 40-45 km/h (25-28 mph), which is also the normal speed for a regular snow plow.

Figure 22. Norwegian snow plow with tow behind sweeper. Source: Norwegian Public Roads Administration

Continued on next page....

Case Study: Norway Public Roads Administration (Continued)

Experience from Gjøvik

Gjøvik has an inland climate with cold winters and lots of snow.

In Gjøvik there are 2 sweepers supplied by the Øveraasen company (Figure 23). The use of sweepers was included as a specific requirement when the contract was developed. The sweeper is mounted on a trailer and has brushes as well as equipment for brine application. The length of the lorry (re: truck) with plow and trailer is 22 metres (72 ft). The plow has extra rubber blades for removing slush. The length of the brush is 3.5 metres (11.5 ft) and the diameter is 1.1 metres (3.6 ft). Plastic brushes are used. Driving speed is 0-40 km/h (0-25 mph), but in difficult weather conditions with a lot of snow the recommended maximum speed is 30 km/h (18.6 mph).

Experience with this equipment is favourable also in Gjøvik.

Figure 23. Another example of a tow behind sweeper used in Norway. Source: Norwegian Public Roads Administration

Shared experience

Since the NPRA does not buy the equipment, we do not have a full overview of the costs, but the estimated price of this type of sweeper is approximately $200,000 (US Dollars). Additional costs include the costs of increased fuel consumption, brush wear, and maintenance of the equipment. Savings include reduced salt consumption and less environmental pollution.

Advantages:

- The road is much cleaner after snow clearing
- Less salt is required
- Less slush on the road during snowfall leads to improved road safety
- The road dries faster
- A dry road surface reduces the wear on studded tires
- A dry road means less risk of ice at low temperatures
- Less need for gritting (re: sanding) when temperatures are too low for salt application
- Less spray on windscreens, signs, etc. along the road
- Road marking is kept visible to a greater extent
- Fewer complaints from road users

Continued on next page...

Case Study: Norway Public Roads Administration (Continued)

Disadvantages:

- More expensive to buy and use
- Requires more training of snow-clearing personnel
- Can only apply brine, not dry or pre-wetted salt. This can be a disadvantage at low temperatures
- Hard to get close enough to railings and obstacles on the right side
- Advanced and demanding equipment
- May cause a lot of drifting snow behind the device with dry snow
- Long vehicle combination with limited manoeuvrability

As the equipment is expensive to purchase and use, the NPRA needs to specify that the equipment is required for contractors to use under the contracts. If not, they will not invest money in this equipment.

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Case Study: Norway Public Roads Administration

On some pedestrian and cycle paths in cities with a lot of cycling, salt is used to keep the paths bare.

Here it is a great advantage to use brushes to achieve bare paths without using too much salt. Plastic brushes are used here, in addition to ordinary plow or snow blades.

Figure 24. The use of smaller scale sweepers to manage snow on pedestrian and cycle paths in Norway. Source: Norwegian Public Roads Administration

There are also sweepers designed for pedestrian and cycle paths, which can sweep and apply salt in one operation. This equipment is well suited for wide pedestrian and cycle paths, but less suitable for paths of varying widths and with many sharp curves. The equipment works best when the road has an even surface and there is ample room to sweep the snow to the side. If there is a lot of snow, the carrier machine should have a plow in front to remove most of the snow before sweeping. When snowfall is heavy and roadside snowbanks from snow removal are high, the brushes have trouble getting the snow off the roadway.

Figure 25. A tow behind sweeper attached to a tractor, used to clear snow for pedestrian traffic on sidewalks. Source: Norwegian Public Roads Administration

The equipment in Figure 25 has a diameter of 0.8 metres (2.5 ft).

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Case Study: Norway Public Roads Administration (Continued)

A disadvantage of this equipment is that it is heavy and can put a great amount of strain on roads with poor load-bearing capacity. The brushes can also put a great amount of strain on asphalt surfaces of poor standards and may cause asphalt pieces to come loose and create potholes. The asphalt surfaces are particularly vulnerable in the spring when load-bearing capacity is poor due to spring thaw, i.e. the melting of frozen water within the road structure weakens the road.

The effect of the brushes depends on the speed of clearing, the amount of snow, and the wetness of the snow (Figure 26). The picture below shows the testing of snow removal with brushes on dry snow at different clearing speeds.

Figure 26. Field research investigating the travel speed and the use of front mounted sweepers for winter maintenance operations in Norway. Source: Norwegian Public Roads Administration

Figure 27. Graphic of snow removal efficiency of brushes by percent at 5, 10, and 20 km/ton of snow (3.1, 6.2, 12.4 m/ton).

In Norway there is a project going on that involves the testing of different methods for winter maintenance of pedestrian and cycle paths to achieve better conditions for pedestrians and cyclists all year round. This project will continue until 2021 and will hopefully give us some more experience with this type of equipment.

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Opportunities for Future Expansion

As agencies continue to test and modify their snow plow blades for optimal snow and ice removal, the lessons learned will continue to encourage further innovation beyond the traditional snow plow blade. Using combination plow blades in coordination with onboard roadway sensors could allow for automatic deployment of the best blade for the current conditions.

Additional Resources – Mechanical Methods

- Clear Roads: Plow Blades Website
  - https://clearroads.org/equipment-plow-blades/
  - https://clearroads.org/multiple-blade-plow-prototypes/
- The Fundamentals of Plowing, Anti-Icing, De-Icing and Sanding
  - https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119185161.ch6
- Investigate Plow Blade Optimization
  - https://trid.trb.org/view/1373418
- Snow Plow Cutting Edges for Improved Plowing Performance, Reduced Blade Wear, and Reduced Surface Impacts
  - http://www.dot.state.mn.us/research/TRS/2010/TRS1101.pdf
- Using Mechanical Ice Breakers to Improve Snow and Ice Removal Operations
  - https://sicop.transportation.org/wp-content/uploads/sites/36/2017/07/CA-Ice-Breaker-Report.pdf

Segmented Plow Blades

- Joma Snow plow Blade Life Span: A Survey of State Practice
  - https://lrrb.org/media/reports/TRS1403.pdf

*Additional information on mechanical snow removal technologies available in Norway is provided in Appendix C – Supplemental Information, Snow Equipment used in Norway.

Methods to Reduce Chloride Use

Some agencies have strived to reduce chloride use due to an increasing awareness of environmental impacts, costs, or the need to regulate salt use. Reductions in chloride use can be accomplished through the use of alternative materials or methods that reduce the application rate and or number of applications, many of which are discussed throughout these case studies. Any tool or method that allows an agency to only apply what is needed to maintain safety and mobility falls into this category, often referred to as a Best Management Practice (BMP). Often use of BMP leads to a reduction in chloride use, as well as cost savings from reduced material use and loss, reduced use of wear and tear on vehicles, and person hours.

One way to check if you are working toward reducing your chloride use based on the use of BMPs is to consider the three R's:

- Is the product applied in Right place?
- Is the product applied at the Right time?
- Is the product applied in the Right amount?

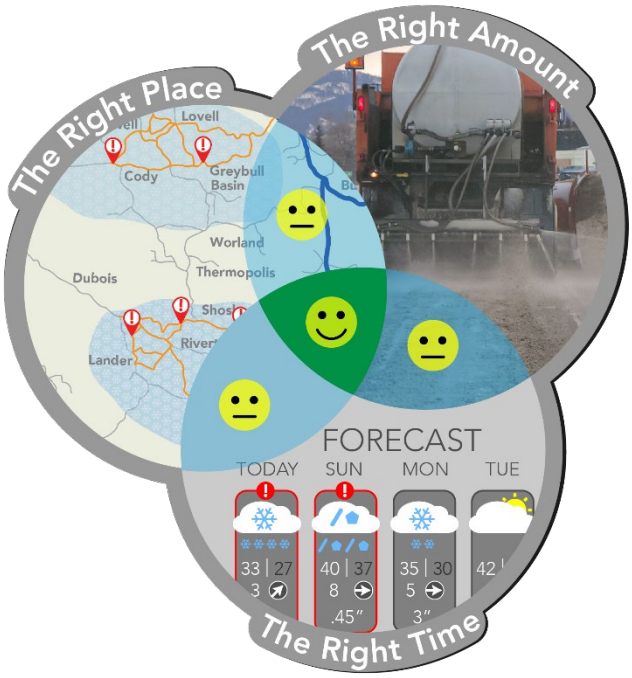

Figure 28. The 3 R's of Chloride Reduction

Examples of Implementation

New York State Department of Transportation

In 2018, New York State Department of Transportation established two pilot programs at Mirror Lake and Lake George to reduce road salt use while maintaining level of service in order to protect local aquatic ecosystems. These pilot projects utilized best management practices including using brine for anti-icing (also see the case study on Direct Liquid Application Routes), segmented plow blades (also see the case study on Mechanical Snow Removal), AVL to track salt use (also see the case study on Automatic Vehicle Location (AVL), and data to monitor salt use to application rates (also see the case study on Using Data and Reporting to Make Informed Decisions).

Michigan Department of Transportation

Due to increasing levels of service during the winter season, Michigan Department of Transportation (MDOT) has increasingly been applying road salt, but a recent study of Due to increasing levels of service during the

Current Usage
Common
Key Components
• Staff Training
Implementation Considerations
• There is no "one size fits all" solution to reducing salt use. An agency must consider their needs, goals, and current conditions to determine which combination of materials or methods are most appropriate. • Chloride salts are the most widely used deicers in the US but there is an increasing awareness of their negative impacts on the environment – including impacts to water, soil, vegetation, aquatic biota, and wildlife. • All deicing products will have some impact on the near road environment. Make sure you are aware of these for each product used. • Keeping data on salt reduction efforts can allow an agency to track effectiveness and costs, data collection can ensure the long-term success of salt reduction efforts. • Agencies have had success with making small steps towards salt reduction and using data to inform next steps.

winter season, Michigan Department of Transportation (MDOT) has increasingly been applying road salt, but a recent study of 371 lakes in Michigan found that 44% were at risk of long-term salinization. With an increasing awareness of the environmental impacts of road salt, MDOT has implemented a number of salt management initiatives including using spreaders, driving slowly to reduce bounce and scatter of materials, and pre-wetting salt with brine (also see the case study on Pre-Wet and Slurry Technology). In addition, a maintenance decision support system (MDSS) is used to determine optimal material application rates depending on pavement and weather conditions (also see the case study on Using Data and Reporting to Make Informed Decisions).

Minnesota Department of Transportation

The Minnesota Department of Transportation (MnDOT) works to reduce salt use while providing safe roads for motorists. Through these efforts, MnDOT has created the Salt Sustainability Programs which includes the creation of best practices and training materials which are available on their website. Trainings cover equipment, calibration, decision making including maintenance decision support systems and material selection, and material handling and storage.

Case Study: Dupage County, Illinois Transportation Department and The Conservation Foundation

What started as a concern by two separate industries turned into a mutually beneficial partnership. In 2004 the state of Illinois adopted a chloride total maximum daily load (TMDL) that threatened to have impacts on the local wastewater treatment industry. The DuPage River Salt Creek Workgroup (DRSCW) was working with the wastewater treatment industry on identifying ways to meet all water quality goals. As part of this effort they identified elevated chloride levels in area surface waters due to winter maintenance deicing as one area for improvement. As a part of this effort they approached the Dupage County Division of Transport. Working with the Division's Manager a series of technical workshops were launched. This began the working relationship between the two organizations.

After a few conversations they realized quickly they could work toward the same goal – they would rather work to modify practices internally, than have the state or federal government step in and regulate what they were doing.

They realized quickly that developing training workshops to share information could reach a broad audience. They initially developed two trainings, one addressed parking lots and the other public roads. They invited members of the local communities, public works staff, winter maintenance staff, mayors, school boards, hospitals, colleges, park districts, and private contractors. In these trainings they were able to talk about regulations, current chloride levels, how operations impacted them, and how they could influence chloride levels through changes in practices. The first workshops were coordinated using wastewater funding, but since then attendance fees and equipment and product vendor sponsorships have covered the workshop costs. These workshops have steadily grown and are now at capacity of over 100 attendees at each and a third workshop is under consideration.

Specific changes that were implemented in Dupage County resulting from this partnership included:

- Using liquids (anti-icing and pre-wetting)
    - The initial greatest improvement in chloride reduction they saw was from the use of salt pre-wet with an agriculturally based additive at the stockpile.
- Equipment calibration
- Obtaining and utilizing ground temperature data to make informed decisions
- Monitoring vehicle speed to avoid loss of material during application.

Like many local transportation operations, they were operating on an extremely limited budget, so changes had to be very practical and involve equipment they had. From 2007 to 2017 Dupage County saw a 40% reduction in chloride use as a result of these practices. They stressed that these efforts were done in small steps, with little changes each storm, each season. This allowed for acceptance by staff and the ability to build trust in the changes that were being implemented.

As the new practices were implemented, data was collected to track effectiveness and savings. However, in hindsight they wished they had collected more data. They stressed that data collection does not need to be fancy, for example they have drivers report salt use over the radio, or write salt loaded from the shop on a clipboard. While automated systems are great, they may not be feasible for everyone (also see the case study on Using Data and Reporting to Make Informed Decisions). They recommend creating a working environment where data recording is part of the job.

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Case Study: Dupage County, Illinois Transportation Department and The Conservation Foundation (Continued)

The state of Illinois storm water permit (MS4) was reissued in 2017 and made several references to chlorides. This was in large part based on the work of the DRSCW.

Contact: Stephen McCracken, Director of Watershed Protection: smccracken@theconservationfoundation.org

Contact: John Kawka, Retired Manager of Highway Operations: johnkawka2468@gmail.com

Figure 29. Image of side-by-side comparison of road condition following treatment with liquids (left) versus normal practice without liquids (right) in Dupage County, Il. Conditions were air temperature of -15°F with blowing and drifting snow. Source: Dupage County DOT

Opportunities for Future Expansion

Advances in winter maintenance technologies and materials, as well as advances in conditions monitoring, will allow an agency to effectively reduce road salt usage while maintaining level of service.

Additional Resources

- Clear Roads – Manual of Best Practices
  - http://clearroads.org/wp-content/uploads/dlm_uploads/0537_2015-Clear-Roads-Best-Practice-Guide-WEB.pdf
- Best Practices Guidelines for Sustainable Salt Use
  - https://www.sima.org/docs/default-source/best-practices-documents/bp_sustainablesalt__digital.pdf?sfvrsn=4
- Minnesota Department of Transportation – Salt Sustainability Website
  - http://www.dot.state.mn.us/maintenance/salt_sustainability.html
- Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge
  - https://link.springer.com/article/10.1007/s11270-011-1064-6
- Iowa's Winter Maintenance Technologies Research
  - https://www.iowadot.gov/research/pdf/Research%20News%20August%202009.pdf
- Potential Solutions for Reducing Road Salt Use in New Hampshire
  - http://www.rebuildingi93.com/documents/environmental/Potential-Solutions-for-Reducing-Road-Salt-Use.pdf

Route Optimization/Fleet Optimization

Route optimization aims to create snow plow routes that maximize efficiency and therefore minimize costs (both monetary and time) while maintaining snow and ice removal operations. Route optimization allows an agency to use their fleet in the most effective manner by reducing route times, route overlaps, and costs. Route optimization tools are software packages that generate routes based on mathematical algorithms to minimize route time or costs or to maximize a truck load of material for application to meet an agency's winter maintenance level of service goals. This software takes into consideration fleet size, garage locations, vehicle capacity, and other constraints in order to create optimal routes that make sense in a real-world context. Route optimization can be data intensive but has been reported to reduce route lengths by an average of 5 to 10%. Fleet optimization is very similar to route optimization (in fact some literature uses the terms interchangeably) and ensures that the right vehicles are in the optimal place at the optimal time.

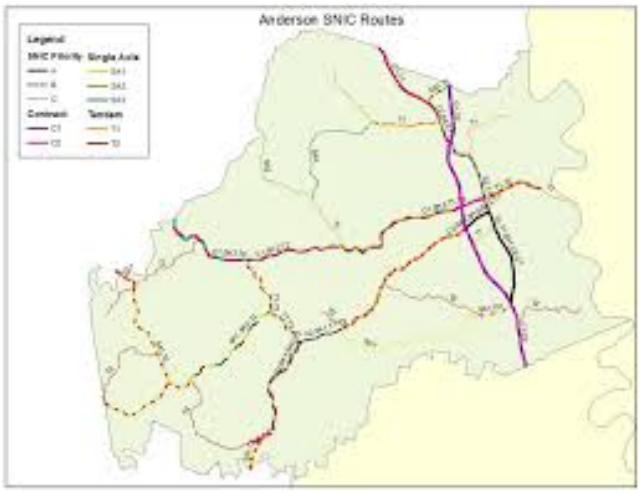

Figure 30. Snow plow Route Map Source: Blandford et al. (2018)

Examples of Implementation

Kentucky Transportation Cabinet

The Kentucky Transportation Cabinet (KYTC) developed optimized snow plow routes using ArcMap's Network Analysis and Vehicle Routing software for four counties. Snow plows were routed based on route priority, vehicle type, fuel stations, salt availability, and number of vehicles. KTYC initiated this analysis with the goal of optimizing snow and ice removal to improve safety and reduce time needed to treat roadways. Using these optimized routes, KYTC found they were able to treat their roadways using fewer snow plows, eliminating a total of nine vehicles and generating cost savings of up to $225,000 annually.

Current Usage
Common
Key Components
• Routing Software • Automatic Vehicle Location (AVL) • Staff Training
Implementation Considerations
• Automatic vehicle location (AVL) systems are a great companion to route optimization and fleet optimization. AVL allows an agency to monitor vehicle locations and can facilitate route diversions when necessary. • Optimization software is not perfect, an agency should review and test routes prior to the winter season in order to determine if and where modifications are needed.

Ohio Department of Transportation

In 2018 the Ohio Department of Transportation conducted a study to use route optimization software to determine optimal fleet size and snow plow routes. Using ESRI's ArcGIS vehicle routing problem software, optimal routes were determined to meet the state's level of service requirements. ODOT Districts 1, 2, and 10 were used to test the model. Results found that by allowing maintenance boundaries to extend beyond a single county, routes could be optimized to decrease treatment time and decrease the total number of vehicles by 29 trucks while maintaining the same level of service.

Opportunities for Future Expansion

AVL can be used in coordination with route optimization software in order to effectively re-route vehicles in real-time as needed.

Additional Resources

- Clear Roads Identifying Best Practices for Snow plow Route Optimization
  - https://clearroads.org/project/14-07/
- Role of Route Optimization in Benefiting Winter Maintenance Operations
  - https://journals.sagepub.com/doi/abs/10.1177/0361198118796354?journalCode=trra
- Snow and Ice Removal Route Optimization in Kentucky
  - https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=2582&context=ktc_researchreports
- Snow Plow Route Optimization in Delaware
  - https://cpb-us-w2.wpmucdn.com/sites.udel.edu/dist/1/1139/files/2018/05/Rpt.-269-Snow-Plow-Route-Optimization-Li-187ajks.pdf
- Federal Highway Administration Every Day Counts Weather-Savvy Roads
  - https://ops.fhwa.dot.gov/publications/fhwahop18075/index.htm

Salt Alternatives

Road salt has been the traditionally used deicer for improving snow and ice removal from roadways but there has been an increasing awareness of the negative impacts that chlorides can have on the environment. Some agencies strive to reduce chloride use due to environmental issues and the need to regulate salt use. This can be done through winter maintenance operations efficiencies like using data to improve operations, using variable application rates, anti-icing, equipment calibration, or through the use of salt alternatives. Salt alternatives include acetates, formates, glycols, succinates, and agricultural byproducts. While there is no clear "best" deicing material, each has its pros and cons. Through increasing use of these products more agencies are conducting studies and providing information on conditions where these products may be viable.

Many examples of blending chloride-based deicers with agriculturally derived products have been highlighted in Blended Liquid Deicing Products and Pre-Wet and Slurry Technology.

Examples of Implementation

Minnesota Department of Transportation

During the winter season of 2018-2019, the Minnesota Department of Transportation (MnDOT) began testing the use of potassium acetate (KAc) during their winter maintenance operations. MnDOT has had previous success using KAc in the Duluth area on bridges and tunnels and is looking to expand its use. KAc was found to be efficient at deicing at lower temperatures (around -20°F).

Colorado Department of Transportation

Colorado Department of Transportation (CDOT) uses magnesium chloride ($MgCl_2$) both before and after a storm on their highways since 1996 and has since expanded their use of the chemical. $MgCl_2$ was found to lower the freezing/melting point of water and to work quickly due to its moisture absorbing abilities. In 2009, CDOT conducted a survey of winter maintenance professionals and laboratory testing, comparing the effectiveness of $MgCl_2$ and sodium chloride (NaCl). The use of $MgCl_2$ instead of traditional sodium chloride (re: rock salt, salt brine) was found to be cheaper and require lower application rates. NaCl (solid) costs around $20 to $40 per ton delivered and salt brine costs around $0.10 to $0.30 per gallon to make; whereas $MgCl_2$ costs $0.53 to $0.84 per gallon (typically delivered). Application rates used for $MgCl_2$ were 20 to

Current Usage
Less Common
Key Components
• Material Storage • Staff Training
Implementation Considerations
• While rock salt is the most commonly used and cheapest deicer, it is harmful to both the environment and to physical structures. Salt alternatives work to reduce these negative impacts and could potentially provide more efficient snow and ice removal. • Some salt alternatives like acetates, formates, and beet juice have been found to be more effective at lower temperatures when compared to chlorides. • Some salt alternatives are more expensive than traditional rock salt, but an agency can still see overall savings through less material use.

100 gallons per lane mile and varied depending on traffic volume and storm conditions. CDOT found liquid $MgCl_2$ to be a good alternative to traditional road salt.

Calgary, Alberta

In 2017, the City of Calgary began pilot testing the use of beet juice mixed with salt brine in order to reduce reliance on salt for winter maintenance. This change was a result of a 2016 study that found declines in local fish and bug populations were linked to the city's salt usage. These efforts have been expanded in the following winter seasons after Calgary saw success. Calgary is currently using a 40,000-gallon tank truck to spray their blend of salt brine and 10-35% Beet 55 on their downtown streets. This mixture has reduced corrosion and harm to the environment while providing some cost reductions. Calgary plans to reevaluate the use of beet juice at the end of the season to decide if they will further expand the program.

Deicer Type	Lowest Functional Temperature	Relative Cost	Relative Toxicity	Environmental Impacts	Infrastructure Impacts
Chlorides	NaCl: 15°F $MgCl_2$: -5°F $CaCl_2$: -15°F	Low $30-$100/ton (NaCl) $100/ton ($MgCl_2$) $120-$300/ton ($CaCl_2$)	High	Accumulate in the environment. Impact water quality, aquatic, and terrestrial flora and fauna	Pavements (concrete impacts from $CaCl_2$ and $MgCl_2$) and metals
Acetates	KAc: -12°F NaAc: 0°F CMA: 0°F	Moderate $600-$1200/ton (KAc) $1000-$1500/ton (NaAc) $600-$2000/ton (CMA)	Moderate	Moderate Biological Oxygen Demand (BOD)	Pavement and galvanized steel
Formates	NaFm: 0°F KFm: -20°F	High $200-$350/ton (NaFm) $1000-$16000/ton (KFm)	Moderate	Moderate BOD	Pavement and galvanized steel
Glycols	-20°F	Moderate $10-40/gal	High	High BOD	Limited
Agriculturally Based		Low to Moderate $12-$35/ton (corn syrup) $156-$192/ton (corn steeps) $345/ton (molasses) $95-$140/ton (distillers grain)		Lower impact, localized dissolved oxygen depletion, can spur algae growth	Limited
Sand	All temperatures	Low	Low-Moderate	Air quality impacts, water quality impacts	Limited

Table 3. Summary of commonly used deicing materials, effective temperature, relative cost, toxicity, environmental impacts and impact to infrastructure. Recreated from TRS 1706 (2017).

The No Salt Option

Currently in winter maintenance operations chlorides are king. Salt, in the form of rock salt and salt brine, continue to be the most commonly used products due to their low cost, ease of use, and familiarity. For agencies looking to reduce or stop use of chlorides, we highlight some examples of how some agencies have done this.

Abrasives

Abrasives include materials like gravel, sand, ash, cinders, sawdust, etc. Abrasives do not work to melt or break up snow and ice, instead they help increase friction on the roadway. Abrasives are often used in combination with plowing. The more angular the abrasive particles are, the more effective the friction treatment. But abrasives are a short-term solution because they break down over time with traffic. This often requires areas treated with abrasives to be treated multiple times to maintain the friction benefits, resulting in larger environmental impacts caused by the abrasives. These negative environmental impacts include degradation of water quality, air quality, and roadside vegetation. Abrasives do not dissolve, but instead become broken up into smaller pieces. As a result the use of abrasives require clean up to sweep or vacuum up the material left on the roadway. Due to the large impacts and additional costs associated with clean up, abrasives are typically used in very specific conditions and targeted locations, such as when it is too cold for deicer chemicals to be effective, in areas where friction is needed to maintain safety (curves, hills, etc.), on low volume/low speed settings, and unpaved roads.

Table 4. Summary of pros and cons when using abrasives.

Pros	Cons
• Low upfront costs • Provides immediate friction improvements • Ability to use in low-temperature conditions when deicer chemicals might be less effective • Cleaned up abrasives can be reused following screening and cleaning with approval from environmental quality agencies	• Abrasives do not melt or reduce snow or ice on the roadway • Friction improvements are temporary due to displacement from traffic – higher traffic volume or traffic speeds can increase displacement • Should be pre-wet to reduce loss of material • Abrasives need to be cleaned up, which adds additional cost • The use of abrasives can have damaging environmental impacts

Examples of Implementation

Lake Tahoe, California

After Lake Tahoe was listed as “impaired” due to fine sediment pollution, El Dorado County has made strides to reduce the number of contaminants coming off their roadways due to winter maintenance operations. El Dorado County maintenance crews have implemented best management practices including applying the right products at the right time and sweeping abrasives after storms. El Dorado County switched their abrasives material from volcanic ciders to Washoe sand. This switch to sand has helped to improve water quality due to it being a sturdier grain compared to cinders and its weight causing it to sink to the bottom of the lake, whereas cinders would remain suspended. The City of South Lake Tahoe has improved the efficiency of abrasive use by focusing applications on key areas of public safety concern, including intersections and steep roadways. The city and county have also increased the use of brine for anti-icing and pre-wetting to reduce the amount of snow and ice buildup on the roadway and reduce the amount of sand

that scatters when applied, resulting in a 30 percent reduction in sand use. Caltrans has reported success from these efforts including improved water quality of Lake Tahoe and fine sediment particles have been reduced.

British Columbia Ministry of Transportation

The British Columbia Ministry of Transportation (TranBC) uses a mix of gravel and crushed stones to improve friction on their roadways. TranBC choose this abrasive to reduce loss of material from vehicles and high wind speeds. Particle sizes are large enough to be effective but small enough to keep vehicle damage to a minimum. This size depends on the type of highway where the material is being applied. Lower volume highways can use a large particle size (up to 0.49 inches diameter), whereas on higher volume provincial highways particles can only be up to 0.37 inches diameter. British Columbia has implemented various measures to mitigate air quality concerns related to the use of abrasives, including choosing durable materials that are larger particle sizes (coarse sand, crushed stone, gravel), reducing application rates through spot treating focus areas and using abrasives in coordination with deicers, and through abrasive material clean up. British Columbia schedules clean up as soon as possible in the spring as weather permits. Equipment used includes mechanical broom sweepers, vacuum sweepers, and regenerative air sweepers. The British Columbia Ministry of Water, Land and Air Protection provides a checklist to ensure environmental protection.

