TRANSPORTATION RESEARCH SYNTHESIS

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TRS 0902
Published May 2009

Anti-icing in Winter Maintenance Operations: Examination of Research and Survey of State Practice

Introduction

Anti-icing, a proactive snow and ice control strategy that is sometimes practiced as the first line of defense in a winter maintenance operation, came into practice during the 1990s. As anti-icing is most commonly conducted, a small amount of liquid chemical is applied to the roadway or bridge deck prior to a storm to prevent ice from forming a bond with the surface. The benefits of anti-icing are well documented in national studies and manuals, and in field tests conducted by various state departments of transportation, including Minnesota DOT.

Mn/DOT is developing an anti-icing guide that will be incorporated into the department's existing winter training program. The guide will be used by front-line supervisors and managers to better manage their winter operations and by operators to assist them in effectively performing their snow and ice control duties.

To prepare for development of the anti-icing guide, Mn/DOT asked us to review relevant research to identify existing anti-icing practices, field strategies and procedures, and application rates. We also reviewed 12 transportation agencies' anti-icing guidelines and procedures to identify current patterns of practice.

Summary

We conducted a broad review of the research related to anti-icing programs and identified seven key topic areas:

- National guidance
- Handbooks and manuals
- Best practices
- Product selection
- Anti-icing technology
- Prewetting
- Equipment

This research synthesis highlights studies that are representative of the activities in a particular topic area; related **Transportation Agency Documents** are also included for some topics. Key findings by topic area follow:

National Guidance

- A 2007 NCHRP report provides a decision tool to assist anti-icing program managers in selecting materials based on their cost, performance, and impacts on the environment and infrastructure.
- Strategies and tactics for developing an effective anti-icing program are presented in two 2004 NCHRP reports. The reports include a step-by-step procedure for determining an appropriate treatment strategy and recommended practices to minimize the use of anti-icing materials to mitigate environmental impacts.

Prepared by CTC & Associates LLC

- A 1999 FHWA report provides guidance for six types of winter weather events and recommendations for selecting and applying materials.
- The reports highlighted in this section reflect some common wisdom with regard to recommended anti-icing strategies, including:
    - Apply anti-icing treatments in advance of an anticipated weather event.
    - Pavement temperatures above 20° F to 23° F are recommended for anti-icing with liquid chemicals.
    - A 23 percent (or 23.3 percent) solution of liquid sodium chloride has been proven effective.
    - Dry solid chemicals are appropriate for use in an anti-icing program. Prewetting of dry materials is recommended if sufficient moisture is not present on the pavement.
    - Anti-icing is not recommended in windy conditions, or when pavement temperatures fall below or rise above threshold temperatures.
    - Streamer or pencil nozzles are recommended for applying liquid chemicals; fan nozzles are not recommended.

Handbooks and Manuals

- Publications by the Utah LTAP Center, Salt Institute, and the Minnesota Local Road Research Board provide similar guidance, including:
    - Anti-icing is effective for heavy frosts.
    - Liquid sodium chloride is effective to –6° F.
    - Pavement temperature is critical to determining the appropriate treatment.
    - Apply liquid chemicals with streamer nozzles.
    - Do not anti-ice under windy conditions.

Best Practices

- Two studies conducted for the Ohio Department of Transportation sought to optimize the use of salt brine as an anti-icing protocol. Researchers examined the decay of salt brine subjected to traffic and developed a decision tree that can be used to determine when and how to anti-ice.
- A 2006 Connecticut study reviewed alternatives for winter maintenance operations, noting the benefits of anti-icing and discussing alternatives to the use of sodium chloride. Alternatives to sodium chloride are also considered in a 2004 Western Transportation Institute study that recommends improved anti-icing practices as a way minimize environmental impacts. Researchers consider general practices and the use of sodium chloride, chloride-based deicers, and chloride alternatives.
- Western Transportation Institute researchers examined the advantages and disadvantages of anti-icing in a 2005 study. Constraints identified in the study include training and management, reliance on accurate weather forecasts, and public perception.
- A 2004 conference paper presents performance measurement tests of liquid anti-icing chemicals that can be used in a quality control program.
- The Wisconsin Transportation Information Center and the Transportation Association of Canada present anti-icing techniques and strategies in concise syntheses of best practices. Fact sheets from transportation agencies in Colorado, Maine, Minnesota and North Dakota present anti-icing as a best practice to the general public.
- A PowerPoint presentation from the Virginia Department of Transportation offers training for field commanders on anti-icing and road weather information systems.