Flagstaff, Arizona

After switching to the chemical deicer, Ice Slicer, Flagstaff maintenance crews noticed roadside ponderosa pines turning brown. The City conducted a study to determine if the chemical deicer was associated with the tree deaths. As a result of this study the City decided to switch to using volcanic cinders as an abrasive on their roadways. Arizona Department of Transportation has found the cinders to provide ample traction after plowing and found cinders to be more environmentally friendly than salt or sand. Additionally, cinders are a local resource.

Non-Chloride Based Deicing Products

As shown in Table 3, there are many non-chloride deicing products on the market. Use of these by DOT and local road agencies to replace chlorides is limited at best. Often acetate based deicing products are used in automated spray systems at key locations, like bridges and trouble spots in remote locations. Other noted applications include use in sensitive areas or to protect landscaping.

If you are interested in using a non-chloride based product the Clear Roads Qualified Product List (QPL) is a great starting place (see page 6).

Examples of Implementation

Michigan DOT

Michigan DOT has been using CMA, or calcium magnesium acetate, on the Zilwaukee Bridge in Saginaw County, for 31 years. The Zilwaukee bridge, built in the late 1980's, is segmented and held together by steel cable tendons. Bridge life expectancy was always an important factor, and corrosion protection was of critical importance. Acetate based CMA is essentially non-corrosion to metals and was chosen as the deicer for the Zilwaukee bridge.

The cost of CMA this year is $1918.00/metric ton (2019 dollars), and Michigan DOT uses on average about 100 tons of CMA per year for winter maintenance of the bridge. CMA is also applied for ¼ mile leading onto the North Bound, South Bound, and Adams Road to South Bound ramp structures approaching the bridge.

The major benefits for using CMA is that it extends the life of the bridge surface and has limited impacts on the environment.

Alabama DOT

While the state of Alabama may not typically be associated with winter weather, they experience one or two events a season that require winter maintenance operation. When they have larger years and get three to five events in a season, this puts them in the realm of exceeding their winter maintenance operations budget. Of the state's 15,900 bridges, Alabama DOT is responsible for approximately 5,800 of them (Alabama DOT is not responsible for municipal or county road or bridges.) The DOT uses calcium magnesium acetate (CMA) generally in the central part of the state. The thought was to not apply salt on bridges or concrete, with CMA being chosen because it is non-corrosive. The northern region of Alabama has shifted toward using potassium acetate (KAc). Alabama DOT does use salt brine on 95% of roads maintained by the DOT in Alabama which are asphalt.

The northern region likes KAc, and they have found it is similar in cost to CMA, can be applied at about half of the application rate, and it can be more effective at this lower application rate. Currently, KAc is applied at about 16 gals/mile as a liquid anti-icer. As an agency Alabama DOT anti-ices with salt brine, KAc, and CMA about 48-72 hrs in advance of an event when conditions are appropriate.

The CMA being used is most likely leftover in their inventory. The crews know how to use it and will likely continue to use it until their supply is exhausted. Currently, knowledgeable staff are being used to train other maintenance regions on the use of KAc and anti-icing in general.

Opportunities for Future Expansion

As agencies continue to test and modify their materials for optimal snow and ice removal, the lessons learned will continue to encourage further innovation. Through the use of sensor technology or improved forecasting data, an agency will be able to adjust material blends depending on weather and roadway conditions. This technology will allow an agency to calibrate and reduce their material use. Looking forward, other technologies to consider include heated pavements.

Additional Resources

- Clear Roads – Environment
  - https://clearroads.org/environment/
- Field Usage of Alternative Deicers for Snow and Ice Control
  - http://dot.state.mn.us/research/TRS/2017/TRS1706.pdf
- Manual of Environmental Best Practices for Snow and Ice Control
  - http://clearroads.org/wp-content/uploads/dlm_uploads/Manual_ClearRoads_13-01_FINAL.pdf
- Michigan Department of Transportation Current Deicing Practices and Alternative Deicing Materials
  - https://www.michigan.gov/documents/ch2-deice_51438_7.pdf
- Winter Highway Maintenance Operations: Connecticut
  - http://ctcase.org/reports/WinterHighway2015/winter-highway-2015.pdf

Agriculturally Based

- Bio-Based Materials for Improving Winter Pavement Friction
  - https://www.nrcresearchpress.com/doi/abs/10.1139/cjce-2016-0460#.XcSmGVdKi70
- Evaluation of the Performance of Deicing and Anti-Icing Using Organic Alternatives for Sustainable Winter Road Maintenance
  - https://uwspace.uwaterloo.ca/handle/10012/11600
- Evaluation of Organic Anti-Icing Materials for Winter Maintenance
  - https://sustainabletechnologies.ca/app/uploads/2015/11/AlternativeSalt_TechBrief_Nov2015.pdf

Acetates

- Impacts of Potassium Acetate and Sodium-Chloride Deicers on Concrete
  - https://ascelibrary.org/doi/10.1061/%28ASCE%29MT.1943-5533.0001754

Succinates

- Evaluation of Disodium Succinate Hexahydrate as an Alternative Deicer
  - https://trid.trb.org/view/1494681

Chlorides

- Evaluation of Alternative Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers – Phase I
  - https://www.codot.gov/programs/research/pdfs/2009/antiicing.pdf

Abrasives

- Limitations of the Use of Abrasives in Winter Maintenance Operations
  - http://clearroads.org/wp-content/uploads/dlm_uploads/tsr-limitations-of-abrasives.pdf

Using Data and Reporting to Make Informed Decisions

Advances in information technology and information collection systems have allowed agencies to capture data on their winter maintenance operations including fleet tracking, fleet mileage, material use, weather conditions, road conditions, personnel hours, and weather severity, to name a few commonly tracked metrics. Tracking winter maintenance operations allows an agency to make optimal use of resources. This is often done through performance metrics, or level of service guidelines, which can be tailored to meet an individual agency's goals. These metrics allow an agency to track their operations over time and modify operations to improve efficiency while reducing effort and costs. Ideally, data tracking is done automatically but can be accomplished manually, or through the use of computerized systems.

Figure 31. Using data to make informed decisions. Source: WTI, N. Hetherington

WSI/SSI

A winter severity index (WSI) or storm severity index (SSI) is a management tool that allows a winter maintenance agency to measure the severity of a storm in order to evaluate winter maintenance efforts and compare efforts from season to season or storm to storm. A WSI/SSI tool can be tailored to an individual agency's needs and conditions but typically uses data on precipitation, pavement or air temperature, total number of storms, and total storm duration. Many state DOTs are now using WSI/SSI that have been developed specifically to address the needs of their states. The accumulated winter season severity index (AWSSI) WSI/SSI was developed at the national level for the US using specific meteorological weather station data and allows states or regions to pull data and apply the calculated WSI as they choose (https://mrcc.illinois.edu/research/awssi/indexAwssi.jsp). The AWSSI calculation is a meteorological based weather severity tool but has the ability to account for roadway conditions. AWSSI considers the temperature and snowfall for the day and was found to correlate with operations data. Many states have found success in using this method but note that for most states data resolution is limited, so they often seek additional data sources to improve the resolution of the WSI so that they can accurately apply it at the garage level.

Current Usage
Common
Key Components
• Data Management Systems • Staff Training
Implementation Considerations
• Collecting data on your agency's winter maintenance program can track your effectiveness and cost savings. Clear goals will help an agency determine which data to collect and how to collect it. • Data collection can be done manually or using automated systems – while automated systems can reduce workload, any data collection efforts will help ensure long-term success of your winter maintenance program. • Studies have shown measuring can reduce waste by 10 to 30%.

Examples of Implementation

Wisconsin Department of Transportation

The Wisconsin Department of Transportation (WisDOT) collects a variety of data in order to track their winter maintenance operations and examine areas of improvement. Each week, county departments complete winter storm reports which include information on number of storms, type of storm, precipitation type, and snow depth. This information is then fed into the state's storm severity index. This index allows WisDOT to evaluate winter maintenance efficiency including labor and material use based on the storm severity of a county or region. WisDOT also tracks their material use and costs and has begun testing "mostly liquid routes" in an effort to reduce rock salt usage.

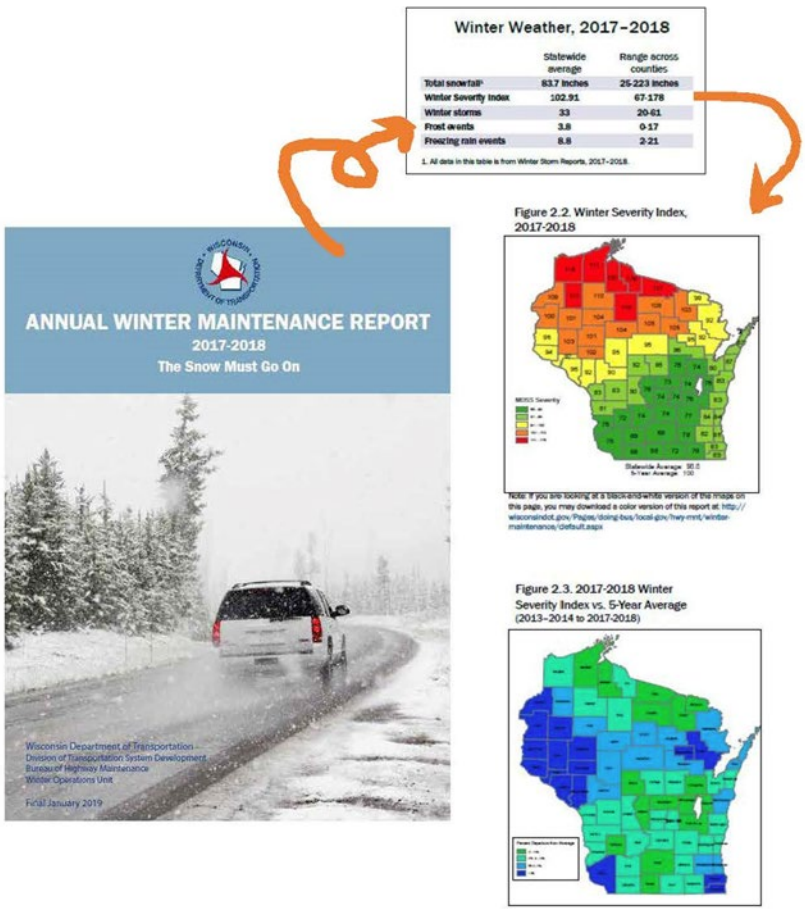

Figure 32. WisDOT annual winter summary report, winter weather data from the 2017-2018 season (pg. 19), weather severity index visualized as colors and numbers by county (pg. 21) (Source: https://wisconsindot.gov/Documents/doing-bus/local-gov/hwy-mnt/winter-maintenance/annual-report-2017-18.pdf).

Idaho Transportation Department

The Idaho Transportation Department (ITD) created a simple easy to use winter severity index. ITD uses RWIS data to support the WSI which incorporates wind speed, layer thickness, pavement temperature, storm duration, and grip (friction) in the calculation tool. Values of 10-80 indicate normal winter events, whereas severe storms and wind events have values up to 500. The greater the number, the more severe the storm. ITD developed this in house in a single district. Once tested, ITD adopted this statewide. ITD shared the calculation methods with Vaisala, their data provider, who automated the data process and calculation for ITD. This has created more time to allow ITD to develop a deeper understanding of how different variables can be used in WSI calculation and how to apply it. Adding additional RWIS sites and ensuring good quality data has helped make this program a success.

MDSS/WebMDSS

The Maintenance Decision Support System (MDSS), and now the web based MDSS, started as an FHWA effort and is now maintained as a multistate pooled fund effort. MDSS and webMDSS are a computer-based customizable winter maintenance tool that provides route specific weather forecast information and treatment recommendations, and now also provides weather severity analysis. These software tools allow an agency to more effectively treat roadways during the winter season.

Examples of Implementation

Indiana Department of Transportation

Indiana Department of Transportation (InDOT) implemented maintenance decision support system (MDSS) statewide during the 2008-2009 winter season with great success. In one winter season, InDOT saw a savings of over $9 million in salt use and $900,000 in over-time expenses. MDSS allowed managers to be more informed of conditions and recommended treatments which allowed for a more proactive winter maintenance strategy.

Minnesota Department of Transportation

In 2009, Minnesota Department of Transportation (MnDOT) utilized MDSS on seven vehicles and 30 computers across the state. MnDOT uses GPS in coordination with AVL in order to track vehicle use statewide. MnDOT uses MDSS as a recommendation. This recommendation would be used if operators believed it was reasonable. Overall, MnDOT has seen differing levels of trust in MDSS.

Dashboards

State departments of transportation use dashboards to track and report on performance measurements. These dashboards act as a report card showing agency efforts and provide a level of accountability to the public.

Examples of Implementation

Iowa Department of Transportation

Iowa DOT has a management dashboard available to the public and another dashboard used internally that tracks actual salt use compared to projected salt usage and road weather conditions. This Salt Use Dashboard is used by managers to evaluate if reasonable salt use rates are being used given the current conditions. This dashboard has encouraged reduced salt usage across the state.

Figure 33. The Iowa DOT public facing dashboard that summarizes key metrics, versus the internal Salt Dashboard that is used to make targeted decisions.

Case Study: Wisconsin Department of Transportation

Wisconsin Department of Transportation has developed the Mobility, Accountability, Preservation, Safety, and Service (MAPSS) Dashboard to meet their goal of providing a safe and efficient transportation system. Each year WisDOT publishes a MAPSS Scorecard which evaluates the DOT's performance and whether their goals are moving forward. As a part of this effort WisDOT evaluates their winter response performance with the goal that roads that are maintained 24 hours a day are cleared within 4 hours and roads that are maintained 18 hours a day are cleared within 6 hours. In 2019 the department met these goals 70% of the time. The MAPSS Dashboard has allowed winter maintenance managers to track their performance over time. WisDOT plans to use this method to track and work towards reducing road salt usage.

Contact: Mike Adams, Wisconsin DOT RWIS Program Manager, michael.adams@dot.wi.gov

Case Study: Idaho Transportation Department

Idaho Transportation Department has a performance measures dashboard on their website. As a part of this effort, ITD tracks the percent of time highways are clear of snow and ice during winter storms for each winter season. The ITD Dashboard allows a user to click on each performance measure to gain more information on how it is measured and how it has changed over time. From 2010 to 2019 ITD has improved their highway winter maintenance. During the 2018-2019 winter seasons, ITD highways were clear of snow and ice 86% of the time.

Contact: Max Thieme, Mobility Services-Winter Operations, Max.Thieme@itd.idaho.gov

Contact: Steve Spoor, steve.spoor@itd.idaho.gov

Opportunities for Future Expansion

Advances in data collection and management will allow an agency to automatically track their material use over time. This data can be used in coordination with weather forecast data or RWIS to help an agency determine if the treatment applied was appropriate and to adjust their material application rates to better fit their needs. The next level of data collection may include data from connected vehicles.

Additional Resources

- Clear Roads: Snow Removal Performance Metrics
  - http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.14-05_Final.pdf
- Performance Measurement for Highway Winter Maintenance Operations
  - https://www.iihr.uiowa.edu/wp-content/uploads/2013/06/IIHR474.pdf
- Operational Data to Access Mobility and Crash Experience During Winter Conditions
  - http://publications.iowa.gov/28697/1/operational_data_in_winter_conditions_Final_Report.pdf

Maintenance Decision Support System (MDSS) & Web-Based MDSS

- FHWA Maintenance Decision Support System Showcase
  - https://ops.fhwa.dot.gov/weather/seminars/mdss_showcase/index.htm
- WebMDSS
  - https://www.webmdss.com/login/?destination=%2F
- Maintenance Decision Support System: Indiana Department of Transportation Statewide Implementation
  - https://mdss.iteris.com/mdss/pfs/files/MDSSReportWinter08-09.pdf
- An Analysis of Maintenance Decision Support System (MDSS) Benefits and Costs
  - https://mdss.iteris.com/mdss/pfs/files/WTI-4W1408_Final_Report.pdf

Weather Severity Index/Storm Severity Index

- Clear Roads – AWSSI Enhancements in Support of Winter Maintenance
  - https://clearroads.org/project/16-02/
- The Accumulated Winter Storm Season Severity Index (AWSSI)
  - https://journals.ametsoc.org/doi/pdf/10.1175/JAMC-D-14-0217.1

Dashboards

- Iowa DOT Salt Use Dashboard
  - https://ops.fhwa.dot.gov/publications/fhwahop12046/rwm11_iowa1.htm
- Wisconsin MAPSS Performance Improvement Program
  - https://wisconsindot.gov/Pages/about-wisdot/performance/mapss/default.aspx

Recommendations

Recommendations have been made for each technology and practice highlighted in the Case Studies to support the adoption and use in winter maintenance operations. Please note the recommendations are based on information gathered from the Appendix A – Literature Review and Case Studies.

AVL/GPS

- Before deploying AVL/GPS, an agency should have clear goals of what data they want to capture and how it will be used. This will inform whether additional sensors are necessary.
    - Example Goals – inform the public of treated routes, document material use by location
- When training snow plow operators to use AVL/GPS, highlight how AVL/GPS systems will benefit the operators themselves by improving accountability. This can improve buy-in and allow an agency to be proactive with concerns surrounding privacy.
- An exhaustive list of best practices and recommendations on the considerations, implementation, and evaluation of AVL/GPS was developed in Clear Roads 16.01 (http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.16-01_Final.pdf) on AVL/GPS which can be found in Chapter 5 of the report:
    - Planning and Decision Making
    - Procurement
    - Methods of Procurement
    - System Implementation
    - Data Collection, Management, and Utilization
    - Operations and Maintenance

Blended Liquid Deicing Products

- Identify your goals for using liquids in winter maintenance operations. Tailor your product choices based on these needs.
    - Example Goals – reduce black ice through increased use of anti-icing or starting to anti-ice, reduce product waste through prewetting to avoid loss of material from bounce and scatter, reduce corrosion, reduce number of or rate of future applications.
    - Example Product Choice – salt brine blended with an agriculturally derived product
- Pavement temperature is key when choosing a liquid deicer. Make sure the chosen product will work within your desired temperature range(s).
- Blending your own deicers allows an agency to control what goes into the blend and the amount needed. Additionally, creating your own blends can reduce costs through the use of locally sourced agricultural by- or co-products.
- Purchasing pre-blended products from a vendor can reduce your agencies liability by reducing staff time creating blends, reducing storage capacity needs, and decrease liability related to improperly mixed blends.

Direct Liquid Application (DLA) Routes

- When determining whether to use direct liquid application (DLA), consider the following three factors:
    - pavement temperature,
    - storm intensity,
    - snow moisture content.
- DLA is most effective when temperatures are greater than 25°F, snow fall is at a rate of approximately one inch per hour, and in drier conditions (i.e., not raining or wet snow/sleet).
- Training is key.

Pre-wet and Slurry Technology

- If you are applying a dry material (salt, sand, etc.) consider trying pre-wetting or slurry in the application to reduce material loss from bounce and scatter during application.
- While you can pre-wet on the stockpile or spray a loaded truck, it is recommended that you pre-wet at the spinner for optimum moisture coverage on each particle. Treating the pile also creates other problems: increased leaching of chlorides into the soil at stockpile sites and inconsistent application of liquid…it's common to have dry spots in the load unless it's being mixed while wetted.

Mechanical Snow Removal

Squeegee Blades

- Squeegee blades are effective at removing slush or lighter snow from a roadway, and even brick or cobblestone.
- Squeegee blades can be used in combination with a cutting-edge blade to clean up any excess snow, slush, or liquid left behind.
- When using a squeegee blade, be cautious of the down pressure used on the blade, as too much pressure can cause premature wearing.

Multi-segmented plow blades

- Multi-segmented plow blades function well on rutted pavements and on pavements with raised markings.

Brooms

- Brooms are more effective with lighter/less dense snowfall. In heavier snowfall the brushes tend to have trouble removing snow off the roadway.
- Brooms do not remove packed snow and ice well from vehicles or even pedestrian traffic (bikes, walking, etc.).

Methods to Reduce Chloride Use and Salt Alternatives

- Identify your goals and performance metrics for reducing chloride use.
    - Example Goals – reduce chloride use by X percent, reduce amount of chloride entering nearby waters

- Identify alternative products and practices that can be used in your area to support your goals to reduce chloride use.
    - Example Goal – Reduce the number of shaded road sections by thinning or removing trees from the right-of-way where feasible.
- When applying chlorides, use the three R's: apply in the Right place, at the Right time, and in the Right amount.
- Collecting data is key to chloride reduction efforts – this data will allow an agency to track effectiveness and cost savings over time and loading to surface and groundwater.

Route and Fleet Optimization

- Route and fleet optimization programs allow an agency to determine the most efficient routes for snow removal based on mathematical algorithms considering location, fleet size, vehicle capacity, and other constraints.
- These programs provide a good starting point but require agency review and input. Agencies should have staff test and provide feedback on each route prior to the winter season in order to determine if modifications are necessary.

Using Data and Reporting to Make Informed Decisions

- Data collection can be simple to complex, inexpensive to expensive.
- Analysis of the collected data is key to making informed decisions.

Doing a lot with a little

Many tools and practices allow an agency to apply only the material that is needed while maintaining an expected level of service (LOS), these are referred to as best management practices. One of the key premises of many best management practices is that they do not require an agency to purchase equipment or material, but instead may require changes in management practices and training time to garner employee buy-in. Often these are identified as low and or low risk changes in practice. Common starting places include:

Equipment Calibration

Equipment calibration ensures that an exact amount of material is coming out the shoot or applicator at a specific setting and or speed. Once you have calibrated your equipment you can then work to ensure the desired amount of material (solids and or liquids) is being applied to the roadway. Equipment calibration can be done manually using basic equipment to catch and weigh material being moved through the spreader or using an automated system. While calibration requires time, equipment calibration is one of the first steps to ensuring reduction in material use. Once calibration becomes a part of normal operations and is routine, the time it takes is greatly reduced. Material spreaders should be calibrated prior to the winter season and after any maintenance has been completed on the spreader or truck, and when application rates seem off.

Pros:

- Equipment calibration ensures that your material spreader equipment is applying the correct amount of material. This can result in cost savings from a reduction in material loss.
- Equipment calibration can be done with very basic equipment – a bucket and scale.
- Training and guidance on equipment calibration is widely available:
    - Clear Roads – Calibration Accuracy of Manual and Ground-Speed-Control Spreaders
        - https://clearroads.org/project/calibration-accuracy-of-manual-and-ground-speed-control-spreaders/
    - Minnesota Department of Transportation – Calibration Training Guides and Videos
        - http://www.dot.state.mn.us/maintenance/training.html

Cons:

- Equipment calibration can initially be time consuming, but this will decrease over time with practice.
- Equipment will need to be calibrated at points throughout a season, if application rates or material use seems off, and if any maintenance is performed on the spreading equipment.

Variable Application Rates and Timing Based on Current Conditions

Variable application rates and timing of deicer applications and plowing allows an agency to tailor their material use depending on current weather and road conditions in order to most effectively treat the roadway. Variable application rates and timing can reduce material use while maintaining roadway LOS and safety. Application rate and timing guidelines are available from a number of agencies and sources, but an agency adopting variable application rates and timing should use this information as a starting point which can be tailored based on your conditions. To support this, good pavement condition data and weather forecasting are highly recommended. If you do not have weather forecast services provided to you, reach out to your location's National Weather Service office or use any of the number of free online weather forecast providers (AccuWeather, Weather Underground, etc.) as a starting point. Adjustment of equipment will likely need to occur to allow for the change in application rates.

Pros:

- Variable application rates and timing can reduce overall material use.
- Variable application rates and timing can be changed incrementally over time using data to make informed changes.

Cons:

- Variable application rates and timing require data and employee buy-in.

Using Data and Reporting to Make Informed Decisions

Many state DOTs have existing data collection platforms, such as RWIS and mobile pavement temperature sensors on their plows, to name a few. Since this data is being collected, why not use it in as many ways as possible? Data sources can be as simple as plow driver logs/reports, to formal reporting, to automated tracking of plows and material used. This data can all be used to aid in making informed decisions. Collecting and applying this data to improve operations and make informed decisions can be as simple as using an Excel spreadsheet, requiring staff time only to evaluate the collected data. Applying this data allows an agency to track their operations over time and to effectively modify operations to meet program goals. This can result in cost savings and reductions in material use and labor over time. Some agencies have developed dashboards that are used to track and report performance metrics over time and to communicate efforts to the public.

Pros:

- Data allows an agency to track their program effectiveness over time and to make incremental changes to meet program goals.
- Using data to inform winter maintenance decisions can result in cost savings and reductions in material use.
- Automated data collection systems, for example from mobile pavement temperature sensors, can reduce workload.
- Data reporting can improve communications and accountability with the public.

Cons:

- Manual data collection can be time intensive.
- Using data to make informed decisions may not require a large financial investment in a program but does require someone time to review and process the data.

The use of best management practices leads to an efficient winter maintenance program which reduces material use, wear and tear on equipment, and person hours while maintaining safety and mobility of your area. Collecting data on changes in winter maintenance operations is key and will allow an agency to track the success of implementation and determine if additional changes are needed. The use of best management practices allows an agency to make relatively low-cost changes to improve their program prior to larger investments in new equipment or materials.

The BMPs are out there, tried and tested, we need training and implementation!

Bringing out the Big Guns

At some point you will have exhausted your ability to implement low cost and low risk best practices for your agency. At this point in time you may be looking to invest in new practices that will require the

purchase of new equipment, new materials, or new technology to find improvements in your winter maintenance program. Many of these pieces of equipment and technologies have been shown to be cost-effective investments through cost-benefit analysis (see examples below).

- Clear Roads - Development of a Toolkit for Cost-Benefit Analysis of Specific Winter Maintenance Practices, Equipment and Operations
    - https://clearroads.org/project/598/
- Understanding the True Costs of Snow and Ice Control
    - https://clearroads.org/project/10-03/
- Cost-Benefit of Various Winter Maintenance Strategies
    - https://clearroads.org/project/13-03/

Prior to making a large investment, conducting a cost-benefit analysis is highly recommended. The above-mentioned tools can be used and provide information on how you modify the analysis for your needs. In some instances, a simple “back of the envelope” calculation can work as well.

Example “back of the envelope” calculation of cost-benefit and payoff for implementation of a new practice.

Costs

Capital cost of Investment: $50,000

Cost to install (person hours and equipment): 8 hrs at $35 hr = $280

Cost to use: monthly subscription fee $99m, or $1188 a year

Cost to maintain: estimated 8 hrs a year per vehicle (initial implementation on 10 trucks)
8 hrs x $35 hr x 10 trucks = $2,800

Total cost estimate: ~$54,300 in the 1st year

Savings

Potential savings: Reduce application rates and frequency of applications, reduce person hours, reduce vehicle time and wear and tear.

Material savings: 20 tons of salt at $50 a ton = $1000 per truck, for 10 trucks $10,000

Person hour savings: 40 hrs a season per truck at $35 hr = $1400, for 10 trucks $14,000

Vehicle time and reduced wear and tear for the 10 trucks: estimate at $500 a truck per season, for 10 trucks $5,000

Total estimated savings: $29,000 in the 1st year

Payoff: $54,300 / $29,000 = 1.87 years or 2 years

For a first-year cost of $54,300 and a first-year potential savings of $29,000, it will take about 1.8 or two winter seasons for the investment to pay for itself. Note that this is simplified and should be checked after the season with actual costs and then recalculated.

When considering larger investments, it is important to always remember your program goals. Consider how this investment will fit into your program and whether it will help you meet your goals. While larger investments in new equipment or technology may have large up-front costs, consider how this investment may affect practices in the long run: will it reduce staff time, improve LOS, reduce chloride use? These are all things that should be considered when conducting a cost-benefit analysis. Continue to use your best management practices as you make changes to your program. This will ensure you are moving in the right direction.

Going from Good to Great

Every agency is doing a good job and are great at a few things. When you examine the difference between a "good" job and a "great" job you often see similarities among agencies. Greatness requires going the extra mile, top-down and bottom-up support, funding, training, evaluation and accountability, and striving to improve. When initiatives become great successes, it can often be attributed to a point person, or champion, serving as the leader, and not giving up on the idea.