Product Selection

- An approved product list provided by the Pacific Northwest Snowfighters Association includes products that have passed a variety of tests and meet environmental and health standards.
- Methods to assist in material selection are addressed in the following:
    - A 2007 Salt Institute newsletter article highlights the decision tool included in *NCHRP Report 577*.

    - University of Iowa researchers proposed a method for selecting chemicals for specific anti-icing needs in a 2001 report. Products are scored by weighting seven categories and assigning grades to each category.
- A 2008 TRB Annual Meeting paper presents the results of experiments to determine the lifetime of salt brine residue from anti-icing applications on asphalt concrete and portland cement concrete.
- The effects of anti-icing chemicals are considered in the following studies:
    - A 2008 South Dakota study investigated the effects of liquid anti-icing chemicals on portland cement concrete.
    - Researchers in a 2006 Oregon study evaluated the effects of liquid magnesium chloride on the friction values of open-graded pavements.
    - Corrosion effects of two liquid anti-icing chemicals were considered in a 2002 Colorado study.
- The use of alternative chemicals is considered in the following:
    - A 2009 Colorado study evaluated alternative anti-icing chemicals and proposed a composite index to assist in product evaluation.
    - A blend of ice control chemicals developed by the McHenry County, Ill., Transportation Division is highlighted in a 2006 Salt Institute newsletter article.
    - Michigan's use of agricultural by-products for anti-icing is evaluated in a 2002 study.
    - A 2006 Michigan Department of Transportation document includes a discussion of the use of two anti-icing agents: calcium magnesium acetate and potassium acetate.

Anti-icing Technology

- Cargill's SafeLane surface overlay, which is designed to absorb and store liquid deicing chemicals that are applied to the roadway surface, is evaluated in a 2009 Virginia study.
- Fixed automated spray technology is examined in a variety of studies and reports. Findings from these studies include:
    - Problems have been identified with regard to system maintenance. Most sites receive no preventative maintenance, except for an annual draining and flushing of the system at the start of the summer.
    - Installation is a challenge, and difficulties appear to be expected in areas related to software and system activation.
    - Careful selection of appropriate sites is recommended; all facilities should be above ground.
    - Active sensors produce a more accurate determination of brine freezing point than do passive sensors.
    - Achieving full system automation is challenging.

Prewetting

- Documents from Maine and Michigan agencies consider the use of liquid calcium and salt brine as prewetting liquids for dry solid anti-icing and deicing agents, and evaluate appropriate application rates.

Equipment

- Two reports from the Maine Department of Transportation discuss the evaluation and modification of the Schmidt STRATOS salt spreader.
- Anti-icing equipment used by the Iowa Department of Transportation is detailed in two documents that offer recommendations for modification and a photo gallery of the types of equipment used to support anti-icing operations.

National Guidance

Three NCHRP reports, a 1999 AASHTO guide, and a 1996 FHWA report offer wide-ranging guidance to anti-icing program managers. Some reports address anti-icing with a narrow focus—for example, selecting materials to mitigate environmental impacts—while other reports take a comprehensive look at anti-icing operations.

Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts, *NCHRP Report 577*, 2007.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_577.pdf
This report presents guidelines for the selection of snow and ice control materials through an evaluation of their cost, performance, and impacts on the environment and infrastructure.

Page 18 of the PDF discusses the appropriate use of dry solid chemicals in anti-icing programs:

> Anti-icing applications are not limited to liquid chemicals. Properly timed applications of either dry or prewetted chemicals can prevent bond formation if these materials can be held in place and not removed by traffic action. As such, anti-icing with solids can be very effective on sidewalks and other areas not subject to vehicle action.

A decision tool is described on page 98 of the PDF:

> The decision tool mathematically combines product rankings and agency objectives for general categories and provides a product score that can be compared with other products.

A guidebook to the decision tool, purchase specifications, and quality assurance monitoring begins on page 166 of the PDF.