Steps to Implementation

Taking on anything new can be daunting and overwhelming, particularly if you do not know where to begin. This section provides tools and input to help make this process easier. The following bullets provide general guidance and lessons learned on how to implement a new system, method, or technology.

- Collaborate within your agency – ensure everyone has a seat at the table.
- Set goals for your winter maintenance program or identifying existing performance metrics for improvements.
- Identify low hanging fruit (low cost and or low risk)
    - As discussed above in *Doing a lot with a little,* identifying low cost or no cost options specific to your agency can be a great place to start.
- Develop a plan to address your goals with top to bottom support.
    - Use data to track your costs, progress, successes, and lessons learned.
- Re-evaluate your winter maintenance program after implementation, determine if larger changes are necessary, start slow, and build up using small incremental changes.
- Identify larger capital investments based on your agency's strategic goals.
    - Example;
        - Goal: Our goal is to use all of the RWIS data we are collecting.
        - Capital investment to support this: Having a staff member serve as a data manager, create a Data Dashboard (internal and or public facing).
- Develop a plan to purchase and implement the new technology with top to bottom support.
    - Use data to track your costs, progress, successes, lessons learned.
    - Consider a gradual roll out with highest possibility of success.
- Collect and assess data on the feasibility of expanded use, upgrades, changes needed, or improvement that can be made.

Figure 34 outlines basic steps that be followed to support implementation of any new practice or technology.

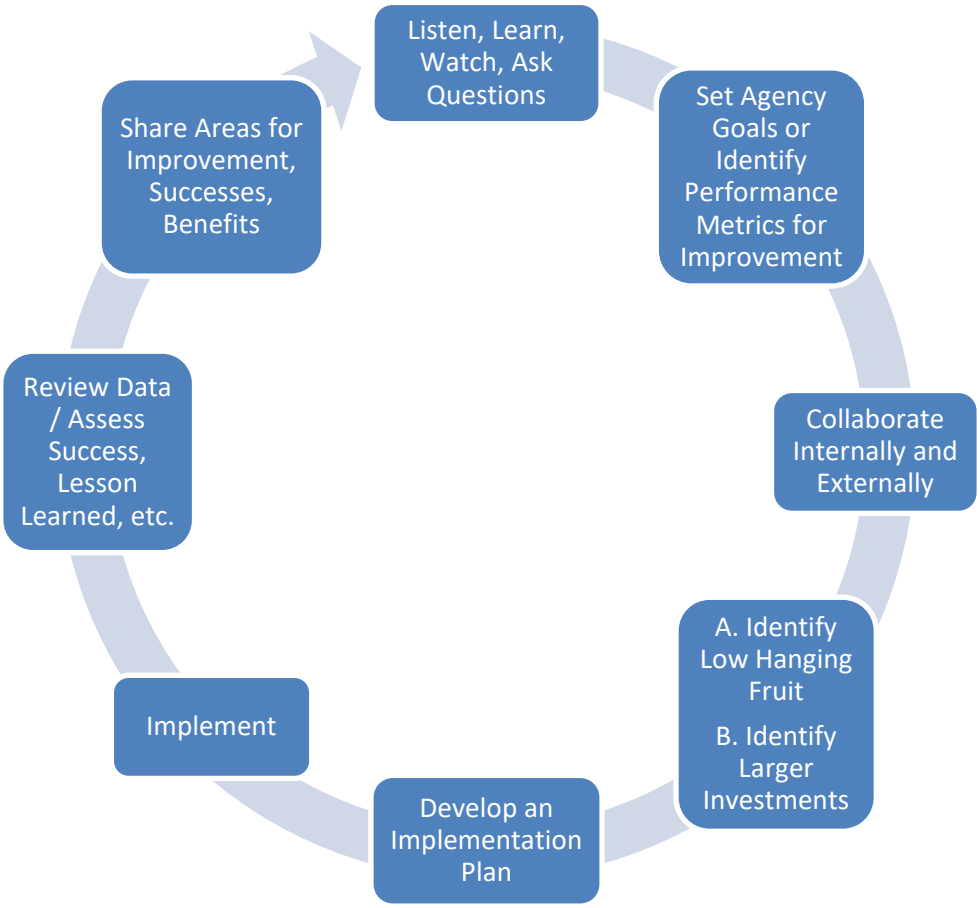

Figure 34. Steps to Implementation

Training to Support Implementation

The importance of training throughout this process cannot be overstated. Training before, during, and after implementation of any changes to your winter maintenance program will lead to greater employee buy-in and can improve adoption and long-term success of the new system, method, or technology. Train the trainer or mentorship programs have been particularly successful in aiding in information retention.

> Training before, during, and after changes to your winter maintenance program is the best way to ensure adoption and success!

Where to Look for Training Support

- For new technologies or equipment, enlist the help of the vendor/manufacturer to provide training.
- Utilize existing resources:
  - Available training modules

        - Iowa DOT, Winter Operations Training Series consists of 13 modules from preseason preparation, to appropriate attire, to wing plow techniques. https://www.youtube.com/playlist?list=PLurY2WfsVWKn9ismDC4Uz3IbRivAnf0Ld
        - Clear Roads Computer Based Training for Winter Maintenance Operators https://clearroads.org/request-for-training-modules-form/ https://clearroads.org/computer-based-training/
        - AASHTO T3 Prep for the Winter Season with Personal Safety and Maintenance Training https://tc3.transportation.org/about/news/prep-for-the-winter-season-with-personal-safety-and-maintenance-training/
        - APWA eCourses https://www.apwa.net/MYAPWA/Education___Credentialing/APWA_eLearning_Portal/MyApwa/Apwa_Public/Education_and_Events/eLearning_Portal.aspx?hkey=3c0f25e3-955c-4c50-b53c-94059ee06cda
        - Consortium for Innovative Transportation Education (CITE), Road Weather Management Certificate http://www.citeconsortium.org/cite-courses/certificate-programs/road-weather-management/
    - Reach out to your state's Local Technical Assistance Program (LTAP) for training support. https://nltapa.org/
    - Webinars on the topic
        - Many of Clear Roads completed research projects have a 30 min to 1 hour webinar recording that summarizes the work. Click on the project of interest to find more information: https://clearroads.org/completed-research/.
        - The Transportation Research Board (TRB) offers webinars on various transportation related topics including winter maintenance, road weather, and maintenance and equipment. https://webinar.mytrb.org/Webinars
        - Federal Highway Administration (FHWA) Every Day Counts (EDC) program identifies proven innovations that facilitate greater efficiency at the State and local levels. As a part of the FHWA EDC-5, FHWA offers recordings of webinars to introduce each innovation including one on weather-responsive management strategies. https://www.fhwa.dot.gov/innovation/everydaycounts/edc_5/edc5-orientation-webinars.cfm
          Round 4 of the EDC program (EDC-4) included weather-savvy roads which use integrated mobile observations and Pathfinder strategies to improve safety during winter weather conditions. https://collaboration.fhwa.dot.gov/dot/fhwa/RWMX/Pages/Weather-Savvy-Roads-Webinars.aspx
    - Podcasts
        - The American Association of State Highway and Transportation Officials (AASHTO) Snow and Ice Pooled Fund Cooperative Program (SICOP) offers a podcast called *SICOP Talks Winter Ops*, which covers all things winter maintenance. https://sicop.transportation.org/stwo/

- Conference attendance, training, peer exchanges, and certificate programs
  - APWA offers certificate programs during conference attendance:
    - Winter Maintenance Operators
    - Winter Maintenance Supervisors

    https://www.apwa.net/MYAPWA/Education___Credentialing/Certificate_Programs/MyApwa/Apwa_Public/Education_and_Events/Certificate_Programs.aspx?hkey=b1616f4a-d9ba-4e59-a0d1-82c1bb2bbbc2

  - A comprehensive list of conferences offered in the next year can be found on the Federal Highway Administration (FHWA) website: https://ops.fhwa.dot.gov/aboutus/calendar.htm
- Develop or use your own in-house training. Your winter maintenance staff are experts at what they do, use their knowledge, encourage mentoring of newer staff, etc.

Implementation Best Practices Check List

The following best practices and recommendations were provided in Clear Roads 16.01 (http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.16-01_Final.pdf) but can apply universally to almost any project.

Implementation Checklist

- ☑ Involve agency leadership, management, workers, operators
- ☑ Identify needs, goals, performance metrics for improvement, and objectives
- ☑ Conduct research and/or pilot projects
    - Identify issues and opportunities
    - Leverage other agencies' experience
- ☑ Identify staffing and resources needed
- ☑ Establish an implementation plan.
    - Consider phased implementation
    - Make sure to consider long term operations and maintenance costs.
- ☑ Provide outreach and training to all levels of system users before, during, and after implementation.
    - Be prepared to deal with cultural changes.
    - Communicate and demonstrate the purpose and any changes to alleviate concerns and create buy-in with the users.
- ☑ Conduct recurring training to improve the agency's ability to achieve operations objectives.
    - "Train the trainer" programs help retain system knowledge within the agency.
- ☑ Establish a performance management program to document performance and benefits.
    - Communicate the benefits.

Research Needs

The following list includes research needs that were identified throughout the project. Research needs will improve the understanding of how to support implementation of alternative methods for deicing within the winter maintenance community.

1. How to put together a winter maintenance dashboard, public facing and internal?
2. How to get buy-in from staff on changes in practices? How to create cultural change?
    a. How do you effectively encourage staff to serve as the leaders/champions for implementation of new ideas?
3. Cost-benefit analysis of sweepers – consider repair, replacement parts, equipment maintenance, impacts to pavements, specific training required, etc.
4. Cost-benefit analysis of ice breakers – consider repair, replacement parts, equipment maintenance, impacts to pavements, specific training required, etc.
5. Cost-benefit analysis of AVL/GPS technology? Is it worth the investment and, if so, why?
6. How to best use AVL/GPS technology to make better decisions about deicer applications, route timing, equipment and staff needs, etc.?
7. Are there truly any alternative options to salt? Thinking big and beyond the use of deicers, how can DOTs move away from using salts?
8. How to get contractors on board with: New technology? Equipment calibration? Sustainable practices? Modifying deicer application rates?
9. Does incentivizing work? For contractors? Within State transportation agencies?
10. Assessing the true variability of application rates used compared to LOS guidelines – for state DOTs, local transportation agencies, and contractors?
11. Best practices on how data can be used in performance measurement.
12. How to best prewet particles to maximize saturation and minimize the amount of liquid used?
13. Map out cold spots, location on the roads. Then determine why they are occurring – shading, drainage issues, other? Finally, assess how to treat cold spots (e.g., tree removal, heated pavement, deicers, etc.)

Conclusions

Findings from this project highlight the fact that many alternative methods and materials for deicing are well known, documented, and tested. But what was lacking were case examples that provide information on what worked and what did not, and contacts at agencies who have tried these practices, technologies, and products. There is no clear "one size fits all" solution to improving winter maintenance practices, but by tracking your own agencies data and using experience from others highlighted in this report and others, you can work to slowly implement changes in your organization.

This report presents information on alternative methods for deicing that have been identified around the world. A literature review was used to identify practices, equipment and technology, and products. From this a survey was developed to capture more information on each topic, identify potential case studies, and interviewees. Potential case studies were developed using information gained from the literature search, survey responses, and interviews, on the following topics:

- Automatic Vehicle Location (AVL)
- Blended liquid Deicing Products
- Direct Liquid Applications (DLA)
- Pre-wet and Slurry applications
- Mechanical Snow Removal Methods
    - Ice Breakers
    - Rubber, Squeegee Plow Blades
    - Multi-Segmented Plow Blades
    - Brooms, Sweepers
- Methods to Reduce Chloride Use
- Route Optimization
- Salt Alternatives for Deicing/Anti-icing
- Using Data to Make Informed Decisions
    - WSI/SSI
    - MDSS, Web MDSS
    - Dashboards

Recommendations were developed to support implementation for each of the case studies, as well as the concepts of implementing small, easy to implement improvements and larger, more complicated concepts to implement. Throughout the process, research needs and knowledge gaps were identified to help advance this field.

References

Acharya, S. G., M. V. Sheladiya and G. D. Acharya, "Preventive Measures for Corrosion of Deicers to metals: Need of the Hour," CORCON, Rajasthan, India, 2018.

Akin, M., Y. Zhang and X. Shi, "Pavement Surface Treatments for Ice-Prone Locations in the Illinois Highway System," Illinois Center for Transportation, Springfield, IL, 2018.

Akin, M., Y. Zhang and X. Shi, "Developing Friction Data to Support the Optimal Use of Pre-Wet Deicing Salt for Enhanced Winter Mobility," Center for Advanced Multimodal Mobility Solutions and Education, Charlotte, NC, 2018.

Albers II, T. P. D. “Best Practices for Winter Maintenance Roadway Deicer Applications in the State of Nebraska,” Lincoln, NE, 2015, p. 99.

Arabzadeh, A., H. Ceylan, S. Kim, K. Gopalakrishnan and A. Sassani, "Superhydrophobic Coatings on Asphalt Concrete Surfaces: Toward Smart Solutions for Winter Pavement Maintenance," Transportation Research Record: Journal of the Transportation Research Board, vol. 2551, pp. 10-17, 2016.

Arvidsson, A. K. "The Winter Model - A New Way to Calculate Socio-Economic Costs Depending on Winter Maintenance Strategy," Cold Regions Science and Technology, vol. 136, pp. 30-36, 2017.

Bandara, N., E. Jensen, and F. Holt, “Evaluating the Use of Tow Plows in Michigan (No. SPR-1623).” Lawrence Technological University, Department of Civil and Architectural Engineering. 2016.

Bandara, N. & E. Jensen, “Cost–Benefit Analysis of Using the Tow Plow for Winter Maintenance.” Transportation Research Board 97th Annual Meeting, Washington, DC. 2017.

Bennett, D. “Using Mechanical Ice Breakers to Improve Snow and Ice Removal Operations.” Caltrans Division of Research, Innovation and System Information. 2016.

Bergner, D. "Advances in Winter Maintenance Practices to Improve Roadside Safety," Transportation Research Circular Number E-C220, pp. 612-625, 2017.

Blandford, B., E. Lammers and E. Green, "Snow and Ice Removal Route Optimization in Kentucky," Transportation Research Record: Journal of the Transportation Research Board, vol. 2672, no. 45, pp. 294-304, 2018.

Bradford, Z. Tahoe in Depth: New products, practices help stormwater from harming lake. Tahoe in Depth. Winter 2016-17. Published online January 6, 2017.

British Columbia, Ministry of Water, Land and Air Pollution. Best Management Practices to Mitigate Road Dust from Winter Traction Materials. March 2005.

British Columbia, Ministry of Transportation and Infrastructure. Winter Traction - why small rocks, instead of sand. TranBC. Published online February 17, 2011.

Chebot, D., W. White, and S. Velinsky, “Improved Deicing Methods for Snow and Ice Removal: Evaluation of the Epoke Sander/Spreader for Caltrans Operations.” Caltrans Division of Research, Innovation and System Information. 2015.

Chen, H., Y. Wu, H. Xia, B. Jing and Q. Zhang, "Review of Ice-Pavement Adhesion Study and Development of Hydrophobic Surface in Pavement Deicing," Journal of Traffic and Transportation Engineering, vol. 5, no. 3, pp. 224-238, 2018.

Clear Roads, Annual survey of state winter maintenance data. https://clearroads.org/winter-maintenance-survey/. Accessed January 31, 2020, last updated 2020.

CTC & Associates LLC, “Levels of Service in Winter Maintenance Operations: A Survey of State Practice.” Clear Roads Pooled Fund Study. 2009.

Dane County Department of Land and Water Resources, "The Future of Winter Maintenance Involved Liquid Only Strategies," Dane County Department of Land and Water Resources, WI, 2017.

Daniels III, J. W., E. Heymsfield, R. F. Saunders and M. L. Kuss, "Development of Automated Electrical Heat Grid for Pavement Snowmelt," Thermal Science and Engineering Progress, vol. 10, pp. 169-178, 2019.

Druschel, S. J. "Salt Brine Blending to Optimize Deicing and Anti-Icing Performance and Cost Effectiveness: Phase III," Minnesota Department of Transportation, St. Paul, MN, 2017.

Elhouar, S., D. Dragoo, Y. Khodair, Y. and Y.S. Lee, “Performance Evaluation of Snow and Ice Plows.” Illinois Center for Transportation/Illinois Department of Transportation. 2015.

Federal Highway Administration, “Chemical Deicers and Concrete Pavement: Impacts and Mitigation - Technical Brief,” Washington, DC: Federal Highway Administration, 2018.

Federal Highway Administration. “Leveraging Multiple Communications Systems for Vehicle-Based Data Sharing: Nevada Department of Transportation Case Study.” USDOT Federal Highway Administration. 2018.

Habibzadeh-Bigdarvish, O., X. Yu, G. Lei, T. Li and A. J. Puppala, "Life-Cycle Cost-Benefit Analysis of Bridge Deck De-Icing Using Geothermal Heat Pump System: A Case Study of North Texas," Sustainable Cities and Society, vol. 47, 2019.

Hajibabai, L., & Y. Ouyang, Dynamic Snow Plow Fleet Management Under Uncertain Demand and Service Disruption. IEEE Transactions on Intelligent Transportation Systems, 17(9), 2574-2582. 2016.

Hanke, H., P. Nutz, H, Maier-Farkas, J. Neuhold, J., et al. “International Development of Application Methods of De-Icing Chemicals-State of the Art and Best Practice.” No. 2019R08EN. 2019.

Heavey, J., T. A. Volk and P. A. Townsend, "Shrub Willows: An Ideal Plant Choice for Living Snow Fences with Multiple Benefits," Washington State University, 2018.

Helsel, M., B. Boyce, T. Poling, S. Sundararajan and P. Pisano, “Collaboration Across the Road Weather Enterprise: The Pathfinder Project.” No. FHWA-HOP-16-086. United States. Federal Highway Administration. 2016.

Hirt, B. "Liquid-Only Diet," Roads & Bridges, pp. 12-15, September 2011.

Hirt, B. & S. Petersen, “Installing Snow plow Cameras and Integrating Images into MnDOT’s Traveler Information System.” Minnesota Department of Transportation. 2017.

Hossain, S. M. K., L. Fu, T. Donnelly, Z. Lamb and M. Muresan, "Field Investigation of the Effectiveness of Prewetting Strategy for Snow and Ice Control of Transportation Facilities," Journal of Cold Regions Engineering, vol. 30, no. 3, 2016.

Hosseini, F., S. M. K. Hossain and L. Fu, "Bio-Based Materials for Improving Winter Pavement Friction," Canadian Journal of Civil Engineering, vol. 44, no. 2, pp. 99-105, 2016.

Jiang, C. “Evaluation of the Performance of Deicing and Anti-Icing Using Organic Alternative for Sustainable Winter Road Maintenance,” Ontario, Canada: Thesis Presented to the University of Waterloo, 2017.

Jungwirth, S. & X. Shi, "Laboratory Investigation of Naturally Sourced Liquid Deicers and Subsequent Decision Support," Journal of Cold Regions Engineering, vol. 31, no. 3, 2017.

Kaur, J. “Field Evaluation and Performance Analysis of Different Pre-Wetting Ratios for Sustainable Salting,” Ontario, Canada, 2018, p. 178.

Liu, J., J. Xu and S. Lu, "Investigations on Microwave Deicing Effects on Graphite-Modified Concrete," Royal Society of Chemistry - RSC Advances, vol. 7, 2017.

Maine Snow and Ice Control Best Practices Working Group, "Maine Environmental Best Management Practices Manual for Snow and Ice Control," Maine Snow and Ice Control Best Practices Working Group, 2015.

Miller, T., B. Gleichert, H. Crabtree, J. Hendershot, R. Nuveman and W. Schneider, "Role of Route Optimization in Benefiting Winter Maintenance Operations," Transportation Research Record, vol. 2672, no. 12, pp. 232-242, 2018.

Mirzanamadi, R., C.-E. Hagentoft, P. Johansson and J. Johnsson, "Anti-Icing of Road Surfaces Using Hydronic Heating Pavement with Low Temperatures," Cold Regions Science and Technology, vol. 145, pp. 106-118, 2018.

Muresan, M., S. M. K. Hossain, L. Fu and R. Xie, "A Survey of Current Winter Maintenance Practices for Parking Lots and Sidewalks in Municipalities in Canada and the United States," Transportation Research Board 96th Annual Meeting, Transportation Research Board, 2017.

Nar, S., B. Cortez, M. Atkins-Baker, A. Fecteau, and E. Stevens, Why street beets aren't available to all Calgarians yet. Published online 1/25/2019 in The Calgary Journal.

National Academies of Sciences, Engineering, and Medicine. "Integrating Social and Behavioral Sciences Within the Weather Enterprise." National Academies Press, Washington, DC. 2018.

Nazari, M. H., T. Oh, A. C. Ewing, D. A. Okon, Y. Zhang, B. Avalos, E. Alnuaimi, E. A. Havens and X. Shi, "Bio-Based Renewable Additives for Anti-Icing Applications," Center for Environmentally Sustainable Transportation in Cold Climates, Fairbanks, AK, 2018.

Nutile, S. A. & M. E. Solan, "Toxicity Test of "Eco-Friendly" De-Icing Formulations Using Chironomus Dilutus," Environmental Pollution, vol. 246, pp. 408-413, 2019.

Porter, L. W. "Training Video for the Implementation of Liquid-Only Plow Routes," Clear Roads Pooled Fund - Minnesota Department of Transportation, St. Paul, MN, 2018.

Quirion-Blais, O., A. Langevin, and M. Trépanier, "A Case Study of Combined Winter Road Snow Plowing and De-Icer Spreading." Canadian Journal of Civil Engineering, 44(12), pp.1005-1013. 2017.

Rao, R., J. Fu, Y. Chan, C. Y. Tuan and C. Liu, "Steel Fiber Confined Graphite Concrete for Pavement Deicing," Composites Part B, vol. 155, pp. 187-196, 2018.

Schneider, W., M. Crow, W.A. and Holik, "Investigate Plow Blade Optimization (No. FHWA/OH-2015/24)." Ohio Dept. of Transportation. Office of Statewide Planning and Research. 2015

Schneider IV, W. H., T. J. Cutright, M. J. Crow and A. Pelfrey, "Evaluation and Analysis of Liquid Deicers for Winter Maintenance," Federal Highway Administration Report Number 2017/30, Columbus, OH, 2017.

Sevigny, M. Snow season in Flagstaff pits snow-free roads against Ponderosa Pines. KNAU Marketplace. Published online January 1, 2016.

Shi, X. & L. Fu, Sustainable Winter Road Operations, Oxford, UK: Wiley Blackwell, 2018.

Stamatiadis, P., N. Gartner, Y. Xie, D. Chen, D., and R. Diaz Jr, "Evaluation and Enhancement of MassDOT Traveler Information Programs." Report No. 19-001. 2019.

Sullivan, J. & J. Dowds, "Emergency Operations Methodology for Extreme Winter Storm Events." University of Vermont, Burlington, VT. 2018.

Takahashi, N., K. Sato, R. A. Takunaga and N. Nakajima, "Laboratory and Field Evaluation of Sodium Propionate for Snow and Ice Control," in 96th Annual Meeting of the Transportation Research Board, Washington, DC, 2017.

Takahashi, N., K. Sato, R. Tokunaga, N. Nakajima, S. Yamanaka, and S. Kasamatsu, "Evaluation of Disodium Succinate Hexahydrate as an Alternative Deicer," in 97th Annual Meeting of the Transportation Research Board, Washington, DC, 2018.

Toth, C., M. Waisley, J. Schroeder, M. Omay, C. Castle, and S. Cook, “Michigan Department of Transportation (MDOT) Weather Responsive Traveler Information (Wx-TINFO) System-Final Report.” No. FHWA-JPO-16-323. 2016.

Toronto and Region Conservation Authority, “Evaluation of Organic Anti-Icing Materials for Winter Maintenance - Technical Brief,” Toronto, ON: Toronto and Region Conservation Authority, 2015.

Usman, T., L. Fu, C. Jiang and M. Perchanok, "Sustainable Traction with Winter Sand," in 96th Annual Meeting of the Transportation Research Board, Washington, DC, 2017.

Usman, T., L. Fu, J. Kaur, M. Perchanok, and H. McClintock, "Optimize Pre-Wetting for Sustainable Winter Road Maintenance." In TAC 2017: Investing in Transportation: Building Canada's Economy--2017 Conference and Exhibition of the Transportation Association of Canada. 2017.

Wojtowicz, J., & W.A. Wallace, “Use of Social Media by Transportation Agencies for Traffic Management.” Transportation Research Record, 2551(1), 82-89. 2016.

Xiao, D. X., S. Owusu-Ababio and R. Schmitt, "Evaluation of the Effects of Deicers on Concrete Durability," Wisconsin Department of Transportation, Madison, WI, 2018.

Xu, G., L. Sturges, M. Chapman, C. Albrecht, D. Bergner and X. Shi, "Snow Removal Performance Metrics," Transportation Research Record: Journal of the Transportation Research Board, vol. 2613, pp. 61-70, 2017.

Yu, X., A. Puppala & N. Zhang, "Use of Geothermal Energy for Deicing Approach Pavement Slabs and Bridge Decks, Phase 1: Final Report," University of Texas at Arlington, Arlington, TX, 2017.

Appendix A – Literature Review

This information gathered in the literature search was used to develop a summary document provided below. Sources of information are organized by area of relevance (e.g., State of the Practice, Route Optimization, etc.), and then ranked 1, 2, or 3 based on their relevance to this project. Sources ranked 1 have been reviewed in detail and the summary includes the title, reference, and a paragraph description of relevant information that will be used in the project. Sources ranked 2 or 3 have been reviewed and are determined to be generally relevant (2) or related (3) but may be too detailed or specific or slightly off topic. For sources ranked 2 or 3, the summary provides the title, reference, and key words for easy reference and later use. The sources ranked 2 will likely be used, while the sources ranked 3 may not be used. Fifteen documents were identified and ranked as key documents that will be used. Seventeen documents were identified and ranked as relevant documents that may or may not be used, and seven documents were identified and ranked as related documents that may or may not be used.

1	Key documents that will be used
2	Relevant documents that may or may not be used
3	Related documents that may or may not be used

Literature Review Update

State of the Practice

1 *A Survey of Current Winter Maintenance Practices for Parking Lots and Sidewalks in Municipalities of Canada and the United States*

M. Muresan, S. M. K. Hossain, L. Fu and R. Xie, "A Survey of Current Winter Maintenance Practices for Parking Lots and Sidewalks in Municipalities in Canada and the United States," Transportation Research Board 96th Annual Meeting, Transportation Research Board, 2017.

The paper, presented at the 96th Annual Meeting of the Transportation Research Board in January 2017, presents the results from an online survey of winter maintenance contractors and city and municipality agencies in 58 cities across the United States and Canada. The survey was designed to capture current trends in winter maintenance of sidewalks and parking lots, including snow control methods used, materials used, and application rates. For minor snow events (less than 5 cm of snow), most respondents performed some type of deicing (either plowing and salting or using salt only). Only 5 percent of these respondents were using a pre-salting method to reduce material use. For heavy snow events (more than 5 cm of snow), most respondents (70 percent) reported using plowing rather than applying salt. Other maintenance methods mentioned including treating sand with 5 percent salt and the use of potash. Most respondents used conventional chloride salts. Around 36 percent of respondents use pre-wetted salt for winter maintenance; typically, sodium chloride brine was used as the pre-wetting chemical. Nearly half of all respondents stated that they were unaware of the amount of material used on parking lots and sidewalks and that they did not have condition-specific maintenance standards.