Snow and Ice Control: Guidelines for Materials and Methods, *NCHRP Report 526*, 2004.
http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_526.pdf
This report provides guidelines for selecting roadway snow and ice control strategies and tactics for a wide range of winter maintenance operating conditions. Recommendations from the report include:

Product Application: Dry Solid Chemicals

- Dry solid chemicals can be used to pretreat roadways before a snow or ice event if applied at traffic speeds below 30 mph and with traffic volume less than about 100 vehicles per hour.
- The use of fine-graded salt during anti-icing operations generally is not cost effective compared to the use of coarse-graded salt. This is true for most forms of frozen precipitation, including freezing rain and sleet.
    - Fine-graded salt dilutes faster than coarse-graded salt and has to be reapplied more often and at greater rates during a winter weather event than coarse graded salt to achieve a similar chemical effectiveness.
    - The fast brine generation of fine-graded salt when applied to a pavement will produce a wet pavement sooner than coarse-graded salt, but the condition will not be long lasting. This situation can quickly lead to a refreeze of the brine solution unless additional salt applications are made.
    - The use of fine-graded salt is better suited for the treatment of thin ice and, when prewetted, as a pretreatment for frost conditions when applied just prior to daylight.

Product Application: Liquid Chemicals

- A 23 percent solution of liquid sodium chloride (NaCl) applied at 40 to 60 gallons per lane mile (or equivalent effective amount of other chemical) has proven to provide protection from conditions resulting from nonprecipitation events.
- Anti-icing with a liquid chemical is a good strategy when the pavement temperatures are above about 20° F at the onset of a snowfall event. Liquid chemicals are probably not a good choice at pavement temperatures below about 20° F.
- Treating frost/black ice/icing that has already occurred with liquid chemicals is an excellent tactic.
- Liquid ice control chemicals are particularly well suited to pretreating for anticipated frost/icing/black ice situations. Here, the water evaporates and the residual dry chemical is relatively immune to dispersal by traffic.
- At pavement temperatures higher than about 28° F, liquid chemicals are a very effective treatment for thin ice in the absence of precipitation. The ice-melting process in this situation is almost immediate.

Prewetting

- In theory, only a sufficient amount of liquid to wet every particle of a dry chemical is required for prewetting. The actual rate to achieve this wetting will vary with the particle size distribution. In practice it has been found that 10 to 12 gallons of a NaCl solution will be sufficient for 1 ton of dry chemical of coarse gradation.

When Not to Anti-ice

- Anti-icing is not a good strategy when the pavement temperatures are below about 20° F, at the onset of a snowfall event, or at any freezing pavement temperatures when the snowfall event is preceded by rain.
- Anti-icing with liquid chemicals is not recommended during freezing rain or sleet events.
- Anti-icing with solid or prewetted solid chemicals is not a good strategy when the pavement temperatures are below about 15° F at the onset of a winter weather event. The use of chemicals below these minimum pavement temperatures will require excessive amounts of chemicals to be used.

Precautions

- Liquid chemicals should be limited to lower moisture content events, pavement temperatures above 20° F, and cycle times less than about 1.5 hours. This will minimize the risk of forming an ice/pavement bond.
- It is not advisable to use liquid chemicals during moderate or heavy snow, sleet, and freezing rain events.
- The use of liquid chemicals during general snow and ice events requires more caution and information in order to achieve satisfactory results. Liquid chemicals are more sensitive to pavement temperature, dilution, and ice/pavement bond than solid chemicals.
- There have been rare circumstances when using a liquid chemical has resulted in slippery conditions in the absence of precipitation or freezing pavement temperature. This phenomenon seems to be related in many instances to the combined effect of relative humidity, pavement temperature, and chemical type. The untreated areas between strips should help minimize the potential for this type of slipperiness.
- Crosswind speeds in excess of about 15 mph may cause local snow drifting and inhibit anti-icing operations.
- There is always the potential danger of chemical residuals becoming diluted and resulting in a refreeze condition, whether at elevated or low temperatures.

Equipment Considerations

- When using chemicals other than liquid NaCl, it is recommended that streamer or pencil nozzles or holes in the spray bar be used to apply strips of chemical to the surface.
- Liquid chemical sprayers should be set closer to the pavement during windy conditions to avoid spray loss.
- The spacing of nozzles or holes should be in the range of 8 inches.

Residual Effect of Application

- In the absence of precipitation, liquid chemical treatments are effective for at least three days and possibly up to five days depending on traffic volume. If the liquid treatment is allowed to dry before the event, it will be slightly more effective.