Keywords: Survey of Practice, Sidewalks, Parking Lots, Materials, Methods, Application Rates

1 *Advances in Winter Maintenance Practices to Improve Roadside Safety*

D. Bergner, "Advances in Winter Maintenance Practices to Improve Roadside Safety," Transportation Research Circular Number E-C220, pp. 612-625, 2017.

Bergner examines best practices that transportation agencies use to efficiently restore safety and mobility after winter storm events and how these strategies can reduce winter weather related crashes. Basic descriptions of winter maintenance practices and technologies are given including improved weather forecasting and monitoring, changes in level of service, planning of snow control routes, dissemination of winter maintenance efforts to the public, training programs, and incorporating crash data into planning and preparation for upcoming winter season.

Keywords: State of the Practice, Methods

1 *Best Practices for Winter Maintenance Roadway Deicer Applications in the State of Nebraska*

T. P. D. Albers II, “Best Practices for Winter Maintenance Roadway Deicer Applications in the State of Nebraska,” Lincoln, NE, 2015, p. 99.

This thesis presented to the University of Nebraska analyzed data from a survey of winter maintenance personnel in Nebraska and compared the results with data from Maintenance Decision Support (MDSS) software to determine the current state of the practice in Nebraska. Survey results found that city and county maintenance personnel across the state prefer to use road salt or a mixture of 10 percent Ice Slicer with road salt. If products like Geomelt were used, ratios up to 20 percent Geomelt are preferred, as higher ratios were found to clog spreaders. Additionally, using pre-wetted salt was found to reduce solid material use by up to 25 percent. Ultimately a table of recommendations for deicer usage based on weather conditions and temperature was created based on survey results in order to provide a list of best practices for winter maintenance crews that are not a part of the Nebraska Department of Roads.

Keywords: Survey of Practice, Materials, Methods, Deicing, Recommendations

1 *Sustainable Winter Road Operations*

X. Shi and L. Fu, Sustainable Winter Road Operations, Oxford, UK: Wiley Blackwell, 2018.

This textbook edited by Shi and Fu examines how aspects of sustainability can be incorporated into the various aspects of winter maintenance operations. The triple bottom line approach suggests that an agency consider the environmental, economic, and social impacts of their actions. Of particular interest in this textbook is section 3, which covers decision-support guidelines, methods, and toolboxes covering everything from management and planning strategies, innovative practices like snow fences, anti-icing, and pre-wetting, to things like “green” materials and performance metrics.

Keywords: State of the Practice, Materials, Methods

1 *Maine Environmental Best Management Practices Manual for Snow and Ice Control*

Maine Snow and Ice Control Best Practices Working Group, "Maine Environmental Best Management Practices Manual for Snow and Ice Control," Maine Snow and Ice Control Best Practices Working Group, 2015.

This manual presents best management practices for a variety of winter maintenance topics: administrative, material selection, application process, application equipment, storage, and location specific.

Keywords: State of the Practice, Best Practices, Sustainability

3 *Chemical Deicers and Concrete Pavement: Impacts and Mitigation*

Federal Highway Administration, “Chemical Deicers and Concrete Pavement: Impacts and Mitigation - Technical Brief,” Washington, DC: Federal Highway Administration, 2018.

Keywords: State of the Practice, Deicers, Impacts, Pavement Deterioration

3 *Evaluation of the Effects of Deicers on Concrete Durability*

D. X. Xiao, S. Owusu-Ababio and R. Schmitt, "Evaluation of the Effects of Deicers on Concrete Durability," Wisconsin Department of Transportation, Madison, WI, 2018.

Keywords: State of the Practice, Survey of Practice, Deicers, Impacts, Pavement Deterioration, Brine, Freeze Guard, Beet 55, Pre-Wetting

3 *Preventive Measures for Corrosion of Deicers to metals: Need of the Hour*

S. G. Acharya, M. V. Sheladiya and G. D. Acharya, "Preventive Measures for Corrosion of Deicers to metals: Need of the Hour," CORCON, Rajasthan, India, 2018.

Keywords: State of the Practice, Survey of Practice, Deicers, Impacts, Metal Corrosion

Materials

Agriculturally Based

1 *Bio-Based Materials for Improving Winter Pavement Friction*

F. Hosseini, S. M. K. Hossain and L. Fu, "Bio-Based Materials for Improving Winter Pavement Friction," Canadian Journal of Civil Engineering, vol. 44, no. 2, pp. 99-105, 2016.

Hosseini et al. conducted field studies to examine the effectiveness of three bio-based alternatives to conventional salts. Materials tested included conventional brine (23 percent sodium chloride by mass), Snowmelt (bio-based), Fusion (mix of bio-based and chloride salt), and Caliber M1000 (mix of bio-based and chloride salt). Materials were tested using three application rates: 3, 6, and 9 L/1000 ft^2 and during differing weather conditions. Results of this study found that bio-based materials resulted in 10 to 40 percent improvement in road friction levels. Results show that application rates tested did not indicate significant differences, therefore a rate as low as 3L/1000 ft^2 could be used, making bio-based

alternatives an attractive alternative to reduce material usage. Pavement surface temperature is a significant factor in the performance. Brine and Caliber M1000 performed well in warmer conditions, whereas Snowmelt performed better in colder conditions. Fusion was not significantly affected by pavement surface temperature.

Keywords: Materials, Agro-Based, Bio-Based, Snowmelt, Fusion, Caliber M1000

1 *Bio-Based Renewable Additives for Anti-Icing Applications (Phase II)*

M. H. Nazari, T. Oh, A. C. Ewing, D. A. Okon, Y. Zhang, B. Avalos, E. Alnuaimi, E. A. Havens and X. Shi, "Bio-Based Renewable Additives for Anti-Icing Applications," Center for Environmentally Sustainable Transportation in Cold Climates, Fairbanks, AK, 2018.

Nazari et al. examined bio-based chemicals in snow and ice control operations and developed an innovative anti-icing solution using beet sugar refining by-products and other bio-based additives. The addition of bio-based additives to salt brines helps improve anti-icing and deicing performance at colder temperatures and can reduce application rates as well as environmental impacts. Nazari et al. developed several bio-based liquid anti-icing products for use in winter maintenance operations depending on costs and impacts. Twenty-one anti-icing mixtures with bio-based additives including concord grape extract, glycerol, sodium formate, and sodium metasilicate were analyzed in this study. The best-performing mixture was chosen based on its ice-melting capacity. Overall, the best-performer was a mixture of 0.89 percent concord grape extract, 4.57 percent glycerin, 4.54 percent sodium formate, 0.19 percent sodium metasilicate, 18.4 percent sodium chloride, and water. This mixture outperformed all other mixtures on ice-melting capacity and had half the chemical oxygen demand of a traditional beet juice blend.

Keywords: Materials, Agro-Based, Bio-Based, Anti-Icing

1 *Evaluation of the Performance of Deicing and Anti-Icing Organic Alternatives for Sustainable Winter Road Maintenance*

C. Jiang, “Evaluation of the Performance of Deicing and Anti-Icing Using Organic Alternative for Sustainable Winter Road Maintenance,” Ontario, Canada: Thesis Presented to the University of Waterloo, 2017.

Jiang examines the performance of two organic agricultural-based products, Fusion and Geomelt, for deicing and anti-icing. The performance of these two products was field tested and the results compared against traditional salt brine. The results of the field testing found that salts that were prewetted with an agricultural-based product performed similarly to regular salt brine. When using agricultural-based products as an additive to brines for direct liquid application (DLA), these blended products outperformed traditional salt brine, and at a lower application rate (half of that used for salt brine). In addition, the agricultural-based products were able to maintain a higher level of traction for longer periods of time when compared to traditional salt brine. Finally, in general the field tests showed

that anti-icing through the use of direct liquid application had the greatest benefits for snow and ice control.

Keywords: Materials, Agro-Based, Bio-Based, Anti-Icing, Direct Liquid Application

2 *Evaluation of Organic Anti-Icing Materials for Winter Maintenance*

Toronto and Region Conservation Authority, "Evaluation of Organic Anti-Icing Materials for Winter Maintenance - Technical Brief," Toronto, ON: Toronto and Region Conservation Authority, 2015.

Keywords: Materials, Agro-Based, Bio-Based, Brine, Fusion 2350, Snowmelt, Caliber M1000

3 *Toxicity Test of "Eco-Friendly" De-Icing Formulations Using Chironomus Dilutus*

S. A. Nutile and M. E. Solan, "Toxicity Test of "Eco-Friendly" De-Icing Formulations Using Chironomus Dilutus," Environmental Pollution, vol. 246, pp. 408-413, 2019.

Keywords: Materials, Agro-Based, Bio-Based, Calcium Chloride, Snow Joe, Beet Juice, Urea

Liquids

1 *Evaluation and Analysis of Liquid Deicers for Winter Maintenance*

W. H. Schneider IV, T. J. Cutright, M. J. Crow and A. Pelfrey, "Evaluation and Analysis of Liquid Deicers for Winter Maintenance," Federal Highway Administration Report Number 2017/30, Columbus, OH, 2017.

Schneider et al. conducted field and laboratory tests to evaluate the effectiveness of eight liquid deicers for potential use in the State of Ohio. Deicers tested included: Aquasalina, XO Melt 2, BeetHeat Severe, AQ+Icebyte, IceBan 205, BeetHeat Concentrate, Thermapoint 793, and Cryotech CF7. Schneider et al. recommend the use of traditional brine when the temperature is warmer than 21°F. When temperatures are between 15°F and 21°F, a solution of 30% Thermapoint 793 and brine was found to be effective and economical. When temperatures drop between 0°F and 15°F, using pure Thermapoint 793 was found to be the most effective and economical liquid deicer. Thermapoint 793 is estimated to cost an average of $0.85 per gallon or $26.89 per mile.

Keywords: Materials, Liquid Deicers

1 *International Development of Application Methods of Deicing Chemicals – State of the Art and Best Practice*

Hanke, H., Nutz, P., Maier-Farkas, H., Neuhold, J., et al. "International Development of Application Methods of De-Icing Chemicals-State of the Art and Best Practice." No. 2019R08EN. 2019.

In this World Road Association (PIARC) report, Hanke et al. present results of a survey of winter maintenance practices in countries represented in PIARC in order to gain an understanding of current standards, deicing chemicals, and application methods. A total of 25 surveys from 16 countries were

received. Results found that the use of brine has increased across all countries, particularly for preventative snow and ice control. Pre-wet is the standard for winter maintenance with all respondent countries reporting positive experiences.

Keywords: Materials, Liquid Deicers, International, State of the Art, Brine, Pre-Wet

1 *Salt Brine Blending to Optimize Deicing and Anti-Icing Performance and Cost Effectiveness: Phase III*

S. J. Druschel, "Salt Brine Blending to Optimize Deicing and Anti-Icing Performance and Cost Effectiveness: Phase III," Minnesota Department of Transportation, St. Paul, MN, 2017.

Druschel examined deicers and anti-icers as well as plowing through field tests to determine which factors such as traffic volume, moisture content, and distribution have an impact on winter maintenance performance. Field testing showed that a majority of deicer loss on the roadway is from traffic-induced spray or plowing efforts. Deicers were more effective at warmer temperatures (above 10^{o}F). No significant differences were found between prewet and traditional deicer performance. Finally, traffic, through the interaction of tire pressure and deicer, was found to cause significant improvements in deicer performance.

Keywords: Materials, Liquid Deicers, Anti-Icers, Snow plows

2 *Laboratory Investigation of Naturally Sourced Liquid Deicers and Subsequent Decision Support*

S. Jungwirth and X. Shi, "Laboratory Investigation of Naturally Sourced Liquid Deicers and Subsequent Decision Support," Journal of Cold Regions Engineering, vol. 31, no. 3, 2017.

Keywords: Materials, Liquid Deicers, Naturally-Sourced, Agro-Based, Bio-Based

Pavement Treatments

2 *Anti-Icing of Road Surfaces Using Hydronic Heating Pavement with Low Temperatures*

R. Mirzanamadi, C.-E. Hagentoft, P. Johansson and J. Johnsson, "Anti-Icing of Road Surfaces Using Hydronic Heating Pavement with Low Temperatures," Cold Regions Science and Technology, vol. 145, pp. 106-118, 2018.

Keywords: Materials, Deicing, Pavement Treatments, Heated Pavement, Hydronic Heating Pavement

2 *Development of Automated Electrical Heat Grid for Pavement Snowmelt*

J. W. Daniels III, E. Heymsfield, R. F. Saunders and M. L. Kuss, "Development of Automated Electrical Heat Grid for Pavement Snowmelt," Thermal Science and Engineering Progress, vol. 10, pp. 169-178, 2019.

Keywords: Materials, Pavement Treatments, Heated Pavement, Electrical Heating Grid

2 *Life-Cycle Cost-Benefit Analysis of Bridge Deck De-Icing Using Geothermal Heat Pump System: A Case Study of North Texas*

O. Habibzadeh-Bigdarvish, X. Yu, G. Lei, T. Li and A. J. Puppala, "Life-Cycle Cost-Benefit Analysis of Bridge Deck De-Icing Using Geothermal Heat Pump System: A Case Study of North Texas," Sustainable Cities and Society, vol. 47, 2019.

Keywords: Materials, Pavement Treatments, Geothermal Energy

2 *Use of Geothermal Energy for Deicing Approach Pavement Slabs and Bridge Decks, Phase 1: Final Report*

X. Yu, A. Puppala and N. Zhang, "Use of Geothermal Energy for Deicing Approach Pavement Slabs and Bridge Decks, Phase 1: Final Report," University of Texas at Arlington, Arlington, TX, 2017.

Keywords: Materials, Pavement Treatments, Geothermal Energy, Bridges

2 *Pavement Surface Treatments for Ice-Prone Locations in the Illinois Highway System*

M. Akin, Y. Zhang and X. Shi, "Pavement Surface Treatments for Ice-Prone Locations in the Illinois Highway System," Illinois Center for Transportation, Springfield, IL, 2018.

Keywords: Materials, Pavement Treatments, Ice-Prone Locations, Built-In Technologies, Superhydrophobic Treatments

2 *Review of Ice-Pavement Adhesion Study and Development of Hydrophobic Surface in Pavement Deicing*

H. Chen, Y. Wu, H. Xia, B. Jing and Q. Zhang, "Review of Ice-Pavement Adhesion Study and Development of Hydrophobic Surface in Pavement Deicing," Journal of Traffic and Transportation Engineering, vol. 5, no. 3, pp. 224-238, 2018.

Keywords: Materials, Methods, Pavement Treatments, Hydrophobic Treatments

3 *Investigations on Microwave Deicing Effects on Graphite-Modified Concrete*

J.-l. Liu, J.-y. Xu and S. Lu, "Investigations on Microwave Deicing Effects on Graphite-Modified Concrete," Royal Society of Chemistry - RSC Advances, vol. 7, 2017.

Keywords: Materials, Methods, Pavement Treatments, Microwave Deicing

3 *Steel Fiber Confined Graphite Concrete for Pavement Deicing*

R. Rao, J. Fu, Y. Chan, C. Y. Tuan and C. Liu, "Steel Fiber Confined Graphite Concrete for Pavement Deicing," Composites Part B, vol. 155, pp. 187-196, 2018.

Keywords: Materials, Pavement Treatments, Electrical Heated Concrete

3 *Superhydrophobic Coatings on Asphalt Concrete Surfaces: Toward Smart Solutions for Winter Pavement Maintenance*

A. Arabzadeh, H. Ceylan, S. Kim, K. Gopalakrishnan and A. Sassani, "Superhydrophobic Coatings on Asphalt Concrete Surfaces: Toward Smart Solutions for Winter Pavement Maintenance," Transportation Research Record: Journal of the Transportation Research Board, vol. 2551, pp. 10-17, 2016.

Keywords: Materials, Pavement Treatments, Hydrophobic Treatments, Polytetrafluoroethylene

Sand

1 *Sustainable Traction with Winter Sand*

T. Usman, L. Fu, C. Jiang and M. Perchanok, "Sustainable Traction with Winter Sand," in 96th Annual Meeting of the Transportation Research Board, Washington, DC, 2017.

Usman et al. conducted field tests to examine the performance of pre-wet sand versus conventional dry sand for improving friction on pavement surfaces during winter weather conditions. Additional field testing was conducted to determine the rate of pre-wet sand that would provide similar results to traditional dry sand. Results show that a pre-wet sand rate of 485 Kg/2-Ln-Km had similar friction values to conventional dry sand applied at 570 Kg/2-Ln-Km, resulting in a 20 percent reduction in the use of sand.

Keywords: Materials, Sand, Friction, Methods, Pre-Wetting

Sodium Propionate

2 *Laboratory and Field Evaluation of Sodium Propionate for Snow and Ice Control*

N. Takahashi, K. Sato, R. A. Takunaga and N. Nakajima, "Laboratory and Field Evaluation of Sodium Propionate for Snow and Ice Control," in 96th Annual Meeting of the Transportation Research Board, Washington, DC, 2017.

Keywords: Materials, Sodium Propionate

Sodium Succinate

2 *Evaluation of Disodium Succinate Hexahydrate as an Alternative Deicer*

N. Takahashi, K. Sato, R. Tokunaga, N. Nakajima, S. Yamanaka, and S. Kasamatsu. "Evaluation of Disodium Succinate Hexahydrate as an Alternative Deicer," in 97th Annual Meeting of the Transportation Research Board, Washington, DC, 2018.

Keywords: Materials, Deicer, Sodium Succinates, Disodium Succinate Hexahydrate

Methods

Communications

1

Collaboration Across the Road Weather Enterprise: The Pathfinder Project

Helsel, M., Boyce, B., Poling, T., Sundararajan, S., & Pisano, P. "Collaboration Across the Road Weather Enterprise: The Pathfinder Project." No. FHWA-HOP-16-086. United States. Federal Highway Administration. 2016.

Dissemination of weather information and its impacts to road networks can improve safety, mobility, and productivity of the transportation system. The Federal Highway Administration (FHWA) Road Weather Management Program and the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) worked together to document the state of the practice for collaboration between State Departments of Transportation and the weather enterprise (both public and private). This report documents best practices to disseminate road weather information and for collaborating with the weather enterprise. The Pathfinder project, which began in 2014, was a pilot project across California, Nevada, Utah, and Wyoming. This project documented current collaborations between State DOTs and the weather enterprise, with a focus on the I-80 corridor. This report presents seven guidance steps for improving collaboration between State DOTs and weather enterprise: (1) identify partners, (2) determine qualifying collaboration events, (3) select communication mediums and set procedures, (4) establish a point person at each participating entity, (5) synchronize forecast schedules, (6) establish definitions and create shared resources, and (7) create shared impact messages for the public.

Keywords: Methods, Communications, Pathfinder Project, Weather Enterprise

1

Installing Snow plow Cameras and Integrating Images into MnDOT's Traveler Information System

Hirt, B. and Petersen, S. "Installing Snow plow Cameras and Integrating Images into MnDOT's Traveler Information System." Minnesota Department of Transportation. 2017.

In an effort to provide real-time information on current weather and road conditions, the Minnesota Department of Transportation (MnDOT) installed video dash cameras and ceiling-mounted cameras on 226 snow plows during the 2015-2016 winter season. Images captured by these cameras were uploaded in near-real-time to MNDOT's traveler information website and MnDOT's 511 mobile app for the traveling public. Post-implementation, MnDOT surveyed snow plow drivers and their supervisors to gather lessons learned. Most snow plow drivers did not consider the cameras to be a distraction, though supervisors tended to express more positive reactions to the cameras when compared to the snow plow drivers. Lessons learned through this survey process encouraged MnDOT to reach out to snow plow drivers and their supervisors to communicate the benefits of the cameras for the traveling public and to discuss issues of privacy. MnDOT has recommended additional snow plows be equipped with cameras to continue to provide images on the state's traveler information system.

Keywords: Methods, Communications, Traveler Information Systems, Snow plow, Cameras

1 *FHWA Weather-Savvy Roads: Leveraging Multiple Communications Systems for Vehicle-Based Data Sharing: Nevada Department of Transportation Case Study*

USDOT Federal Highway Administration. "Leveraging Multiple Communications Systems for Vehicle-Based Data Sharing: Nevada Department of Transportation Case Study." USDOT Federal Highway Administration. 2018.

Since 2011 the Nevada Department of Transportation has been piloting a hybrid communications platform for integrated mobile observations (IMO). This platform uses dedicated short-range communications (DSRC), cellular, wi-fi, and radio communications technology to improve information dissemination and reduce costs through leveraging existing communications infrastructure. Using this hybrid communication platform, Nevada DOT was able to improve communications and road weather data in the Reno, Carson City, and Lake Tahoe areas.

Keywords: Methods, Communications

1 *Use of Social Media by Transportation Agencies for Traffic Management*

Wojtowicz, J., & Wallace, W. A. "Use of Social Media by Transportation Agencies for Traffic Management." Transportation Research Record, 2551(1), 82-89. 2016.

Social media is increasingly becoming a channel to disseminate real-time information to a large number of people. In this paper, Wojtowicz & Wallace examine how social media is being used to support traffic management efforts during planned and unplanned events and identify best practices for disseminating real-time information to the traveling public using social media. The social media usage and communications plan of the Washington State Department of Transportation (WSDOT) are examined as a case study. Twitter has enabled WSDOT to reach out and interact with the public to provide real-time traffic updates, which have received favorable responses from the public.

Keywords: Methods, Communications, Social Media, Traffic Management, Public Expectations

2 *Integrating Social and Behavioral Sciences Within the Weather Enterprise*

National Academies of Sciences, Engineering, and Medicine. "Integrating Social and Behavioral Sciences Within the Weather Enterprise." National Academies Press, Washington, DC. 2018.

Keywords: Methods, Communications, Weather Enterprise, Weather Forecasting, Social and Behavior Science, Weather Hazard Response, Improving Communication

2 *Evaluation and Enhancement of MassDOT Traveler Information Programs*

Stamatiadis, P., Gartner, N., Xie, Y., Chen, D., & Diaz Jr, R. "Evaluation and Enhancement of MassDOT Traveler Information Programs." Report No. 19-001. (2019).

Keywords: Methods, Communications, Traveler Information Systems, Traffic Management, Real-Time Information, Public Expectations

2 *Emergency Operations Methodology for Extreme Winter Storm Events*

Sullivan, J. and Dowds, J. "Emergency Operations Methodology for Extreme Winter Storm Events." University of Vermont, Burlington, VT. 2018.

Keywords: Methods, Communications, Response Plans

2 *Michigan Department of Transportation Weather Responsive Traveler Information System*

Toth, C., Waisley, M., Schroeder, J., Omay, M., Castle, C., & Cook, S. "Michigan Department of Transportation (MDOT) Weather Responsive Traveler Information (Wx-TINFO) System-Final Report." No. FHWA-JPO-16-323. 2016.

Keywords: Methods, Communications, Traveler Information Systems, Road Condition Reporting, Mobile Data Collection

Level of Service Changes

1 *Levels of Service in Winter Maintenance Operations: A Survey of State Practice*

CTC & Associates LLC. "Levels of Service in Winter Maintenance Operations: A Survey of State Practice." Clear Roads Pooled Fund Study. 2009.

Level of service is often used to coordinate winter maintenance operations. This Clear Roads Pooled Fund Study examined how states use level of service in their winter maintenance operations. A survey was conducted in 2007; 14 state departments of transportation, 1 township, and 1 Canadian agency responded. Survey responses found that half of the agencies were using service level classification that related to average daily traffic; other methods used to determine level of service included corridor significance and road classifications (bare pavement, etc.). Sixty-nine percent of respondents used bare pavement or a similar indicator as a performance measure. A quarter of respondents did not use any performance measures in their winter maintenance operations.

Keywords: Methods, Level of Service, Survey of the Practice

2 *The Winter Model - A New Way to Calculate Socio-Economic Costs Depending on Winter Maintenance Strategy*

A. K. Arvidsson, "The Winter Model - A New Way to Calculate Socio-Economic Costs Depending on Winter Maintenance Strategy," Cold Regions Science and Technology, vol. 136, pp. 30-36, 2017.

Keywords: Methods, Level of Service, Socio-Economic Factors

Liquid-Only Plow Routes

1 *Liquid-Only Diet*

B. Hirt, "Liquid-Only Diet," Roads & Bridges, pp. 12-15, September 2011.

In this article for Roads & Bridges, Hirt examines the benefits of direct liquid application (DLA) for winter maintenance. DLA offers benefits of reduced environmental impact, reductions in material use, cost savings, and improved effectiveness over solid chemicals. In Utah, DLA is being used on a mountain pass on I-80 both before and during winter storms along with plowing with great success. Utah Department of Transportation conducted a level-of-service study on this stretch of road and earned an A (outperforming other routes that still rely on solid salts); in addition, maintenance crews see the added benefits of less labor and a reduction in material use. In colder conditions, Utah Department of Transportation will add 5% calcium chloride into the brine mixture to depress the freezing point to -10°F. A previous study conducted by Clear Roads found that the decision to use DLA came down to three factors (1) pavement temperature, (2) storm intensity, and (3) moisture content. In general DLA works best at temperatures greater than 25°F and in storm conditions with rates around 1 inch of snow per hour. DLA works better for storms with dry to average moisture content; with wet snow DLA has the tendency to be diluted quickly.

Keywords: Methods, Direct Liquid Application, Liquid-Only Routes

2 *The Future of Winter Maintenance Involved Liquid Only Strategies*

Dane County Department of Land and Water Resources, "The Future of Winter Maintenance Involved Liquid Only Strategies," Dane County Department of Land and Water Resources, WI, 2017.

Keywords: Methods, Direct Liquid Application, Liquid-Only Routes

2 *Training Video for the Implementation of Liquid-Only Plow Routes*

L. W. Porter, "Training Video for the Implementation of Liquid-Only Plow Routes," Clear Roads Pooled Fund - Minnesota Department of Transportation, St. Paul, MN, 2018.

Keywords: Methods, Direct Liquid Application, Liquid-Only Routes

Performance Metrics

1 *Snow Removal Performance Metrics*

G. Xu, L. Sturges, M. Chapman, C. Albrecht, D. Bergner and X. Shi, "Snow Removal Performance Metrics," Transportation Research Record: Journal of the Transportation Research Board, vol. 2613, pp. 61-70, 2017.

Performance metrics can help a transportation agency measure level of service, compare service across regions or over time to benchmark performance, and optimize limited funding. Xu et al. examined performance measures used by transportation agencies for winter maintenance through a literature review and a survey of 51 transportation agencies across the United States, Canada, and Europe. Restoring safety and mobility was the most commonly reported goal in the literature review and survey responses. The most commonly reported performance metric used to achieve this goal is time to reach the established level of service criteria. Many survey respondents stated an interest in severity index

related performance metrics that would allow for better comparison of winter maintenance operations from storm to storm or season to season.

Keywords: Methods, Performance Metrics

Pre-Wetting

1 *Field Investigation of the Effectiveness of Prewetting Strategy for Snow and Ice Control of Transportation Facilities*

S. M. K. Hossain, L. Fu, T. Donnelly, Z. Lamb and M. Muresan, "Field Investigation of the Effectiveness of Prewetting Strategy for Snow and Ice Control of Transportation Facilities," Journal of Cold Regions Engineering, vol. 30, no. 3, 2016.

Prewetting salt or mixing salt with a liquid before application can increase the moisture content of the salt, reduce salt bounce on the roadway, and result in cost savings for winter maintenance. Despite its benefits, little research has been conducted to analyze the performance of prewetted salt in real-world conditions. Hossain et al. conducted field studies to test the performance of conventional dry salt and prewetted salt for snow and ice control. Field tests were conducted under a variety of winter weather conditions to compare the snow melting performance of regular dry salt vs. prewetted salts in terms of the time it took to regain bare pavement. The results found that prewetted salt performed similarly to dry salt but required 20 percent less material. However, the benefits of prewetted salt decrease as the amount of snow on the pavement increases.

Keywords: Methods, Pre-Wetting

1 *Developing Friction Data to Support the Optimal Use of Pre-Wet Deicing Salt for Enhanced Winter Mobility*

M. Akin, Y. Zhang and X. Shi, "Developing Friction Data to Support the Optimal Use of Pre-Wet Deicing Salt for Enhanced Winter Mobility," Center for Advanced Multimodal Mobility Solutions and Education, Charlotte, NC, 2018.

Prewetting deicers provide a cost-effective method to improve deicer performance by improving ice melting abilities and reducing bounce and scatter of material. While prewet deicers are being used by many agencies, there has been little analysis into determining the best prewet ratios, rates, or product type. Akin et al. conducted a literature review and a survey of winter maintenance agencies in the pacific northwest states to examine the current state of prewetting practices. The most common liquid-to-solid ratio used by respondents was 10-12 gallons per ton (46%). Around 30% were using ratios of 15-30 gallons per ton. Prewet application rates varied from 100 to 450 pounds per lane mile for salt, though some agencies alter their application rates depending on temperature or snowfall rate. Akin et al. tested these findings in the laboratory and found that prewet liquid-to-solid ratios from 8 to 16 gallons per ton were able to improve the ice melting capacity of solid salts.

Keywords: Methods, Pre-Wetting

1 *Field Evaluation and Performance Analysis of Different Pre-Wetting Ratios for Sustainable Salting*

J. Kaur, "Field Evaluation and Performance Analysis of Different Pre-Wetting Ratios for Sustainable Salting," Ontario, Canada, 2018, p. 178.

Kaur examined the performance of salt at various pre-wet ratios of 10% and 20%, as a comparison with the Ministry of Transportation Ontario's current standard ratio of 5%. Each ratio was tested based on friction, amount of material used, and road surface condition. Results from field studies found that the higher prewet ratios of 10% and 20% improved friction levels by 11% and 15% respectively when compared to the standard 5% ratio. The 10% ratio used 13% more salt and reduced sand usage by 22% when compared to the standard 5% ratio. The 20% ratio used 19% less salt and reduced sand usage by 35% when compared to the standard 5% ratio. A visual analysis of the road conditions found that the 20% ratio had less snow coverage when compared to the other ratios.

Keywords: Methods, Pre-Wetting, Ratios

2 *Optimize Pre-Wetting for Sustainable Winter Road Maintenance*

Usman, T., L. Fu, J. Kaur, M. Perchanok, and H. McClintock. "Optimize Pre-Wetting for Sustainable Winter Road Maintenance." In TAC 2017: Investing in Transportation: Building Canada's Economy--2017 Conference and Exhibition of the Transportation Association of Canada. 2017.

Keywords: Methods, Pre-Wetting, Ratios

Mechanical Methods

1 *Cost-Benefit Analysis of Using the Tow Plow for Winter Maintenance*

Bandara, N. & Jensen, E. "Cost–Benefit Analysis of Using the Tow Plow for Winter Maintenance." Transportation Research Board 97th Annual Meeting, Washington, DC. 2017.

A Tow Plow or trailer mounted snow plow allows for a snow plow to maintain two roadway lanes in a single pass. A Tow Plow can optimize winter maintenance operations by reducing the time necessary to clear the roadway. Bandara and Jensen analyzed data from the 2013-2014 winter season to determine the benefits of using a Tow Plow vs. not using one for four-lane and six-lane freeways in rural Michigan. The authors found that using a Tow Pow significantly lowered the amount of time needed to maintain the roadway resulting in lower total delay costs to the public. The authors found that using a Tow Plow was particularly beneficial when storm precipitation was greater than 3.5 inches. The cost benefit analysis found that using a Tow Plow can result in significant savings for the Michigan Department of Transportation.

Keywords: Mechanical Methods, Plowing, Tow Plow, Cost-Benefit Analysis

1 *Using Mechanical Ice Breakers to Improve Snow and Ice Removal Operations*

Bennett, D. (2016). "Using Mechanical Ice Breakers to Improve Snow and Ice Removal Operations." Caltrans Division of Research, Innovation and System Information.

California Department of Transportation (Caltrans) maintains over 9,000 miles of lane miles each winter season. Caltrans currently experiences conditions where hardpack snow and ice bond to the pavement, resulting in a hard layer of ice that makes conventional removal difficult. Caltrans uses both brine and granular salt with brine to help facilitate ice removal with a snow plow. In an effort to reduce winter maintenance costs and the use of salt, Caltrans has begun to consider alternative methods. In this paper, Bennett conducted a survey of state DOTs to determine the state of the practice for mechanical ice breaking. The results show that current ice breaking methods are varied and tend to be tailored to an individual department's conditions and needs. Current methods used by states include segmented flexible plow blades, multiple-blade plows, and underbody scrapers.

Keywords: Mechanical Methods, Ice Breakers, State of the Practice

1 *Improved Deicing Methods for Snow and Ice Removal: Evaluation of the Epoke Sander/Spreader for Caltrans Operations*

Chebot, D., White, W., and Velinsky, S. (2015). "Improved Deicing Methods for Snow and Ice Removal: Evaluation of the Epoke Sander/Spreader for Caltrans Operations." Caltrans Division of Research, Innovation and System Information.

In this report for Caltrans, Chebot et al. assessed the differences between the Epoke spreader and the agency's current fleet of V-Box spreaders to determine if Caltrans should upgrade its fleet. The authors compared material spread, material uniformity, and ease of use for both spreaders. Tests show that the V-Box spreaders had a more erratic material spread resulting in some areas receiving more material than others. The Epoke spreader resulted in a more uniform spread of material and was estimated to result in a 25 percent decrease in materials usage over the 10-year life span of the spreader. As a result of this research, Caltrans plans to update its fleet to include the Epoke spreader, which will allow Caltrans to use new methods like liquid and pre-wet spreading. In addition, the new Epoke spreaders have sensors that would allow Caltrans to track material usage and vehicle locations.

Keywords: Mechanical Methods, Snow plow, Sander, Spreader, Epoke Spreader, V-Box Spreader

1 *Performance Evaluation of Snow and Ice Plows*

Elhouar, S., Dragoo, D., Khodair, Y. and Lee, Y.S. "Performance Evaluation of Snow and Ice Plows." Illinois Center for Transportation/Illinois Department of Transportation. 2015.

In this report Elhouar et al. present a literature review and survey of winter maintenance professionals to determine best practices for snow and ice control. Results show that in general a plow experiences higher stresses when plowing concrete pavement vs. asphalt pavement. Using an underbody scraper with a front body plow was considered most effective in clearing the road during heavy snow events. However, winter maintenance involved several parameters that can affect performance. Elhouar et al.

recommend a follow-up project to examine trends in plow operations in order to optimize snow and ice removal.

Keywords: Mechanical Methods, Snow plow, Ice plow, Plow Blades, Performance

1 *Investigate Plow Blade Optimization*

Schneider, W., Crow, M., and Holik, W. A. (2015). "Investigate Plow Blade Optimization (No. FHWA/OH-2015/24)." Ohio Dept. of Transportation. Office of Statewide Planning and Research.

Schneider et al. examined the snow removal effectiveness of five different plow blades for Ohio DOT: hardened steel, carbide tipped, JOMA, PolarFlex, and BlockBuster XL Classic. The plow blades were tested across six maintenance garages across the state of Ohio for two winter seasons. In addition to video captured to show the effectiveness of each blade type, data was collected on average wear per mile used. Data showed that ODOT could achieve cost savings with any plow blade except the carbide tipped blade and the standard hardened steel blade with no counterbalance. ODOT could see an average savings of $778 per PolarFlex blade and $426 per BlockBuster XL Classic blade vs. the standard hardened steel blade.

Keywords: Mechanical Methods, Snow plow, Plow Blades

2 *Evaluating the Use of Tow Plows in Michigan*

Bandara, N., Jensen, E. and Holt, F. "Evaluating the Use of Tow Plows in Michigan (No. SPR-1623)." Lawrence Technological University, Department of Civil and Architectural Engineering. 2016.

Keywords: Mechanical Methods, Plowing, Tow Plow

Route Optimization

1 *Role of Route Optimization in Benefiting Winter Maintenance Operations*

T. Miller, B. Gleichert, H. Crabtree, J. Hendershot, R. Nuveman and W. Schneider, "Role of Route Optimization in Benefiting Winter Maintenance Operations," Transportation Research Record, vol. 2672, no. 12, pp. 232-242, 2018.

The Ohio Department of Transportation (ODOT) uses a fleet of 1,600 snow plows to maintain their roadways during the winter season. Traditionally, county boundaries served as maintenance boundaries for ODOT fleets. In this paper, Miller et al. explored removing these boundaries to better optimize snow plow routes in order to decrease the amount of time it takes to treat roads and reduce costs. Route optimization models (ROM) were created using ESRI's ArcGIS vehicle route problem – this software allowed the authors to examine optimal routes to meet level of service requirements. For analysis, ODOT Districts 1, 2, and 10 were used to test the model. The results show that optimizing snow plow routes can decrease the time required to treat the road and reduce the necessary fleet size. In addition, the route optimization model showed that by adding new maintenance facilities the optimized fleets could provide a greater level of service in the study districts.

Keywords: Methods, Route Optimization, ESRI ArcMap

1 *Dynamic Snow Plow Fleet Management Under Uncertain Demand and Service Disruption*

Hajibabai, L., & Ouyang, Y. (2016). Dynamic Snow Plow Fleet Management Under Uncertain Demand and Service Disruption. IEEE Transactions on Intelligent Transportation Systems, 17(9), 2574-2582.

Hajibabai and Ouyang examine a modelling method that integrates the random nature of winter storms (state time, location, severity, etc.) in order to minimize maintenance vehicle deployment times and maximize benefits. The model was tested in a real-world scenario in Lake County, Illinois showing that the model is able to solve fleet optimization problems effectively.

Keywords: Methods, Route Optimization

2 *A Case Study of Combined Winter Road Snow Plowing and De-Icer Spreading*

Quirion-Blais, O., Langevin, A. and Trépanier, M. "A Case Study of Combined Winter Road Snow Plowing and De-Icer Spreading." Canadian Journal of Civil Engineering, 44(12), pp.1005-1013. 2017.

Keywords: Methods, Route Optimization, Dual Demand Routing

2 *Snow and Ice Removal Route Optimization in Kentucky*

B. Blandford, E. Lammers and E. Green, "Snow and Ice Removal Route Optimization in Kentucky," Transportation Research Record: Journal of the Transportation Research Board, vol. 2672, no. 45, pp. 294-304, 2018.

Keywords: Methods, Route Optimization, ESRI ArcMap

Snow Fences

2 *Shrub Willows: An Ideal Plant Choice for Living Snow Fences with Multiple Benefits*

J. Heavey, T. A. Volk and P. A. Townsend, "Shrub Willows: An Ideal Plant Choice for Living Snow Fences with Multiple Benefits," Washington State University, 2018.

Keywords: Methods, Snow Fences, Vegetation

Appendix B – Survey

Survey Questionnaire

Survey Results

In total, 91 surveys were collected; 83 were collected via Qualtrics and 8 paper surveys were collected. Location information was captured for 69 survey responses. These surveys represent six countries including the United States, Canada, Denmark, Norway, Russia, and South Korea (see Figure 35. Total Responses by Country). Fifty-eight respondents were located within the United States and seven within Canada. Responses were received from 28 states and 2 Canadian provinces (see Figure 36).

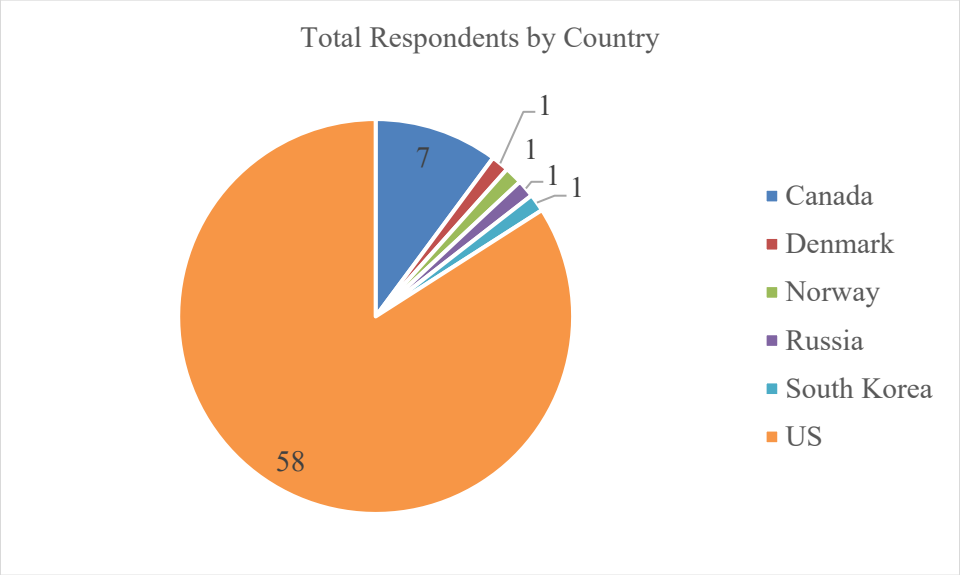

Figure 35. Total Responses by Country

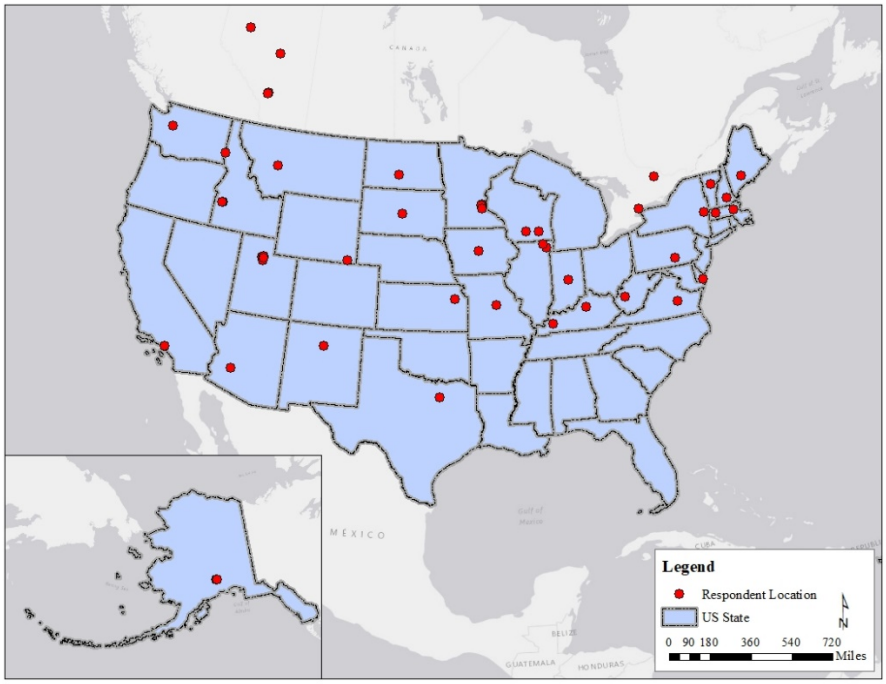

Figure 36. Locations of US and Canadian Respondents

Respondent Agency Type and Job Title

Respondents were asked to provide information on their agency and job title. All ninety-one respondents provided information on their agency type. Most respondents (66 percent) were working with a state Department of Transportation (DOT), see Figure 37. Fourteen respondents replied "Other"; text entries from these respondents included Canadian Provincial Agencies, Universities or Research Institutes, and Private Companies, see Table 5.

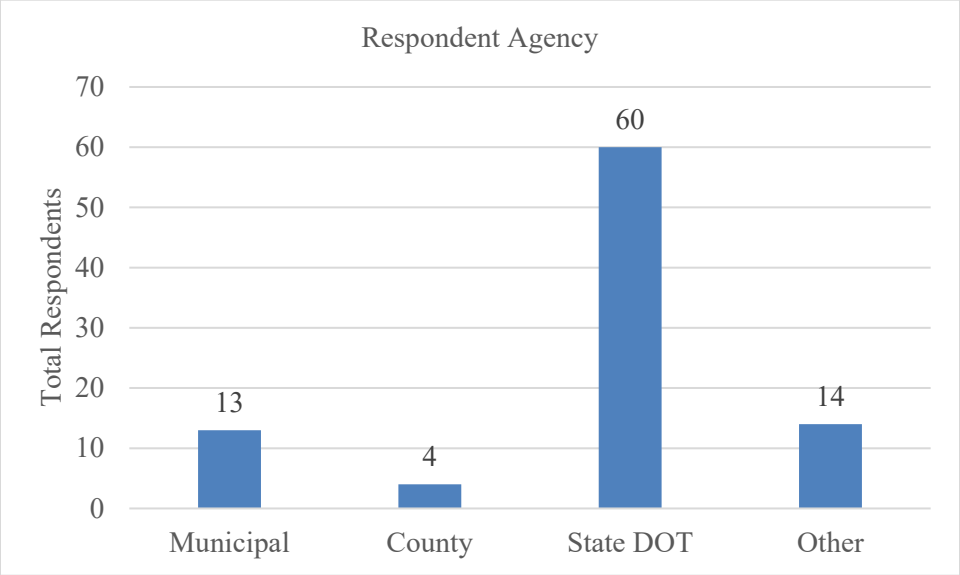

Figure 37. Respondent Agency Type

Table 5. Respondent Agency Type - Text Responses

Country	State	Agency - Other Text
CANADA	AB	Alberta Province
CANADA	AB	Canada - Municipal
CANADA	AB	University
CANADA	ON	Ministry of Transportation, Ontario
SOUTH KOREA		Research Institute
US	IA	Iowa State University
US	IN	Private concessionaire to a state DOT
US	MA	LTAP
US	MN	Supplier
		Canada - Municipal
		Government Agency
		Private
		Private contractor
		Province

Current Methods to Apply Deicers and Anti-Icers

Respondents were asked about which methods they currently used to apply deicers and anti-icers. Eighty-six respondents provided information on their current methods. **Deicing (solid materials), pre-wet (solid with added liquid), and anti-icing (liquid) were the most commonly used methods with over 86 percent of respondents currently using these methods,** see Figure 38. These methods were reported from most respondent countries except for **Denmark, which only reported anti-icing**. **About half of the respondents are using direct liquid application.** All respondents that reported using direct liquid application (N=41) were from either the US or Canada. Three respondents replied "Other"; text responses provided included electrically conductive concrete heated pavement systems, straight salt, and slurry.

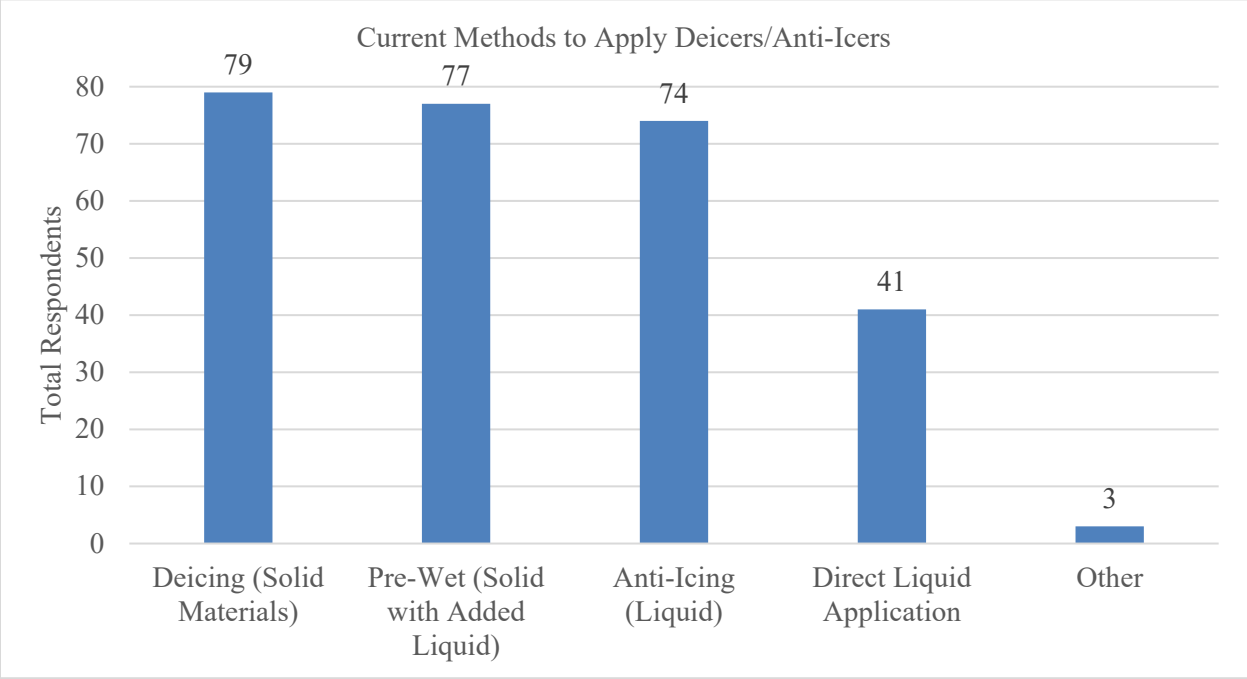

Figure 38. Current Methods Used to Apply Deicers and Anti-Icers

Current Equipment Used to Apply Materials

Respondents were asked to list the current equipment their agency used to apply materials including solids, pre-wet, liquids, and other.

Solids

Sixty-one respondents provided information on the equipment their agency used to apply solid materials. Sanders (N=23) and spreaders (N=27) were the most commonly used equipment to apply solid materials to the roadway, see Table 6 for the summary of results. Other equipment included dump trucks, spinners, and combination units. Eleven respondents (18%) reported specifically using a V-Box sander or spreader, see Table 7. Five respondents (8%) used a slide-in unit and three respondents (5%) used a tailgate unit (2%). Specific equipment manufacturers mentioned included Force America, Henderson, Smith, and Viking.

Table 6. Current Equipment Used to Apply Solid Materials

Current Equipment Used to Apply Solid Materials	Total Respondents	Percent of Total Respondents (N=61)
Chutes	1	2%
Combination Units	1	2%
Dump Truck	1	2%
Hopper	1	2%
Sand	1	2%
Sander	23	38%
Snow plow	6	10%
Spinner	3	5%
Spreader	27	45%
Tandem Saddle Tanks	1	2%
Trucks	3	5%

Table 7. Sander/Spreaders Used to Apply Solid Materials

Sander/Spreader Types	Total Respondents	Percent of Total Respondents (N=61)
ander	19	31%
Sander - Slide-In	2	3%
Sander - V-Box	1	2%
Sander - With Drop Spinners	1	2%
Spreader	9	15%
Spreader - Combination	1	2%
Spreader - Force America 5100, 6100	1	2%
Spreader - Slide-In	3	5%
Spreader - In Box	1	2%
Spreader - Precision	1	2%
Spreader - Tailgate	1	2%
Spreader - V-Box	10	16%

Pre-Wetting

Fifty-six respondents provided information on the equipment their agency is using to apply pre-wet materials, see Table 8. Similar to the responses for solid materials, most respondents were using either sanders (N=13) or spreaders (N=16) to apply pre-wet materials. Saddle tanks attached to sanders/plows were commonly reported equipment with fourteen respondents (26%). Other equipment used to apply pre-wet included brine trucks, sprayers at the spinner, and spray bars attached to a plow or truck. Five

respondents specifically mentioned the capacity of their pre-wet tanks or systems; tank capacity ranged from 100 gallons to 400 gallons.

Table 8. Current Equipment Used to Apply Pre-Wet Materials

Current Equipment Used to Apply Materials - Pre-Wet	Total Respondents	Percent of Total Respondents (N=53)
Boom Application to Loaded Solids and Spray at Spinner	1	2%
Brine Truck	2	4%
On-Board Tanks/Pumps	1	2%
Overhead Spray at Depot, Treat at the Spinner	1	2%
Plow	5	9%
Pre-Wet Pump at Spinner	1	2%
Pre-Wet Sprayer	4	8%
Sander	13	25%
Slurry Box	1	2%
Spinner	1	2%
Spreader	16	30%
Tanks - Pre-Wet, Saddle	4	8%
Tow Plow	2	4%
Truck	5	9%

Table 9. Reported Tank Capacity – Pre-Wets

Country	State	Current Equipment Used to Apply Materials - Pre-Wet
RUSSIA		Saddle tanks 5 to 20gpt
US	ID	V-Box spreaders are equipped with liquid saddle tanks for liquid. Current spreaders have 150 gallon capacity, while new spreaders will have 400 gallon capacity
US	MN	100-200-gallon saddle tanks attached to plow trucks that dump liquid onto the salt spinner
US	MN	1-ton truck 300 gallon truck

Liquids

Forty-nine respondents provided additional information on the types of equipment their agency uses to apply liquid snow and ice control materials, see Table 10. Most respondents use some form of a tanker truck or tanks attached to a plow. Six respondents (18%) are using some form of a slide-in tank. Four respondents (from Alaska, North Dakota, South Dakota, and Alberta, Canada) are using tanks on a tow plow. A respondent from New York stated the agency was using some form of equipment built in-house

to apply liquid snow and ice control materials but did not provide further information. Tank sizes reported for liquid materials had a much larger capacity compared to the tank sizes reported for pre-wet materials. Fifteen respondents reported their tank capacity for liquid materials; tank sizes ranged from 1,000 gallons to 6,000 gallons, see Table 11.

Table 10. Current Equipment Used to Apply Liquid Materials

Current Equipment Used to Apply Materials - Liquids	Total Respondents	Percent of Total Respondents (N=49)
Brine	2	4%
Brine Truck	5	10%
Spreader	3	6%
Deicer	1	2%
Dump Truck - Saddle Tanks or Slide-In Tank	3	6%
In-House Built System	1	2%
Plow	1	2%
Slide-In Tanks	8	16%
Small Spot Sprayer Unit	1	2%
Spray Truck	5	10%
Trailer with Tank	5	10%
Tanker	11	22%
Tanks	5	10%
Tow Plow	4	8%
Truck	7	14%

Table 11. Reported Tank Capacity - Liquids

Country	State	Current equipment Used to Apply Materials - Liquids
RUSSIA		spray trucks 15 to 60gplm
US	AK	Slide In- Henderson 3400 gallon
US	CA	Two 1200g tanks, six 450g tanks
US	DE	6000-gallon tanker trucks and 1800 gallon slide in tanks
US	ID	Slide in tanks have 1000, 1750, and 2250-gallon capacity. We also have some 3500 chassis mounted tanks used for liquids
US	ID	Slide in tanks have 1000, 1750, and 2250-gallon capacity. We also have some 3500 chassis mounted tanks used for liquids
US	ID	Three tier, three lane, truck mounted flow regulated anti icing tanks. 3000, 1700, and 1000 gal.
US	ID	1@2500-gallon truck 2@1000 gallon trucks
US	ID	2000-gal tank on 10 wheeler
US	ID	3,000, 1500, and 1000 gallon trucks
US	IN	Viking Cives- 2000 gallon tank
US	KS	1500 Gallon slip in tanks for our dump trucks

US	SD	Tow Plow and Liquid trucks with 1000 gallon slide in poly tanks
US	SD	Tow Plow and Liquid trucks with 1000 gallon slide in poly tanks
US	WV	Slide in 2,000 gallon spray units
		1500 gallon slip in tanks for dump trucks

Mechanical Methods

Respondents were asked to check all mechanical methods that their agency was currently using to remove snow and ice. Eighty-three respondents provided information on their current mechanical methods. The front plow was used by almost all respondents (98 percent), see Figure 39. Wing plows were also common; they were reported by 78 percent of respondents. Ice breakers (N=5) and squeegees (N=2) were reported the least. Ice breakers were used in Alaska, Minnesota, South Dakota, and Utah. Respondents from Alberta, Canada and South Dakota reported using squeegees.

Seven respondents reported using a combination plow blade. Respondents were asked to explain the type of combination plow blades they were using, see Table 12. There was not a commonly reported combination plow blade, instead blades ranged from multi-segmented plow blades to blades with extra rubber to remove slush to composite blades.

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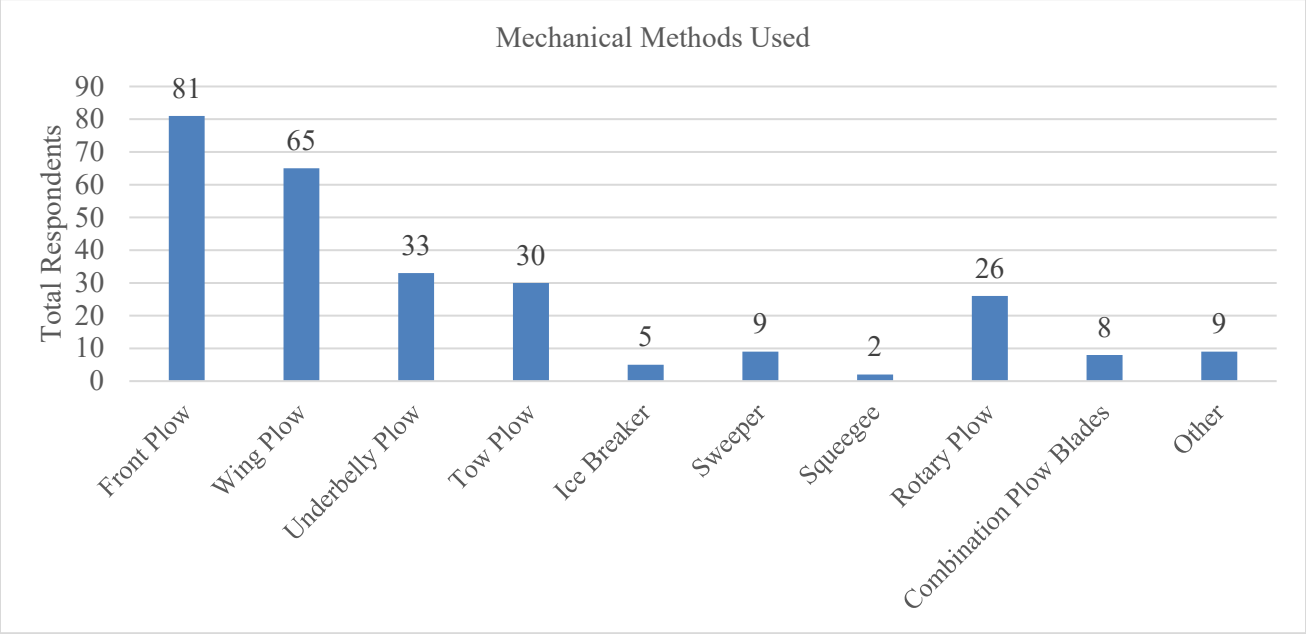

Figure 39. Mechanical Methods Used

Table 12. Plow Blade Types Used

Country	State	Combo Plow Blades
CANADA	AB	Combo Rubber/Steel blade front V plow
NORWAY		plows with extra rubber blades to remove slush
US	ID	Carbide bits with soft backer plates, Joma Bits, Razors
US	KY	Steel and Rubber
US	MA	More than 50% of edges are composites, mostly Kuper
US	MA	Multi segmented blades
US	ME	Viking-Cives Spring tooth plow

Nine respondents reported using other mechanical methods for snow removal. Other mechanical methods reported by the respondents included V-plows, graders with a wing plow, and snow blowers (see Table 13).

Table 13. Other Mechanical Methods Used

Country	State	Other Mechanical Methods Used
CANADA	AB	V-Plow
US	ID	Front End Loaders, Motor Graders
US	ID	grader with wing
US	ID	Grader with wing.
US	ID	Snow Blower (rotary), Grader with bull blade, wing and ice bits.
		Dozer and snow blower for heavy snow. Motor graders with front U/V plows and wings
		Grader

Technologies

Respondents were then asked to provide information on the technologies their agency used to apply snow and ice control materials. Eighty respondents provided information on the technologies they were currently using. **Automated vehicle location (AVL) and global positioning systems (GPS) were the most commonly reported technologies** being used by 78 percent of respondents, see Figure 40. **Ground speed controllers and mobile mounted sensors on plows were also common**. Thirty-two respondents provided information on the types of mobile mounted sensors that they were using; **the most commonly reported sensors were pavement temperature and air temperature sensors**, see Table 14. Other sensors used included dew point, plow up/down, spreader on/off, and cameras. Twenty percent of respondents indicated that they are using maintenance decision support systems (MDSS).

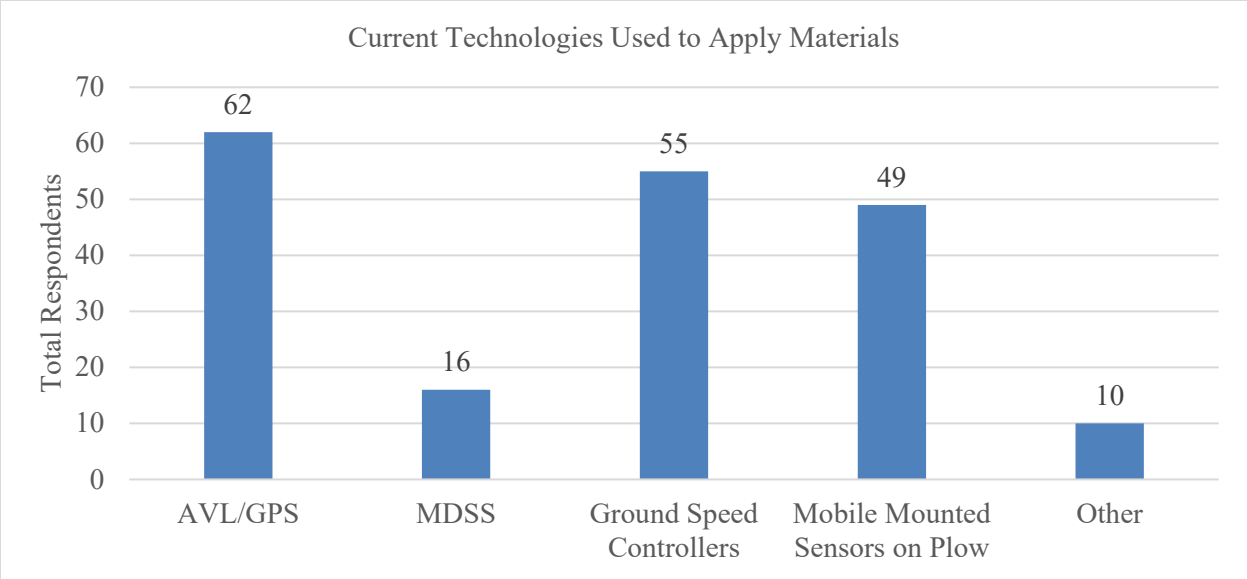

Figure 40. Current Technologies Used to Apply Snow and Ice Control Materials

Table 14. Mobile Mounted Sensor Types

Mobile Mounted Sensor Type	Total Respondents	Percent of Total Respondents (N=49)
Pavement Temperature	25	51%
Air Temperature	10	20%
Dew Point	2	4%
Force America Spreader Controls	1	2%
MARWIS – Full Road Weather Information Station on Plow	2	4%
Temperature	2	4%
Cameras	2	4%
Plow Up/Down	2	4%
Roadwatch – Air/Pavement Temperature	2	4%
Spreader On/Off	1	2%
Vaisala/Precise	1	2%

Ten respondents reported using another technology to apply snow and ice control materials. **Road weather information stations/sensors (RWIS) were reported by most of these respondents**, see Table 15.

Table 15. Other Technologies Used to Apply Snow and Ice Control Materials

Country	State	Technologies Used to Apply Materials - Other
CANADA	ON	RWIS
NORWAY		weight cells to control application rate
US	ID	PAVEMENT TEMP SENSOR
US	ID	road sensors at various locations.
US	ID	road weather Information systems (RWIS) NWS Briefings, different weather sites, neighboring states cameras from 511
US	ID	RWIS pavement sensors
US	IN	Joma plow bits and Kuper plow bits
US	TX	Temperature Sensor on Trucks
		RWIS

Products

Deicers

Sixty-seven respondents provided information on the various deicers or deicer blends that their agency currently uses, see Table 16. **Most respondents (N=54) use straight salt; application rates for straight salt ranged from 100 to 800 pounds per lane mile (lb/l-m) with an average of around 280 lbs/l-m, see** Table 17**.** Twenty-five respondents provided information on thirty-two salt/abrasive mixes with either anti-skid, sand, or stone reported as the abrasive, see Table 18. These mixes ranged from 10 percent sand with 90 percent abrasive to 67 percent salt with 33 percent abrasive. **A fifty-fifty mix of salt to abrasive was the most common ratio. Application rates for salt/abrasives mixes ranged from 100 to 1,000 lbs/l-m with an average of around 350 lbs/l-m.** Nine respondents specifically mentioned that their deicer application rates vary depending on factors like ground speed, road width, storm conditions, and temperature.

Table 16. Deicer (Solid) Materials Used

Deicer (Solid) Used	Total Respondents	Percent of Respondents (N=67)
Antiskid	2	3%
Brine	5	8%
Brine/Agricultural Product	2	3%
Calcium Chloride	2	3%
Cinders	1	2%
Hot Mix Sanding Chips 10-50% Salt Added	1	2%
Ice Slicer	7	11%
Magnesium Chloride	4	6%
New Deal	1	2%
Rapid Thaw	1	2%
Salt	54	82%
Salt/Beet Heet	1	2%
Salt/Ice Slicer	1	2%
Salt/Magnesium Chloride	2	3%
Salt Workx Ice Kicker	1	2%
Salt/Abrasive	25	38%
Sand	7	11%
Sanding Chips	1	2%
Slurry	1	2%

Table 17. Deicing Salt Used and Application Rates

Country	State	Deicers Used (Solid) - Blend	Application Rate
CANADA	AB	Salt	KG per lane KM50, 100, 150, 200, 300
CANADA	AB	rock salt from NSC minerals	no current spec, up to operator
CANADA	AB	rock salt	
CANADA	ON	Salt	
CANADA	ON	Salt	50 - 350 ton/lane mile
NORWAY		NaCl	10-40 g/m2
RUSSIA		Salt	
SOUTH KOREA		NaCl	130kg/km/lane
US	AK	Sodium Chloride	300#/ LM
US	AK	salt	500lbs per lane mile
US	AZ	Salt	150-400 lbs per lane mile
US	CA	Salt	300 lb per lm
US	DE	rock salt	250 lb per lane mile
US	ID	salt	200-300
US	ID	salt	75-500 pplm
US	ID	Salt	Tons
US	ID	Salt	50lbs -550lbs
US	ID	Salt	100 pds/mile up to400 pounds/mile
US	ID	Salt	200 / LM
US	ID	Salt	25-350 lbs. per lane mile
US	ID	Straight Salt	150 LBS. per lane mile to start with
US	ID	Salt	100-400 lbs/mile
US	ID	ROAD SALT	200-300 TON PLM
US	ID	Salt	Varies by storm conditions and temperature
US	ID	Salt	
US	ID	Sodium Chloride	100 - 500 lbs per lane mile
US	ID	rock salt	varies
US	ID	salt	200-500 lbs per mile
US	ID	salt	100 to 300 tons per mile
US	ID	100% salt	100-300 lbs per mile
US	IL	Treated salt, mag chloride	100-500 lbs/lane mile
US	IN	NaCl	between 150-400 lbs/ln mile
US	IN	Salt with 10 gal per ton prewet	200 lbs per lm
US	KS	NaCl	varies
US	KY	Rock Salt	250 lbs per Lane Mile - Interstate
US	KY	Rock Salt	400 lbs per two-lane mile on two lane roads
US	MA	Road salt	250-400

US	MA	Rock Salt	250lbs p/mile
US	MA	Rock salt	150-400 lbs. per mile
US	MA	Pre-wet salt	250lbs p/mile
US	ME	Rock Salt	200 to 600 lbs./LM
US	MN	salt	lbs. 100-500
US	MN	Salt blended at 4 gallons per ton with Beet Heet	100-1000 lbs. per lane mile
US	MT	Salt	150 lbs./ln mile
US	ND	pre-wet Salt	100lb/mi and up
US	NH	Rock Salt	250 lbs. per lane mile
US	PA	Rock Salt	100 to 400lb Per SLM
US	SD	Salt	50-500 tons per lane mile
US	TX	Road Salt	200-400 lbs. per lane mile
US	UT	All the brands above standard salts as well	100-500 lbs./lane-mile depending on temps
US	UT	Broken Arrow Rapid Thaw	100-500 lbs./lane-mile depending on temps
US	UT	Compass DriRox	100-500 lbs/lane-mile depending on temps
US	UT	SaltWorx Ice Kicker	100-500 lbs/lane-mile depending on temps
US	VA	Salt (Sodium Chloride)	100-400 lbs/lane mile
US	VT	sodium chloride	250-800 lbs/ mile
US	WI	Rock Salt - straight NaCl	Policy = 300 #/lm with some latitude for trouble spots & intersections
US	WV	100 % salt	100-250 #/LM
		Sodium chloride	
		rock salt	based on ground speed
		sand pretreated with Mag Chloride	based on ground speed

Table 18. Salt/Abrasive Mixes and Application Rates

Country	State	Deicers Used (Solid) - Blend	Application Rate
CANADA	AB	sand with 4% NaCl	unknown
CANADA	AB	50/50 sand salt	KG per Lane KM 100, 150, 200, 250, 300, 350, 400, 450
CANADA	AB	50% sand, 50% SMT?	unknown
CANADA	ON	70/30 sand salt	
CANADA	ON	50/50 salt sand	
US	AK	Sand w/6% salt	Varies
US	AK	Sand with 5% salt	As needed
US	ID	Salt and anti-skid blend	varies by storm conditions and temperature
US	ID	Salt/Anti-skid 1to1	Tons
US	ID	1/2 salt to 1/2 antiskid (3/8)	100 lbs/ml to 400 pds/mile
US	ID	Antiskid/salt 1:3	50-400 lbs. per lane mile
US	ID	Sodium Chloride + antiskid material 1 to 1 ratio	100 to 700 lbs per lane mile
US	ID	straight salt /brine	varies
US	ID	salt/sand	500-600
US	ID	10/90 salt /sand	300-500 lbs per mile.
US	ID	3:1 sand/salt	350 lbs per mile
US	ID	50/50 salt /sand	150-500 lbs per mile.
US	ID	1 salt to 1 sand	varies
US	ID	50%salt 50% sand	100 to 400 tons per mile
US	ID	2 salt to 1 sand	varies
US	MO	rock salt, abrasives 1 to 1	25 to 200 pounds per lane mile
US	MT	10% Salt/sand	400-1000 lbs/lnmile
US	MT	15% Salt Sand	250-700 lbs/lnmile
US	MT	50% Salt Sand	150-300 lbs/lnmile
US	ND	Salt/Sand	100lb/mi and up
US	SD	Salt/Sand 20/80	100-1000 tons per lane mile
US	UT	2 parts Standard salt, 1-part deslicking grit for a 2:1 ration	100-300 lbs/lane-mile mixed
US	VA	Stone, sand & Salt	100-400 lbs/lane mile
US	VA	Stone and Salt	100-400 lbs/lane mile
US	WV	3:1 abrasive/salt	200-500 #/LM
US	WV	2:1 abrasive/salt	200-500 #/LM
US	WV	1:1 abrasive/salt	200-500 #/LM
US	WY	sand 95- salt 5	600 #/LM
		sand with 2% salt	based on ground speed
		Sand/Salt (salt 5% by weight)	500kg/lane km

Pre-Wet

Fifty-seven respondents provided information on the various pre-wet blends that their agency currently uses, see Table 19. Various **salt brine mixes were the most commonly reported pre-wet material** (N=29). Pre-wet reported **typically involved solid salt wet with salt brine and applied at a range of 100 to 500 lbs/l-m, or an average application rate of 275 lbs/l-m**. The volume of liquid added ranged from 4 to 30 gals/ton, or an average of 12 gals/ton of liquid added to solid material for pre-wetting, see Table 20. Other salt brine additives included corrosion inhibitor, Beet Heet, calcium chloride, and magnesium chloride. Nine respondents reported using a magnesium chloride brine with solid salt, sand or antiskid. Nine respondents reported using a calcium chloride brine with either solid salt or solid calcium chloride. Seven respondents reported using a variable application rate for their pre-wet materials, only one respondent mentioned that application rates vary depending on temperatures. A respondent from Wisconsin reported only using pre-wet materials for colder conditions.

Table 19. Pre-Wet Materials Used

Pre-Wet Used	Total Respondents	Percent of Respondents (N=57)
Brine	16	28%
Brine with Corrosion Inhibitor (10 gal per ton)	1	2%
Brine/Beet Heet	2	4%
Brine/Calcium Chloride	1	2%
Brine/Magnesium Chloride	2	4%
Brine/Organics	3	5%
Brine/Salt	9	16%
Brine/Salt/Abrasive	2	4%
Calcium Chloride	7	12%
Calcium Chloride Brine/Calcium Chloride	1	2%
Calcium Chloride Brine/Sand	1	2%
Magic Minus Zero	1	2%
Magnesium	1	2%
Magnesium Chloride	7	12%
Magnesium Chloride Brine/Salt	2	4%
Salt	11	19%
Salt/Abrasive	5	9%
Salt/Beet Heet	3	5%
Salt/Boost	1	2%
Salt/Calcium Chloride	2	4%
Salt/GLT	1	2%
Salt/Magnesium	7	12%
Sand	2	4%
Sand/Calcium Chloride	1	2%
Sand/Magnesium Chloride	1	2%
SB/MMZ	1	2%
Slurry	1	2%
Supermix	1	2%

Table 20. Pre-Wet Salt Brines Used and Application Rates

Country	State	Pre-Wet Used	Application Rate
CANADA	ON	Salt Brine	4 - 10 gallons/ton
US	CA	75 brine, 15 organic, 10 cal chlor	10gal per ton
US	ID	salt brine	12-16
US	ID	Brine	15 g/ton
US	ID	brine	varies
US	ID	23% sodium chloride salt brine.	7-20 gal per ton.
US	ID	salt and brine	100-400lbs salt per mile brine 15 gallons per mile
US	ID	ROAD SALT AND BRINE	200-300 PLM/25 GALLON PLM
US	ID	Salt is pre-wet with salt brine	Varies
US	ID	Salt and 20 gal/ton salt brine	
US	ID	straight salt / brine	varies
US	IN	Enhanced Brine w/corrosion inhibitor 10 gal per ton	
US	IN	Salt Brine w/ corrosion inhibitor 10 gal per ton	50 gal per lm
US	IN	NaCl w/NaCl brine	10 gallons/ton
US	KY	Salt Brine	8 gallons per ton applied at the spinner
US	MA	85/15 brine with AG 64	10-12 gal per ton
US	MA	90/10 brine with AG 64	10-12 gal per ton
US	ME	Salt Brine	10 gal/ton+
US	MN	Brine	5 gal per lane mile
US	MN	90% brine/10% Beet Heet	5 gal per lane mile
US	MT	23.3% Brine	15 gallons/yd
US	NH	Rock Salt with brine	250 lbs per lane mile with 8 gallons of brine per ton of salt
US	NY	Salt brine	8 gal/ton
US	NY	80% salt brine 20% mgcl	8 gal/ton
US	PA	Salt brine	6 to1 12 gallons per ton pre wet
US	SD	Salt Brine	20-60 gal per lane mile
US	UT	Brine	
US	VT	salt brine (sodium chloride)	15-30 gals per ton
US	WI	Salt Brine 23.3 %	variable - unknown
US	WI	Salt Brine with Beet Heet	variable - unknown
US	WI	Salt brine with CaCl2	only for colder conditions
US	WI	salt brine with MgCl	only for colder conditions
US	WV	100% salt with 8 gal/ton 23% by weight NaCl brine	100-250 #/LM
US	WV	2:1 abrasive/salt with 8 gal/ton 23% by weight NaCl brine	200-500 #/LM

US	WV	3:1 abrasive/salt with 8 gal/ton 23% by weight NaCl brine	200-500 #/LM
US	WY	sand salt - 9 gal brine	
		Brine, agg product, calcium	
		Sodium brine	

Anti-Icers

Fifty-five respondents provided information on the various anti-icers (liquid) that their agency is currently using, see Table 21. **Salt brine was the most commonly reported anti-icing liquid used**. Thirty-nine respondents reported using some variation of a salt brine at **application rates ranging from 15 to 200** gallons per lane mile (gal/l-m) (Table 22). Ten respondents reported using an agricultural product including Boost, Beet Heet, Geomelt, or beet juice mixed with salt brine. Other salt brine additives included rock salt, calcium chloride, and magnesium chloride. **Magnesium chloride was the second most commonly reported anti-icing liquid** (N=15). **Application rates for magnesium chloride anti-icer ranged from 15 to 200 gal/l-m.** For all **liquid application rates reported the average is about 40 gals/l-m**. Four respondents reported using straight agricultural or organic products including Beet 55 and beet juice. One respondent from Alberta, Canada reported using potassium on sidewalks. Only one respondent reported using urea for anti-icing.

Table 21. Anti-Icer Materials Used

Anti-Icer Used	Total Respondents	Percent of Respondents (N=55)
Beet 55	1	2%
Beet Juice	1	2%
Boost	1	2%
Brine	27	49%
Brine/Agricultural Product	2	4%
Brine/Beet Heet	4	7%
Brine/Boost	3	5%
Brine/Calcium Chloride/GLT	1	2%
Brine/Corrosion Inhibitor	1	2%
Brine/Geomelt	1	2%
Brine/Magnesium Chloride	2	4%
Brine/Salt	4	7%
Calcium Chloride	7	13%
Magnesium Chloride	15	27%
Organics	1	2%
Potassium	1	2%
Salt	3	5%
Salt/Beet Juice	1	2%
Salt/Calcium	1	2%
Self-Made Brine	1	2%

Supermix	1	2%
Urea	1	2%

Table 22. Salt Brines Used and Application Rates

Country	State	Anti-Icer Used	Application Rate
DENMARK		24% NaCl	15-30 ml/m²
NORWAY		NaCl brine	15-40 g (ml)/m2
US	AK	Enhanced Salt Brine	30-50 gal/ LM
US	AK	Salt Brine	30-50 gal/ LM
US	AK	Salt Brine w/10% calcium and GLT	30 gplm
US	AK	Salt Brine w/20% calcium and GLT	30 gplm
US	AK	Salt Brine w/GLT	30 gplm
US	AZ	Brine	40-70 gal/lane mile
US	CA	75 brine, 15 org, 10 cal chloride	20gal per lm
US	DE	rock salt brine	50 gallons per lane mile
US	ID	Salt Brine	15-40 gallons
US	ID	Salt Brine	30 gal / mile up to 50 gal/mile
US	ID	Brine	35 g/lm
US	ID	brine	35-60 gallons per lane mile
US	ID	SALT BRINE	35-60 GALLONS PLM
US	ID	Salt Brine	Varies
US	ID	brine	varies
US	ID	salt brine.	35 to 45 gallons per mile
US	ID	23% sodium chloride salt brine w/10% Boost	15-50 gal per lane mile.
US	ID	23% sodium chloride salt brine.	15-50 gal per lane mile.
US	ID	straight salt, but mostly brine	varies
US	IN	NaCl brine	45 gallons/ln mile
US	IN	NaCl brine/25% Beet Heet mix	45 gallons/ln mile
US	IN	Enhanced Brine w/corrosion inhibitor	
US	IN	Salt Brine w/ corrosion inhibitor	
US	KY	Salt Brine	40 gallons per lane mile
US	MA	Salt brine	30-60 gal p/mile
US	MA	90/10 brine with AG 64	40-50 gal per mile
US	MA	90/10 brine with AG 64	40-50 gal per mile
US	ME	Salt Brine	40-60 gal/LM
US	MN	Brine	20 gal per lane mile
US	MN	salt brine with beat heat 75%/25%	
US	MN	90% brine/10% Beet Heet	20-60 gal per lane mile
US	MT	23.30%	40-60 gallons/ln mile
US	ND	salt brine/Geomelt	80/20 ratio at 20gal/mi and up
US	NH	brine with mag chloride	30 gallons per lane mile

US	SD	Salt Brine	20-60 gal per lane mile
US	TX	Brine	50 gal per lm
US	UT	Brine	
US	UT	NaCl brine	50-200 gal/lane-mile
US	VA	Brine 23%	20-30 gallons / lane mile
US	WI	salt brine	
US	WI	Straight Salt Brine 23.3%	40 gal / lm
US	WI	Brine + Beet Heet	unknown
US	WV	23% by weight NaCl salt brine	40-60 gal/LM
		Sodium brine	
		80/20 mix salt brine/agg product	20-50 gallons

Other Materials

Two respondents provided information on other snow and ice control materials that their agency was currently using. A respondent from Norway reported using magnesium chloride as a dust preventative. One respondent from Montana uses potassium acetate in a bridge system at an application rate of 0.1 gallons per mile.

Application Rate Modifications

Respondents were asked if they had modified their deicer/anti-icer application rates within the last five years. Seventy-one respondents answered this question. **Around 60 percent of respondents had modified their application rates within the last five years**. Thirty-eight respondents provided more information on these modifications, see Table 23. **Respondents mentioned specific efforts to reduce chloride use, including increasing the use of anti-icers and pre-wet materials**. A few respondents mentioned using **storm data, variable application rates, and improving equipment calibration in order to reduce material usage. Four respondents from Idaho mentioned increasing salt use** due to their wet roads policy or because they changed from a blended product to straight salt.

Table 23. Modifications to Deicer/Anti-Icer Application Rates

Country	State	Modifications to Material Application Rates
CANADA	AB	Using substantially more anti-icing prior to snowstorms.
CANADA	ON	More often calibration of equipment, operator training. Trying to use, past was trying to use more
CANADA	ON	Proper Calibration of the equipment has led to decreased use as previous settings [were] too high for certain conditions
NORWAY		More detailed descriptions to reduce the salt consumption
RUSSIA		We have went to a straight salt application instead of a blend.
US	AK	Started using in all our locations
US	AK	We have increased our pre-wet liquid portion as we see better results bumping up the gallons of liquid/ ton used. We have also increased our anti icing application rate from 10-30 gallons / LM to 30-50 gallons/ LM. Increased rates see better results in lower temperatures.
US	CA	Increased liquid amounts on both prewet and anti-ice per APWA and Clear Road recommendations
US	DE	Decreased rock salt application from 400lb per lane mile to 250lb per lane mile Increased anti ice from 40 gal/lm to 50 gal/lm increased prewet from 8 gal/ton to 14 gal/ton
US	ID	Have been able to cut back on materials, by understanding the Clear Roads matrix better and educating the crew and what to watch for.
US	ID	Increased salt usage to keep roads bare and wet during the storm.
US	ID	ITD has been modifying our application rates to be more cost-efficient while still maintaining our Winter Mobility Scores.
US	ID	More straight rock salt and less sand. Recognition of the effects of chloride application. Have approximately followed the Clear Roads Group recommended rates.
US	ID	more: overall wet road policy increased, so did our product usage
US	ID	Started using more salt
US	ID	Using AVL storm data evaluation. We have increased rates to find the highest efficiency, then reduced them to find the most efficient rates which are still sustainable. Averaging about 25-50% higher rates than 5 years ago.
US	ID	We adjust for the surface temp, lap times, and expected duration of the storms. Varies from 150 lbs/l-m to 450 lbs/l-m
US	ID	We have backed off our usage as we have become more familiar with it. we started hitting everything at 300-400 pounds per mile and now we gauge it by conditions and lap times to an average of 100-250 pounds per mile, heavier if conditions dictate it.
US	ID	We have doubled our initial application rates and increased our during storm rates by 50%, on average.
US	ID	We have gone away from the salt/sand mixtures and have gone to straight salt with salt brine in our saddle tanks. Salt/sand rates were higher due to the sand in the salt 600lbs per mile starting out. Now with the straight salt we can start at 200lbs pre mile.

US	ID	We have modified our application rates in the last five years. We have seen an increase, of usage of materials. Now we are trying to educate and train our operators to lean [cut] back on materials. Check road, weather and all conditions while applying.
US	ID	We have tried reducing application rates to be more efficient, application rates to do the job but not just throw it away or plow it off to save materials but still keep the best possible grip rate.
US	ID	We have used more straight salt and lowered our rates from 400 for anti-icing to 250 per lane mile. We have also upped our pre-wet program we use it on everything we put out now rates from 9 gallons per mile to 15 per mile. We could not afford the high rates for anti-icing and found that a reduced rate would work without performance matrix.
US	ID	We implemented the Clear Roads matrix as our standard. We are always encouraging our operators to evaluate results and strive to be efficient with chemical use based on practice and history.
US	ID	We modify our rates during each storm depending on severity of precipitation, and surface temps. We keep the road surface as safe as possible for the traveling public.
US	IL	Testing all liquid routes.
US	KS	Tried to reduce application rates based on need. Moved to more straight salt application and using less sand.
US	MA	Added brine, increased pre-wet, decreased from 1000+ per lane mile to 250
US	MA	Chloride reduction eliminated MgCl and increased organic proportion. Only had 5% organic with 10% MgCl, now 10% organic with salt brine. Road temps don't require additional chloride in region, just needed to enhance residual salt on pavement...more glue!!
US	MN	Less, mainly training and buy-in
US	MN	We are continuing to utilize more liquid and reduce the solid (salt) deicers. We have played with correct application rates for temperatures and continue to research proper application rates from what we see happen on the roads.
US	MO	We have increased abrasive mixtures if we are getting low on rock salt.
US	NM	Reduced to 150 lbs / mile application switching to Ice Slicer.
US	NY	Less material by utilizing GPS/AVL while achieving same results to lower product waste and lower environmental impact
US	WI	We are doing pilot projects in a few locations experimenting with Direct Liquid Applications (DLA). We have been coining the phrase - Mostly Liquid Applications because there are times, especially at the end of the day when non-liquid products are appropriate to use.
US	WV	We have lowered our application rates due to improved calibration techniques, prewetting and anti-icing practices.
		Removed automated blending station to manual blending station only use salt brine and ag product.
		We started using pre-wet 2 years ago. We are still learning as we go.

Deicing/Anti-Icing Product Modifications

Respondents were asked if they have modified their deicing or anti-ice products over the last five years. Seventy respondents answered this question; forty-three percent of respondents stated that they had changed products. Twenty-eight respondents provided additional information on their material changes, see Table 24. Nine respondents mentioned using more salt brines. Various materials were mentioned as being mixed with a salt brine including Boost, Envirotech AMP, Ice Slicer, and Road Guard 8. Five respondents mentioned the use of agricultural products like Beet Heet or beet juice. Using magnesium chloride was also commonly reported.

Table 24. Modifications to Deicer/Anti-Icer Products

Country	State	Deicer/Anti-Icer Modifications
CANADA	AB	We have added sodium chloride brine and beet juice to our liquid choices
CANADA	ON	Now we use the CaCl brine to pre-wet sand
RUSSIA		We are trialing salt brine but still using mag chloride.
US	AK	We were using Boost SB for Salt Brine additive. We have switched to Envirotech AMP as we get the same results as the Boost by adding only 10% AMP instead of the 20% Boost. The AMP also adheres to the road surface at a molecular level instead of using the carbohydrate found in Boost as a bonding agent.
US	AK	We were using Rivertop corrosion inhibitors until they went out of business. We are now using Paradigm GLT.
US	AZ	Cost of salt. We went from 128 per ton to 86 per ton on average. We are also pushing to pre-wet all of the time
US	ID	ITD District 2 has used liquid magnesium chloride for deicing and anti-icing for many years. Last season, we used salt brine, in addition to mag chloride, in one of our northern sheds.
US	ID	Just started this past year trying Salt Brine. Cheaper without corrosion inhibitors
US	ID	More straight salt less sand. The salt works well on its own less cleanup and less sand in the streams along the road. We use a 50/50 salt sand mix in heavy snow on the mountain passes just to keep the big trucks going. On the lower elevation roads with less grade we put salt down around 200 pounds per mile then try not to apply again until the heavy snow quits.
US	ID	Using more salt
US	ID	We have added in Ice Slicer, and Boost to our toolbox, for use in strategic areas, and during abnormally cold or long-lasting storm events.
US	ID	We have increased our chloride use and almost eliminated any anti-skid material use.
US	ID	We have went to straight salt and got away from salt/sand mixtures and added more salt brine gallon per ton to help.
US	ID	We started prewetting our salt with mag to help activate the product, cutting down on the time spent for the material to start working.
US	IN	We added AMP from Envirotech Services to our salt brine 2 years ago to get us a lower working temperature of the brine for direct liquid application

US	IN	We are trying to reduce our dependence on Magnesium Chloride and Calcium Chloride.
US	KS	Added beet juice - agricultural byproduct to our options
US	MA	Same as prior question – [Chloride reduction, eliminated MgCl and increased organic proportion. Only had 5% organic with 10% MgCl, now 10% organic with salt brine. Road temps don't require additional chloride in region, just needed to enhance residual salt on pavement...more glue!!]
US	MA	Tried CMA added more organic
US	MN	Over the last five years we have used Road guard 8, Apex C and now we are using Beet Heet. We have found that Beet Heet is giving us better results in lower temperatures.
US	MO	We began using mag treated rock salt.
US	NM	Used to use salt
US	TX	TxDOT moved away from using liquid mag chloride for any purpose due to liability issues cited by the producer. We switched to all brine for anti-icing.
US	UT	We added Saltworx's Ice Kicker (blue salt) to the list of high performance salts that we use.
US	VT	We stopped using Magic -0 and went to Promelt ultra 1000, which didn't work as well. We were forced to use more granular salt instead.
US	WI	New products like Beet Heet have replaced older products like Geomelt. I am not sure that there is a noticeable difference in performance or cost, but the salesmen claim there is.
		Removing magnesium, adding sodium brine
		Same as previous question. – [Removed automated blending station to manual blending station only use salt brine and ag product.]

Methods, Equipment, Technology Tested or of Interest

Finally, respondents were asked to list any methods, equipment, technology, practices, or products that their agency was testing or interested in learning about. Forty respondents answered this question. Technology and mechanical methods were the most commonly reported, see Figure 41.

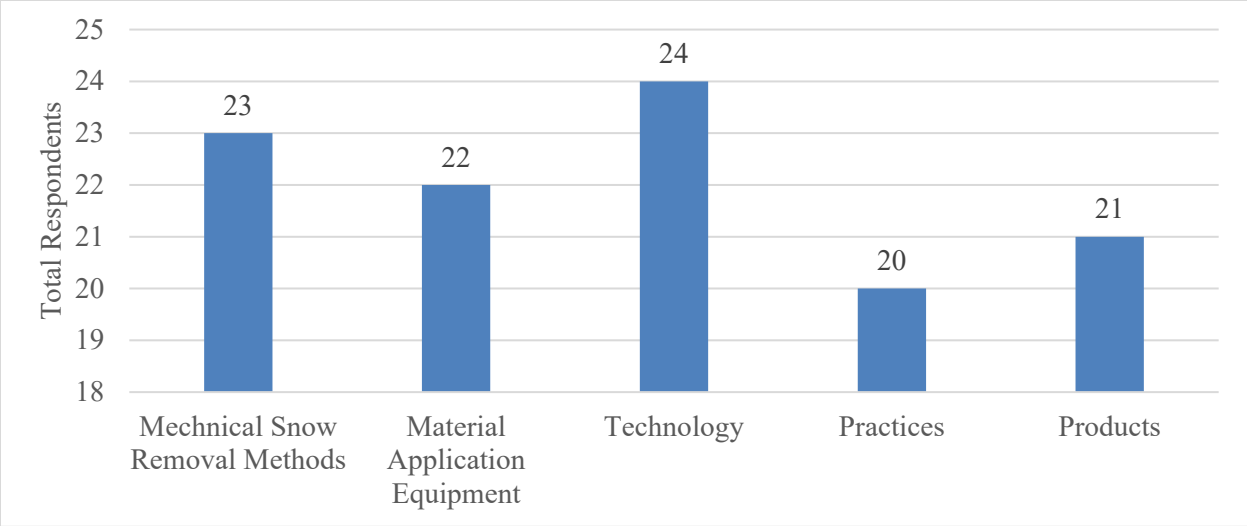

Figure 41. Methods, Equipment, Technology, Practices, and Products responding agencies are testing or interested in.

Mechanical Snow Removal Methods

Seventeen respondents provided additional information on mechanical snow removal methods that they were either interested in or were currently testing, see Table 25. Respondents showed interest in snow plow technologies, including belly brooms on plows, finger plows, and underbelly plows. Various snow plow blades were also mentioned, including segmented blades, composite blades, and an interest in plow blades that could reduce the removal of raised pavement markers. Three respondents from Idaho mentioned that they were testing new snow plows (including loader-mounted rotary snow plows and trucks with augers), new bits to reduce material and labor costs, and improved pre-wet systems. A respondent from Utah mentioned that the agency had tested the SnowLion DW30R and the Raiko Icebreaker T-15 and ultimately chose the Raiko.

Table 25. Additional Mechanical Snow Removal Methods of Interest

Country	State	Additional Mechanical Removal Methods
CANADA	AB	Belly brooms on front plow trucks
CANADA	ON	Multiple plow blades (Scraper, Squeegee, blade)
NORWAY		Sweepers on pedestrian roads
US	AK	Finger plows
US	AK	Long Life cutting edge advancements
US	ID	More advanced plows
US	ID	We are always trying new bits to reduce material cost and labor.
US	ID	We recently purchased a loader mounted rotary snow plow in hopes it would replace our truck mount units.
US	ID	We will be getting a new fleet of trucks with augers and better pre-wet systems. Also wings.
US	MA	Composite blade technology
US	MA	How multi segmented blades affect pavement life
US	MA	Segmented blades
US	ME	Interested in any plow technology
US	TX	Plow blades that limit removal of raised pavement markers
US	UT	UDOT did trial runs on the SnowLion DW30R unit and the Raiko Icebreaker T-15 unit. UDOT ended up buying the Raiko.
US	VA	Squeegee and underbelly plows
US	WY	Surface plowing

Material Application Equipment

Thirteen respondents provided additional information on material application equipment that they were either interested in or were currently testing, see Table 26. Respondents mentioned equipment that varied from anti-icer equipment to slurry generators to v-box spreaders. A respondent in Ontario, Canada expressed interest in testing pre-treatment for sidewalks, bike lanes, and roadways.

Table 26. Additional Material Application Equipment of Interest

Country	State	Additional Material Application Equipment
CANADA	AB	Anti-ice equipment
CANADA	ON	Beet Juice or improved carbohydrates
CANADA	ON	Would like to try pretreatment for sidewalk bike lanes and roadways
NORWAY		Accuracy of spreaders
US	AK	Slurry generators
US	ID	Our new fleet is using auger instead of conveyors.
US	MA	More brine
US	ME	Interested in any spreader technology
US	TX	Interested in results chain v. auger spreaders project
US	WI	Equipment has to change to accommodate for the increased brine use / application rate for DLA. Pumps, spray bars and nozzles are different today.
US	WV	Slurry Generators
US	WY	V-box spreader
		Rex Roth operating systems

Technology

Seventeen respondents provided additional information on winter maintenance technologies that they were either interested in or were currently testing, see Table 27. A respondent from Arizona mentioned that the agency has begun **using reports to help determine proper material application rates in order to reduce salt use**. Respondents from Maine and Utah mentioned that they were looking at both **route optimization and automated vehicle location (AVL)**. Many respondents specifically mentioned being interested in **automated vehicle location (AVL), route optimization, and maintenance decision support systems (MDSS)**.

Table 27. Additional Technologies of Interest

Country	State	Additional Technology
CANADA	ON	AVL/Autonomous plow routing
CANADA	ON	MDSS, Automated BP loss/regain
CANADA	ON	Want to install multiple RWIS stations with cameras
NORWAY		Snow removal and use of salt on pedestrian roads
US	AK	AVL
US	AZ	We are currently using reports to help reduce salt usage along with proper use.
US	IA	Heated Pavement System
US	ID	Telematics, AVL, mobile RWIS, metering, fatigue reduction.
US	ID	We are utilizing ITD Grip rates from our RWIS stations
US	MA	GPS
US	MA	On board friction sensors with spreader units
US	ME	Looking at route optimization and AVL. Interested in other technology as well
US	MT	AVL/MDSS
US	SD	Looking at purchasing MARWIS for friction and water film thickness on our supervisor pickups to help with the reduction of materials
US	UT	UDOT did a trial run on T-Mobile's AVL system, SyncUP Fleet, for the winter of 2018/2019 and are doing a 2nd trial the winter of 2019/2020
US	WY	MDSS
		BSM technology/D+N ???

Practices

Eleven respondents provided additional information on winter maintenance practices that they are either interested in or are currently testing, see Table 28. Three respondents specifically mentioned an interest in **direct liquid application (DLA)**. Other practices that were of interest included pre-wetting, application timing and rates, and equipment calibration.

Table 28. Additional Practices of Interest

Country	State	Additional Practices
CANADA	AB	Prewetting
CANADA	ON	Calibration for staff
CANADA	ON	Currently going through route optimizations
US	AK	DLA
US	AZ	Pre-wet all salt.
US	ID	Application timing and application rates
US	ID	Would like to hear about different practices to maximize our efforts and to save product/money.
US	MA	Salt saturation practices, 60 plus gallon per ton technology
US	ME	Currently initiating another study into practices
US	WI	DLA is new to us.
US	WV	DLA

Products

Twelve respondents provided additional information on snow and ice control products that they are either interested in or are currently testing, see Table 29. Respondents mentioned salt alternatives or methods to reduce chlorides, including the use of calcium magnesium acetate (CMA), organics, Ice Slicer, brines, and pre-wet methods.

Table 29. Additional Products of Interest

Country	State	Additional Products
CANADA	AB	Brine making and blending equipment
CANADA	AB	Non-corrosive deicers
CANADA	AB	Prewetting
CANADA	ON	CMA
CANADA	ON	Would like to try a salt alternative
NORWAY		Testing of new materials and additives
US	ID	Ice slicer, for colder storms.
US	MA	Organics
US	ME	Would love to find a product that realistically competes with salt
US	TX	Liquid and solids blends used by other states

US	UT	High performance MagChloride called APEX Meltdown made by Envirotech.
US	WY	Salt brine, Geomelt/brine, mag chloride, ice slicer

Appendix B Continued – Survey Results, Full Text Responses

Table 30. Current Equipment Used to Apply Solid Materials

Respondent	Country	State	Deicers Used (Solid) - Blend	Application Rate
8	CANADA	AB	hot mix sanding chips with 10-50% salt added	
8	CANADA	AB	Salt	KG per lane KM50, 100, 150, 200, 300
8	CANADA	AB	50/50 sand salt	KG per Lane KM 100, 150, 200, 250, 300, 350, 400, 450
8	CANADA	AB	Sanding Chips	KG per lane KM 100., 150, 200, 250, 300, 400, 500, 600,
82	CANADA	AB	rock salt from NSC minerals	no current spec, up to operator
84	CANADA	AB	sand with 4% NaCl	unknown
84	CANADA	AB	50% sand, 50% SMT?	unknown
88	CANADA	AB	rock salt	
4	CANADA	ON	Salt	
4	CANADA	ON	70/30 sand salt	
4	CANADA	ON	50/50 salt sand	
4	CANADA	ON	Sand	
31	CANADA	ON	Salt	50 - 350 ton/lane mile
69	NORWAY		NaCl	10-40 g/m2
57	RUSSIA		Salt	
71	SOUTH KOREA		CaCl	130kg/km/lane
71	SOUTH KOREA		NaCl	130kg/km/lane
25	US	AK	Sodium Chloride	300#/ LM
55	US	AK	New Deal	varies 1-2 tons per 6,000 feet of runway 75' wide
56	US	AK	salt	500lbs per lane mile
56	US	AK	sand	as needed
56	US	AK	sand with 5% salt	as needed
67	US	AK	Sand w/6% salt	Varies
24	US	AZ	Rapid thaw	150-400 lbs per lane mile
24	US	AZ	Salt	150-400 lbs per lane mile
24	US	AZ	Abrasives	600-1500 lane mile
3	US	CA	Salt	300 lb. per lm
27	US	DE	rock salt	250 lb. per lane mile
38	US	ID	salt	200-300
38	US	ID	salt/sand	500-600
39	US	ID	50/50	100-1100pplm
39	US	ID	salt	75-500 pplm

Respondent	Country	State	Deicers Used (Solid) - Blend	Application Rate
40	US	ID	Mag chloride	Gallons per lane mile
40	US	ID	Salt	Tons
40	US	ID	Salt/Anti-skid 1to1	Tons
42	US	ID	Ice slicer	75-200 lbs per mile.
42	US	ID	100% salt	100-300 lbs per mile
42	US	ID	10/90 salt /sand	300-500 lbs per mile.
42	US	ID	50/50 salt /sand	150-500 lbs per mile.
43	US	ID	Salt	50lbs -550lbs
43	US	ID	Ice Slicer	50-550 lbs.
44	US	ID	straight anti skid	100lbs/mile to 400 lbs/mile
44	US	ID	Salt	100 pds/mile up to400 pounds/mile
44	US	ID	1/2 salt to 1/2 antiskid (3/8)	100 lbs/ml to 400 pds/mile
46	US	ID	Salt	200 / LM
48	US	ID	straight salt /brine	varies
49	US	ID	Straight Salt	150 LBS. per lane mile to start with
50	US	ID	Antiskid / salt 1:3	50-400 lbs. per lane mile
50	US	ID	Salt	25-350 lbs. per lane mile
51	US	ID	Salt	100-400 lbs/mile
52	US	ID	ROAD SALT	200-300 TON PLM
52	US	ID	NONE	
53	US	ID	Salt	Varies by storm conditions and temperature
53	US	ID	Salt and anti-skid blend	varies by storm conditions and temperature
58	US	ID	Salt	
59	US	ID	Sodium Chloride	100 - 500 lbs per lane mile
59	US	ID	Sodium Chloride + antiskid material 1 to 1 ratio	100 to 700 lbs per lane mile
60	US	ID	rock salt	varies
60	US	ID	1 salt to 1 sand	varies
60	US	ID	2 salt to 1 sand	varies
73	US	ID	salt	200-500 lbs per mile
73	US	ID	3:1 sand/salt	350 lbs per mile
74	US	ID	salt	100 to 300 tons per mile
74	US	ID	50%salt 50% sand	100 to 400 tons per mile
74	US	ID	100% sand	100 to 400 tons per mile
26	US	IL	Treated salt, mag chloride	100-500 lbs/lane mile
16	US	IN	Ice Slicer with 10 gal per ton prewet	120 lbs per lm

Respondent	Country	State	Deicers Used (Solid) - Blend	Application Rate
16	US	IN	Salt with 10 gal per ton prewet	200 lbs per lm
16	US	IN		50 gal per lm
28	US	IN	NaCl	between 150-400 lbs/ln mile
32	US	KS	NaCl	varies
32	US	KS	sand	varies
15	US	KY	Rock Salt	250 lbs per Lane Mile - Interstate
15	US	KY	Rock Salt	400 lbs per two-lane mile on two lane roads
5	US	MA	Brine	60g per lane mile
5	US	MA	Road salt	250-400
13	US	MA	Rock Salt	250lbs p/mile
13	US	MA	Pre-wet salt	250lbs p/mile
30	US	MA	Rock salt	150-400 lbs per mile
29	US	ME	Rock Salt	200 to 600 lbs/LM
29	US	ME	Winter Sand	1000 lb./LM
21	US	MN	Salt blended at 4 gallons per ton with Beet Heet	100-1000 lbs per lane mile
86	US	MN	salt	lbs 100-500
75	US	MO	rock salt, abrasives 1 to 1	25 to 200 pounds per lane mile
54	US	MT	Ice Slicer	150 lbs/ln mile
54	US	MT	Salt	150 lbs/ln mile
54	US	MT	10% Salt/sand	400-1000 lbs/lnmile
54	US	MT	15% Salt Sand	250-700 lbs/lnmile
54	US	MT	50% Salt Sand	150-300 lbs/lnmile
37	US	ND	pre-wet Salt	100lb/mi and up
37	US	ND	Salt/Sand	100lb/mi and up
37	US	ND	Slurry	50 gal/ton and up
19	US	NH	Rock Salt	250 lbs per lane mile
6	US	NM	Cinders	2:1 ratio
6	US	NM	Ice Slicer	150#/mile
17	US	NY	Type 1	100-500 lbs/mi
17	US	NY	Type 2	100-500 lbs/mi
17	US	NY	untreated	100-500 lbs/mi
20	US	PA	Salt Brine	6 to1 12 gallons per ton pre wet
20	US	PA	Rock Salt	100 to 400lb Per SLM
34	US	SD	Salt	50-500 tons per lane mile
34	US	SD	Salt/Sand 20/80	100-1000 tons per lane mile
23	US	TX	Brine	50-80 gallons per lm
23	US	TX	Crystal Mag Chloride	65-100 lbs per lane mile
23	US	TX	Road Salt	200-400 lbs per lane mile

Respondent	Country	State	Deicers Used (Solid) - Blend	Application Rate
1	US	UT	Iceslicer	Varies
35	US	UT	Redmond Ice Slicer	100-500 lbs/lane-mile depending on temps
35	US	UT	All the brands above's standard salts as well	100-500 lbs/lane-mile depending on temps
35	US	UT	Broken Arrow Rapid Thaw	100-500 lbs/lane-mile depending on temps
35	US	UT	Compass DriRox	100-500 lbs/lane-mile depending on temps
35	US	UT	SaltWorx Ice Kicker	100-500 lbs/lane-mile depending on temps
47	US	VA	Salt (Sodium Chloride)	100-400 lbs/lane mile
47	US	VA	Stone, sand & Salt	100-400 lbs/lane mile
47	US	VA	Stone and Salt	100-400 lbs/lane mile
45	US	VT	sodium chloride	250-800 lbs/ mile
87	US	WI	23.3 salt brine	
91	US	WI	Calcium Chloride	little use - unknown rate
91	US	WI	Magnesium Chloride	little use - unknown rate
91	US	WI	Rock Salt - straight NaCl	Policy = 300 #/lm with some latitude for trouble spots & intersections
33	US	WV	100 % salt	100-250 #/LM
33	US	WV	3:1 abrasive/salt	200-500 #/LM
33	US	WV	2:1 abrasive/salt	200-500 #/LM
33	US	WV	1:1 abrasive/salt	200-500 #/LM
78	US	WY	brine	35 gal/lm
78	US	WY	Geomelt 30, brine 70	35 gal/LM
78	US	WY	mag chloride	40 gal/LM
78	US	WY	sand 95- salt 5	600 #/LM
7			sand	
10			Sodium chloride	
11			Sand/Salt (salt 5% by weight)	500kg/lane km
11			Add salt to above mixture when required	125kg/lane km (100% ice coverage and cold)
83			rock salt	based on ground speed
83			sand pretreated with Mag Chloride	based on ground speed
83			sand with 2% salt	based on ground speed
89			80/20 mix salt brine/agg product	anti-icing 30-50 gallons, mixing in our salt box 25-50 gallons per ton

Table 31. Current Equipment Used to Apply Pre-Wet Materials

Country	State	Current Equipment Used to Apply Materials - Pre-Wet
CANADA	AB	plow and sander trucks
CANADA	ON	In box spreaders/Cirrus Controllers
CANADA	ON	Spreaders and Combo Units
NORWAY		combi spreaders
RUSSIA		Saddle tanks 5 to 20gpt
US	AK	Saddle Tanks, Henderson FSH 12' Slide in
US	AK	Brine Truck and Tow Plow
US	AZ	Pre wet sprayers
US	CA	Overhead spray at depot, treat at the spinner
US	DE	pre wet pumps applied at spinner
US	ID	Plow
US	ID	Plow and sander
US	ID	MgCl
US	ID	saddle tanks on sander
US	ID	BRINE TRUCK
US	ID	sander truck with prewet system
US	ID	Sanders
US	ID	Sanders w/ mag pump - 6
US	ID	Sanders with side tanks.
US	ID	Truck Mounted Sanders with pre-wet tanks
US	ID	V-box tanks applying liquid spray in the down shut of sander.
US	ID	spray nozzles in sander chutes
US	ID	truck spreader
US	ID	V-Box spreaders are equipped with liquid saddle tanks for liquid. Current spreaders have 150 gallon capacity, while new spreaders will have 400 gallon capacity
US	IN	Tandem/Single Axle with spinners and prewet tanks
US	IN	Viking Cives- Same spreader for solids with a prewet system
US	KS	Same as above – [V-Box Spreaders with conveyor or twin auger]
US	KY	V-Vox and Tailgate Spreaders at the Spinner
US	MA	Truck
US	ME	on-board tanks, pumps, ground speed control
US	MN	100-200 gallon saddle tanks attached to plow trucks that dump liquid onto the salt spinner

Country	State	Current Equipment Used to Apply Materials - Pre-Wet
US	MN	1 ton truck 300 gal truck
US	MO	boom application to loaded solids and spray at the spinner
US	MT	Spray bars
US	ND	Trucks w saddle tanks
US	NH	Liquid saddle tanks
US	NY	Smith, Henderson and Viking Spreaders
US	PA	Spray bar
US	SD	Saddle Tanks attached to Sanders and Tow Plows
US	UT	Force America 5100 and 6100 spreaders fed with conveyor belts. Saddle tanks wet.
US	VA	saddle tanks on slip in spreaders
US	WI	many truck sizes with spinners, augers and or chutes
US	WV	Muni Body and slide in spreader units (chain and auger types)
US	WY	application at the spinner
		Henderson tandem slip in equipped for prewet
		Pre-wet tank systems
		brine, agg product, calcium
		Sand
		Saddle tanks
		Sander
		Sander on plow truck
		Sanders with saddle tanks
		Sprayers
		Tailgate spreaders with saddle tanks spraying into the auger area
		Same as above – [V box spreader inserts with conveyor or auger system]
		Spreaders

Table 32. Current Equipment Used to Apply Liquid Materials

Country	State	Current equipment Used to Apply Materials - Liquids
CANADA	AB	tow plow with tanks
DENMARK		Brine(NaCl) spread with jet nozzles
NORWAY		brine spreaders and combi spreaders
RUSSIA		spray trucks 15 to 60gplm
US	AK	Brine Truck and Tow Plow
US	AK	Slide In- Henderson 3400 gallon
US	AK	Distributor truck
US	CA	2 1200g tanks, 6 450g tanks
US	DE	6000 gallon tanker trucks and 1800 gallon slide in tanks

Country	State	Current equipment Used to Apply Materials - Liquids
US	ID	BRINE TRUCK
US	ID	Plow Truck with tank and spray bar
US	ID	2000 gal tank on 10 wheeler
US	ID	salt brine
US	ID	brine truck
US	ID	Spray trucks
US	ID	1@2500 gallon truck 2@1000 gallon trucks
US	ID	3,000, 1500, and 1000 gallon trucks
US	ID	metered spray bars on tank trucks
US	ID	Truck Mounted Tankers with spray bar equipment
US	ID	truck tank spreader
US	ID	Three tier, three lane, truck mounted flow regulated anti icing tanks. 3000, 1700, and 1000 gal.
US	ID	Slide in tanks have 1000, 1750, and 2250 gallon capacity. We also have some 3500 chassis mounted tanks used for liquids
US	IN	Tandem with slide in bed/semi with tanker trailer
US	IN	Viking Cives- 2000 gallon tank
US	KS	1500 Gallon slip in tanks for our dump trucks
US	KY	Anti-Icing Spray Tanks
US	MA	Holder, truck
US	ME	Slide-in tanks, pumps, ground speed control
US	MO	tractor trailer tanker and saddle tanks on dump trucks
US	MT	Spray Bars
US	ND	Trucks w tanks, towplow tanks, brine trailers
US	NH	Liquid tanks on trailers and tanker trucks
US	NY	in house built
US	SD	Tow Plow and Liquid trucks with 1000 gal slide in poly tanks
US	UT	Drill nozzles on brine trucks.
US	VA	slip in tanks, dedicated brine trucks, & trailers
US	WI	tri-axle, quad axle, milk tank trucks & semi-tractor trailers with spray bars and nozzles
US	WV	Slide in 2,000 gallon spray units
US	WY	gravity hose from tanker
		Various sizes of tanks
		Deicer spray trucks
		1500 gallon slip in tanks for dump trucks
		Brine
		Tanker
		Water truck
		Tankers
		Sprayers

Country	State	Current equipment Used to Apply Materials - Liquids
		Small Spot sprayer unit

Table 33. Mobile Mounted Sensors Used

Country	State	Mobile Mounted Sensors on Plows
US	ID	All plows have combination air/pavement temperature sensors
		Ambient and surface sensors
US	AK	Ambient, Pavement, Dew point mobile sensors
US	ID	Have pavement sensors on snow plows.
US	IN	MARWIS/temp sensors
US	MN	pavement and air temp
CANADA	ON	Pavement and air temp sensors
US	ID	Pavement and air temperature sensor
US	ID	Pavement temp sensor
US	UT	Pavement temp sensors
CANADA	ON	Pavement Temp Sensors
US	ID	Pavement temp sensors
US	AK	pavement temp sensors
US	WI	pavement temp sensors
US	ND	pavement temp sensors, Lufft MARWIS
US	VA	Pavement temp. sensors on pickups and up/down sensors on plows
US	WV	pavement temperature
US	ID	Pavement temperature sensor
US	ID	pavement temperature sensor
US	SD	Pavement temperature sensors
US	ME	Pavement temperature sensors are on all trucks
US	KY	Pavement Temperature Sensors, Plow Up/Down, Spreader On/Off,
US	MN	pavement/air temp gauges
US	KS	Pavement/Air Temperature, cameras
		pavement/air temperature, cameras
US	ID	PLOW SENSOR
US	MT	Road Watch Pavement Temperature Sensor
US	WY	Roadwatch
US	ID	Surface temp and air temp
US	MA	Temp Sensors

		Temperature & dewpoint sensors
		Visala/Precise
		Yes

Table 34. Deicers (Solid) Materials Used

Country	State	Deicers Used (Solid) - Blend	Application Rate
CANADA	AB	50/50 sand salt	KG per Lane KM 100, 150, 200, 250, 300, 350, 400, 450
CANADA	AB	hot mix sanding chips with 10-50% salt added	
CANADA	AB	Salt	KG per lane KM50, 100, 150, 200, 300
CANADA	AB	Sanding Chips	KG per lane KM 100., 150, 200, 250, 300, 400, 500, 600,
CANADA	AB	rock salt from NSC minerals	no current spec, up to operator
CANADA	AB	50% sand, 50% SMT?	unknown
CANADA	AB	sand with 4% NaCl	unknown
CANADA	AB	rock salt	
CANADA	ON	50/50 salt sand	
CANADA	ON	70/30 sand salt	
CANADA	ON	Salt	
CANADA	ON	Sand	
CANADA	ON	Salt	50 - 350 ton/lane mile
NORWAY		NaCl	10-40 g/m2
RUSSIA		Salt	
SOUTH KOREA		CaCl	130kg/km/lane
SOUTH KOREA		NaCl	130kg/km/lane
US	AK	Sodium Chloride	300#/ LM
US	AK	New Deal	varies 1-2 tons per 6,000 feet of runway 75' wide
US	AK	salt	500lbs per lane mile
US	AK	Sand w/6% salt	Varies
US	AZ	Rapid thaw	150-400 lbs per lane mile
US	AZ	Salt	150-400 lbs per lane mile
US	CA	Salt	300 lb. per lm
US	DE	rock salt	250 lb. per lane mile
US	ID	salt	200-300

Country	State	Deicers Used (Solid) - Blend	Application Rate
US	ID	salt/sand	500-600
US	ID	50/50	100-1100pplm
US	ID	salt	75-500 pplm
US	ID	Mag chloride	Gallons per lane mile
US	ID	Salt	Tons
US	ID	Salt/Anti-skid 1to1	Tons
US	ID	10/90 salt /sand	300-500 lbs per mile.
US	ID	100% salt	100-300 lbs per mile
US	ID	50/50 salt /sand	150-500 lbs per mile.
US	ID	Ice slicer	75-200 lbs per mile.
US	ID	Salt	50lbs -550lbs
US	ID	1/2 salt to 1/2 antiskid (3/8)	100 lbs/ml to 400 pds/mile
US	ID	Salt	100 pds/mile up to400 pounds/mile
US	ID	straight anti-skid	100lbs/mile to 400 lbs/mile
US	ID	Salt	200 / LM
US	ID	straight salt /brine	varies
US	ID	Straight Salt	150 LBS. per lane mile to start with
US	ID	Salt	100-400 lbs/mile
US	ID	ROAD SALT	200-300 TON PLM
US	ID	Salt	Varies by storm conditions and temperature
US	ID	Salt and anti-skid blend	varies by storm conditions and temperature
US	ID	Salt	
US	ID	Sodium Chloride	100 - 500 lbs per lane mile
US	ID	Sodium Chloride + antiskid material 1 to 1 ratio	100 to 700 lbs per lane mile
US	ID	1 salt to 1 sand	varies
US	ID	2 salt to 1 sand	varies
US	ID	rock salt	varies
US	ID	3:1 sand/salt	350 lbs per mile
US	ID	salt	200-500 lbs per mile
US	ID	100% sand	100 to 400 tons per mile
US	ID	50%salt 50% sand	100 to 400 tons per mile
US	ID	salt	100 to 300 tons per mile
US	IL	Treated salt, mag chloride	100-500 lbs/lane mile
US	IN	Ice Slicer with 10 gal per ton prewet	120 lbs per lm
US	IN	Salt with 10 gal per ton prewet	200 lbs per lm
US	IN		50 gal per lm
US	IN	NaCl	between 150-400 lbs/ln mile
US	KS	NaCl	varies

Country	State	Deicers Used (Solid) - Blend	Application Rate
US	KY	Rock Salt	250 lbs per Lane Mile - Interstate
US	KY	Rock Salt	400 lbs per two-lane mile on two lane roads
US	MA	Brine	60g per lane mile
US	MA	Road salt	250-400
US	MA	Pre-wet salt	250lbs p/mile
US	MA	Rock Salt	250lbs p/mile
US	MA	Rock salt	150-400 lbs per mile
US	ME	Rock Salt	200 to 600 lbs/LM
US	MN	Salt blended at 4 gallons per ton with beet heet	100-1000 lbs per lane mile
US	MN	salt	lbs 100-500
US	MO	rock salt, abrasives 1 to 1	25 to 200 pounds per lane mile
US	MT	10% Salt/sand	400-1000 lbs/lnmile
US	MT	15% Salt Sand	250-700 lbs/lnmile
US	MT	50% Salt Sand	150-300 lbs/lnmile
US	MT	Ice Slicer	150 lbs/ln mile
US	MT	Salt	150 lbs/ln mile
US	ND	pre-wet Salt	100lb/mi and up
US	ND	Salt/Sand	100lb/mi and up
US	ND	Slurry	50 gal/ton and up
US	NH	Rock Salt	250 lbs per lane mile
US	NM	Cinders	2:1 ratio
US	NM	Ice Slicer	150#/mile
US	NY	Type 1	100-500 lbs/mi
US	NY	Type 2	100-500 lbs/mi
US	NY	untreated	100-500 lbs/mi
US	PA	Rock Salt	100 to 400lb Per SLM
US	PA	Salt Brine	6 to1 12 gallons per ton pre wet
US	SD	Salt	50-500 tons per lane mile
US	SD	Salt/Sand 20/80	100-1000 tons per lane mile
US	TX	Brine	50-80 gallons per lm
US	TX	Crystal Mag Chloride	65-100 lbs per lane mile
US	TX	Road Salt	200-400 lbs per lane mile
US	UT	Iceslicer	Varies
US	UT	All the brands above's standard salts as well	100-500 lbs/lane-mile depending on temps
US	UT	Broken Arrow Rapid Thaw	100-500 lbs/lane-mile depending on temps
US	UT	Compass DriRox	100-500 lbs/lane-mile depending on temps

Country	State	Deicers Used (Solid) - Blend	Application Rate
US	UT	Redmond Ice Slicer	100-500 lbs/lane-mile depending on temps
US	UT	SaltWorx Ice Kicker	100-500 lbs/lane-mile depending on temps
US	VA	Salt (Sodium Chloride)	100-400 lbs/lane mile
US	VA	Stone and Salt	100-400 lbs/lane mile
US	VA	Stone, sand & Salt	100-400 lbs/lane mile
US	VT	sodium chloride	250-800 lbs/ mile
US	WI	23.3 salt brine	
US	WI	Calcium Chloride	little use - unknown rate
US	WI	Magnesium Chloride	little use - unknown rate
US	WI	Rock Salt - straight NaCl	Policy = 300 #/lm with some latitude for trouble spots & intersections
US	WV	1:1 abrasive/salt	200-500 #/LM
US	WV	100 % salt	100-250 #/LM
US	WV	2:1 abrasive/salt	200-500 #/LM
US	WV	3:1 abrasive/salt	200-500 #/LM
US	WY	brine	35 gal/lm
US	WY	Geomelt 30, brine 70	35 gal/LM
US	WY	mag chloride	40 gal/LM
US	WY	sand 95- salt 5	600 #/LM
		Sodium chloride	
		Add salt to above mixture when required	125kg/lane km (100% ice coverage and cold)
		Sand/Salt (salt 5% by weight)	500kg/lane km
		rock salt	based on ground speed
		sand pretreated with Mag Chloride	based on ground speed
		sand with 2% salt	based on ground speed
		80/20 mix salt brine/agg product	anti-icing 30-50 gallons, mixing in our salt box 25-50 gallons per ton

Table 35. Pre-Wet Materials Used

Country	State	Pre-Wet Used - Blend	Application Rate
CANADA	AB	20% Sodium chloride 3% Calcium blend	7%
CANADA	AB	Calcium Chloride	7%
CANADA	AB	sand and CaCl	unknown
CANADA	ON	Salt Brine	4 - 10 gallons/ton
CANADA	ON	Sand with cacl brine	
NORWAY		NaCl	10-40 g/m2

Country	State	Pre-Wet Used - Blend	Application Rate
SOUTH KOREA		Liquid CaCl+Solid CaCl	150kg/km/lane
SOUTH KOREA		Liquid CaCl+Solid NaCl	150kg/km/lane
US	AK	Salt Brine w/GLT	Varies
US	AK	Sodium Chloride	250#/ LM
US	AZ	Mag chloride	8-15 gal/ ton
US	CA	75 brine, 15 organic, 10 cal chlor	10gal per ton
US	DE	rock salt	250lb per lane mile with 14 gallons per ton
US	ID	1 to 1	10 gal per ton
US	ID	23% sodium chloride salt brine.	7-20 gal per ton.
US	ID	23% sodium chloride salt w/ 10% Boost	7-20 gal per ton.
US	ID	50/50	8-20 gplm
US	ID	50:50 Salt/Antiskid with up to 20 gal/ton of MgCl2	up to 20 gal / ton
US	ID	Brine	15 g/ton
US	ID	brine	varies
US	ID	Mag	
US	ID	MgCl	varies
US	ID	ROAD SALT AND BRINE	200-300 PLM/25 GALLON PLM
US	ID	salt	8-20gplm
US	ID	Salt	10 gal per ton
US	ID	Salt	15 gallons
US	ID	salt	12 gallons of salt brine per mile
US	ID	Salt /Mag	5-25 gal. lane mile
US	ID	Salt and 20 gal/ton salt brine	
US	ID	salt and brine	100-400lbs salt per mile brine 15 gallons per mile
US	ID	Salt and Mag	150 lbs and 15 gallons per lane mile to start with
US	ID	salt brine	12-16
US	ID	Salt is pre-wet with magnesium chloride	Varies
US	ID	Salt is pre-wet with salt brine	Varies
US	ID	Salt with 20 gal/ ton of MgCl2	100 lbs to 400lbs salt with up to 20 gal/ ton MgCl2
US	ID	salt with mag	10-25 gal per ton
US	ID	sand/salt	12 gallons per mile
US	ID	Sodium Chloride + antiskid material 1 to 1 ratio / mag chloride	10 gal per ton

Country	State	Pre-Wet Used - Blend	Application Rate
US	ID	Sodium Chloride Sodium Chloride / mag chloride	10 gal per ton
US	ID	straight salt / brine	varies
US	IL	Supermix	10-20 gals/ton
US	IN	Enhanced Brine w/corrosion inhibitor 10 gal per ton	
US	IN	NaCl w/Beet Heet	10 gallons/ton
US	IN	NaCl w/NaCl brine	10 gallons/ton
US	IN	Salt Brine w/ corrosion inhibitor 10 gal per ton	50 gal per lm
US	KS	NaCl	varies
US	KY	32% Calcium Chloride	8 gallons per ton applied at the spinner
US	KY	Salt Brine	8 gallons per ton applied at the spinner
US	MA	85/15 brine with AG 64	10-12 gal per ton
US	MA	90/10 brine with AG 64	10-12 gal per ton
US	MA	Rock salt with CaCL	250 lbs p/mile
US	MA	Rock salt with Mag	250lbs p/mile
US	ME	Blend (SB+MMZ)	10 gal/ton+
US	ME	Magic Minus Zero	10 gal/ton+
US	ME	Salt Brine	10 gal/ton+
US	MN	90% brine/10% Beet Heet	5 gal per lane mile
US	MN	Brine	5 gal per lane mile
US	MN	salt and beat heat, 5 gal per ton	100-500 lbs per mile
US	MO	beet juice and rock salt	25 to 200 pounds per lane
US	MO	brine and rock salt	25 to 200 pounds per lane mile
US	MO	mag treated rock salt	25 to 200 pounds per lane mile
US	MT	23.3% Brine	15 gallons/yd
US	MT	30% MgCl2	8 gallons/yd
US	ND	pre-wet Salt	100lb/mi and up
US	ND	Salt/Sand	100lb/mi and up
US	ND	Slurry	50 gal/ton and up
US	NH	Rock Salt with brine	250 lbs per lane mile with 8 gallons of brine per ton of salt
US	NY	80% salt brine 20% mgcl	8 gal/ton
US	NY	Salt brine	8 gal/ton
US	PA	Salt brine	6 to1 12 gallons per ton pre wet
US	SD	Mag Chloride	15-60 gal per lane mile

Country	State	Pre-Wet Used - Blend	Application Rate
US	SD	Salt Brine	20-60 gal per lane mile
US	UT	Brine	
US	UT	Broken Arrow standard salt w/ Mag or NaCL brine	50-250 lbs/lane-mile depending on temps
US	UT	Compass standard salt w/ Mag or NaCL brine	50-250 lbs/lane-mile depending on temps
US	UT	Morton standard salt w/ Mag or NaCL brine	50-250 lbs/lane-mile depending on temps
US	VA	Calcium Chloride	8-12 gallons/ton solid deicer
US	VT	mag chloride with	5-20% with salt brine
US	VT	salt brine (sodium chloride)	15-30 gals per ton
US	WI	road salt	
US	WI	Salt Brine 23.3 %	variable - unknown
US	WI	Salt Brine with Beet Heet	variable - unknown
US	WI	Salt brine with CaCl2	only for colder conditions
US	WI	salt brine with MgCl	only for colder conditions
US	WV	1:1 abrasive/salt with 8 gal/ton 23% by weight NaCl brine	200-500 #/LM
US	WV	100% salt with 8 gal/ton 23% by weight NaCl brine	100-250 #/LM
US	WV	2:1 abrasive/salt with 8 gal/ton 23% by weight NaCl brine	200-500 #/LM
US	WV	3:1 abrasive/salt with 8 gal/ton 23% by weight NaCl brine	200-500 #/LM
US	WY	sand salt - 9 gal brine	
		32% CaCl	1-5 L/lane km
		Calcium chloride	
		Magnesium chloride	
		rock salt	prewet with 1 liter of mag chloride per ton
		sand	prewet with 1 liter of mag chloride per ton
		sand pretreated with mag chloride	prewet with 1 liter of mag chloride per ton
		Sodium brine	

Table 36. Anti-Icers Used

Country	State	Anti-Icers (Liquid) Used - Blend	Application Rate
CANADA	AB	20% sodium 3% calcium	L per Lane KM 40, 44, 48, 52, 55, 59, 63, 67, 70
CANADA	AB	Beet 55	L per Lane Km 70-100
CANADA	AB	calcium	

Country	State	Anti-Icers (Liquid) Used - Blend	Application Rate
CANADA	AB	Calcium Chloride	L per Lane KM 80, 87, 95, 102, 110, 117, 125, 133, 140
CANADA	AB	calcium chloride	100 l/km
CANADA	AB	potassium	on sidewalks
DENMARK		24% NaCl	15-30 ml/m²
NORWAY		NaCl brine	15-40 g (ml)/m2
SOUTH KOREA		CaCl	160kg/km/lane
SOUTH KOREA		NaCl	160kg/km/lane
US	AK	Enhanced Salt Brine	30-50 gal/ LM
US	AK	Salt Brine	30-50 gal/ LM
US	AK	Salt Brine w/10% calcium and GLT	30 gplm
US	AK	Salt Brine w/20% calcium and GLT	30 gplm
US	AK	Salt Brine w/GLT	30 gplm
US	AK	Urea	.06 / sq ft.
US	AZ	Brine	40-70 gal/lane mile
US	AZ	Mag Chloride	20-50 gal/ lane mile
US	CA	75 brine, 15 org, 10 cal chloride	20gal per lm
US	DE	rock salt brine	50 gallons per lane mile
US	ID	23% sodium chloride salt brine w/10% Boost	15-50 gal per lane mile.
US	ID	23% sodium chloride salt brine.	15-50 gal per lane mile.
US	ID	Boost	20/80 mix with brine
US	ID	BOOST	20 PERCENT BOOST / 80 PERCENT BRINE
US	ID	boost	25 to 30 gallons per mile.
US	ID	Brine	35 g/lm
US	ID	brine	35-60 gallons per lane mile
US	ID	brine	varies
US	ID	Mag	20 gallons per lane mile to start with
US	ID	Mag	
US	ID	mag	30-40 gal per mile
US	ID	Mag Chloride	15-60 gal per lane mi
US	ID	Mag chloride	10 to 35 gallon per lane mile
US	ID	Mag Chloride	25 gallons per mile up to 40 gallons /mile Mag Chloride
US	ID	Magnesium Chloride	Varies
US	ID	Magnesium Chloride	20 to 80 gal per lane mile
US	ID	MgCl	20-60gplm
US	ID	MgCl	varies

Country	State	Anti-Icers (Liquid) Used - Blend	Application Rate
US	ID	pre-wet salt	200 lbs per mile
US	ID	Salt Brine	15-40 gallons
US	ID	Salt Brine	30 gal / mile up to 50 gal/mile
US	ID	SALT BRINE	35-60 GALLONS PLM
US	ID	Salt Brine	Varies
US	ID	salt brine.	35 to 45 gallons per mile
US	ID	straight salt, but mostly brine	varies
US	IL	Supermix	40 gals/lane mile
US	IN	Enhanced Brine w/corrosion inhibitor	
US	IN	NaCl brine	45 gallons/ln mile
US	IN	NaCl brine/25% Beet Heet mix	45 gallons/ln mile
US	IN	Salt Brine w/ corrosion inhibitor	
US	KS	MgCl	varies
US	KS	NaCl	varies
US	KS	NaCl + Beet Juice	varies
US	KY	Salt Brine	40 gallons per lane mile
US	MA	90/10 brine with AG 64	40-50 gal per mile
US	MA	90/10 brine with AG 64	40-50 gal per mile
US	MA	CaCL	8 gallons per ton
US	MA	MagCL	8 gallons per ton
US	MA	Organic anti-icers	10-30 gal p/mile
US	MA	Salt brine	30-60 gal p/mile
US	ME	Salt Brine	40-60 gal/LM
US	MN	90% brine/10% Beet Heet	20-60 gal per lane mile
US	MN	Brine	20 gal per lane mile
US	MN	salt brine with beat heat 75%/25%	
US	MO	beet juice	44 to 88 gallons per lane mile
US	MT	23.30%	40-60 gallons/lnmile
US	MT	30% MgCl2	30-40 gallons/lnmile
US	ND	salt brine/Geomelt	80/20 ratio at 20gal/mi and up
US	NH	brine with mag chloride	30 gallons per lane mile
US	NY	80% salt brine 20% mgcl	8-15 gal/ton
US	NY	Salt brine	8-15 gal/ton
US	SD	Salt Brine	20-60 gal per lane mile
US	TX	Brine	50 gal per lm
US	UT	Brine	
US	UT	High Performance MagChloride	50-200 gal/lane-mile
US	UT	NaCl brine	50-200 gal/lane-mile

Country	State	Anti-Icers (Liquid) Used - Blend	Application Rate
US	UT	Standard MagChloride	50-200 gal/lane-mile
US	VA	Brine 23%	20-30 gallons / lane mile
US	WI	Brine + Beet Heet	unknown
US	WI	salt brine	
US	WI	Straight Salt Brine 23.3%	40 gal / lm
US	WV	23% by weight NaCl salt brine	40-60 gal/LM
		32% CaCl	70-120 L/lane km
		80/20 mix salt brine/agg product	20-50 gallons
		Calcium chloride	
		Sodium brine	

Appendix C – Supplemental Information, Snow Equipment used in Norway

Here are links to some websites from suppliers of snow removal equipment in Norway:

- Aebi-Schmidt, https://www.aebi-schmidt.no/no/produkter/snorydding

Information provided below is quoted from this web address: https://www.aebi-schmidt.no/en/products/snow-clearance/384

"**Hydraulic fine-finish blade for Tarron MS snow ploughs**

Whenever and wherever possible, the use of thawing agents should be reduced further or even completely avoided. The innovative and easy-to-use hydraulic fine-finish blade by Schmidt complies with this requirement in a highly efficient manner by reliably removing snow residues – of course, this high-performance blade also contributes to substantially increasing safety.

Compatible with Schmidt MS snow ploughs – and suitable for heavy duty application on rural roads and motorways

Although the fine-finish blade removes even the finest snow residues with great sensitivity, it demonstrates maximum sturdiness and best-possible material quality during operation: As a result of its stable construction, it is perfectly prepared for application over long distances on rural roads and motorways. The Schmidt fine-finish blade is an accurately fitting attachment for the MS 32 / 34 / 36 / 40 snow ploughs.

Complies with Norwegian statutory requirements – and perfectly adapts to any situation also in terms of technology.

The fine-finish blade, which complies with the statutory requirements, is a system consisting of several parts, designed for at least four blades and mounted similarly to the cutting blades – including the movable outer section. The blade is located behind the trailing edge of the plough frame. Our blade permits a plough swiveling angle of 32 degrees. The cutting blades are easily and rapidly mounted via a convenient clamping device; the cutter edges are made of low-noise rubber.

The fine-finished blade is actuated hydraulically by the vehicle. When deactivated, the machine has a sufficient ground clearance of 100 mm."

- Øveraasen, https://overaasen.no/493/used_equipment

Information provided below is quoted from this web address:
https://overaasen.no/539/black_without_salt

"Black without Salt

A completely new concept consisting of a plough with slush elements and a trailed powerful rotating brush.

The idea is to get safer roads without using the amount of salt that we are used to. The result using this concept is substantially improved friction and road conditions, as well as you achieve major environmental benefits. If required a brine sprayer, with up to 3 lanes working width, can be fitted at the rear end of the sweeper. The brine amount is automatically adjusted and can be GPS – controlled for easy use, reporting and documentation.

With this concept the road is being cleared in four steps:

1. The main blade clears most of the snow.
2. Remains and the slush are removed with the slush elements, which are an integrated part of the main blade.
3. A powerful rotating brush joins efficiently with the roadway profile and removes the remaining snow and slush.
4. If necessary, the road can be sprayed with a small amount of brine. Thanks to the thorough mechanical removal of snow and slush described in steps 1-3, the amount of salt can be reduced considerably compared to what you are used to from the past."

Additional Companies

- GMI, Gratangen Mekaniske Industri, http://www.gmi-as.no/index.php?option=com_content&view=category&layout=blog&id=9&Itemid=52
- C.Grindvold, https://grindvold.no/vinterprodukter/index
- Mahlers, http://mahlers.se/no/mahlers.html

Appendix D – AVL GPS Recommendations, Supplemental Material

AVL/GPS best practices and recommendations for the consideration, implementation, and evaluation of AVL/GPS reported in Clear Roads 16.01 (http://clearroads.org/wp-content/uploads/dlm_uploads/FR_CR.16-01_Final.pdf).

Planning and Decision Making

- Involve agency leadership and management throughout the project.
- Identify agency's needs, goals, and objectives for an AVL/GPS system.
- Assess the number of vehicles within the agency fleet that will require AVL/GPS hardware and integration based on needs and financial flexibility.
- Conduct research and/or pilot projects to gain knowledge as well as identify issues and opportunities prior to full system implementation.
- Consider phased implementation to ease adoption of technology.

Procurement

- Use a Systems Engineering approach in the development of system requirements and specifications.
- Leverage other agencies' experience in requirements and RFP development, to ensure in part that agency expectations are clearly stated.

Methods of Procurement

- Consider the use of a Request for Information (RFI) process to gather information on the current state of AVL/GPA system technology.
- Use the best value procurement for selecting an AVL/GPS vendor.
- Consider the use of a turnkey contract for complex implementation.
- Leverage existing contracting vehicles for expedited procurement.

System Implementation

- Arrange installation schedule to minimize impacts to winter maintenance operations.
- Install AVL/GPS equipment at protected locations with access for maintenance.
- Involve and train agency mechanics for AVL hardware installation.
- Anticipate issues and challenges associated with integration between other equipment and an AVL/GPS system.
- Communicate with bidders regarding anticipated challenges with system integration during procurement.
- Perform regular outreach to maintenance field operations personnel.
- Communicate and demonstrate the purpose the of the system to snow plow operations to alleviate concerns.

- Be prepared to deal with winter maintenance cultural changes.
- Evaluate cellular providers to maximize coverage and supplement with other communication methods to fill the gaps.
- Provide training to all levels of system users before, during, and after system implementation.
- Require AVL vendor to provide initial training to agency winter maintenance staff on system operations and maintenance.
- Communicate the benefits of AVL/GPS system operations as part of the training to establish buy-in with the system among system users.
- Conduct recurring training to winter maintenance agency staff to improve the agency's ability to achieve operations objectives.
- Establish a "train the trainer" program to help retain system knowledge within the agency.

Data Collection and Utilization

- Require AVL vendor to make system data available to the agency.
- Understand the limitations on material usage data accuracy.
- Identify agency staffing and resources needed to support the management of the AVL/GPS system prior to system procurement.
- Use real-time system data to make adjustments to resource allocation and maintenance strategies.
- Integrate other road condition data with mobile observations for AVL/GPS systems.
- Establish a performance management program to document performance and benefits.
- Work with system vendors to develop agency desired data reporting features and performance dashboards.
- Use internal resources to develop agency desired reporting features and performance dashboard.
- Consider sharing vehicle location data with the general public.

Operation and Maintenance

- Obtain support and secure funding to sustain on-going operations and maintenance.

research for winter highway maintenance

Lead state:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Blvd.
St. Paul, MN 55155