Attachment 1, **Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions**, begins on page 38 of the PDF. This portion of the report defines a step-by-step procedure that winter maintenance field personnel can follow in determining an appropriate treatment action to take in response to a variety of conditions. Implicit in the recommended treatment steps is the requirement that plowing, if needed, should be performed before chemical applications are made. A brief summary of the steps appears below:

Step 1: Determine the pavement temperature at the time of treatment and the temperature trend after treatment.

Step 2: Establish the dilution potential that a chemical treatment must: (1) endure before another treatment is made during a winter weather event, or (2) produce a satisfactory result in the absence of precipitation at the end of an event.

Step 3: As needed, adjust the precipitation dilution potential to account for various wheel-path-area conditions.

Step 4: Make an additional adjustment to the precipitation dilution potential for treatment cycle time. This is the time between anticipated successive treatment passes. In the case of pretreating, it is the time between the onset of precipitation and the next anticipated treatment.

Step 5: An extra adjustment to the precipitation dilution potential may have to be made for traffic speeds greater than 35 mph and traffic volume greater than 125 vehicles per hour.

Step 6: Make a judgment of whether an ice/pavement bond condition exists based on field observations or sensor data.

Attachment 2, **Example of Designing a Chemical Snow and Ice Control Treatment**, begins on page 47 of the PDF. This portion of the report puts the steps outlined in Attachment 1 into practice using data from a simulated snow and ice winter weather event.

Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance, *NCHRP Project 25-25, Task 4*, 2004.
http://www.trb.org/NotesDocs/25-25(4)_FR.pdf
This report, prepared in conjunction with NCHRP Project 25-25(04), presents a series of best practices to guide the development of environmental strategic plans in specific functional areas. Points of interest related to anti-icing include:

- Subchapter 8.4., "Stewardship Practices for Reducing Salt and other Chemical Usage," which begins on page 577 of the PDF, includes a discussion of precision application of anti-icing materials, and monitoring, record-keeping and decision support.
- The significance of road weather information is addressed on page 583 of the PDF:
  > National Weather Service forecasts are not sufficiently site-specific and do not include all the data necessary to provide the accurate, real-time storm prediction and road temperatures that make anti-icing strategies effective. Thus, Road Weather Information Systems (RWIS) are an essential tool in a successful anti-icing program.
- An extensive discussion of fixed automated spray technology begins on page 598 of the PDF.

Recommended practices to minimize the application of anti-icing materials include:

- Since anti-icing is preventive in nature it is desirable to have the first application completed two hours prior to the anticipated event, or at a minimum prior to bond forming on the road surface.
- Pavement should be cleared of as much snow, ice, or slush as possible before reapplying a liquid anti-icing material.
- Application rates for liquid anti-icing operations are based on local experience as documented through logs.

Guide for Snow and Ice Control, American Association of State Highway and Transportation Officials, 1999.
Abstract: http://ntlsearch.bts.gov/tris/record/tris/00799075.html
This guide is a comprehensive overview of the components required for a successful snow and ice control program. Chapters address personnel practices, equipment types and capabilities, the materials and chemicals needed for snow and ice removal, and the use of weather information technologies to improve resource allocation.

Manual of Practice for Anti-icing of Local Roads, University of New Hampshire, October 1996.
http://www.t2.unh.edu/pubs/manofpractice.pdf
This manual is a rewrite of the 1996 FHWA publication "Manual of Practice for an Effective Anti-icing Program." Many of the guidelines appearing in the FHWA report apply to heavily traveled roads and require considerable financial and technical resources to execute. The University of New Hampshire Technology Transfer Center's revision of the FHWA guide provides an emphasis on low-volume, low-speed roads.

Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel, *Report No. FHWA-RD-95-202*, June 1996.
http://www.fhwa.dot.gov/reports/mopeap/eapcov.htm
This manual provides information for the successful implementation of an effective highway anti-icing program. Anti-icing operational guidance is provided for six types of winter weather events (see pages 65 through 71 of the Word document):

- Light snowstorm
- Light snowstorm with periods of moderate or heavy snow
- Moderate or heavy snowstorm
- Frost or black ice

- Freezing rainstorm
- Sleet storm

The manual's other recommendations include:

Application Timing

- Snowplowing must remove as much snow or loose ice as appropriate before applying chemicals. Snow on the pavement will dilute the applied chemical and decrease its effectiveness. Because the initial chemical treatment should be placed before a significant accumulation, snowplowing is usually more important for applications during a storm.
- If the agency cannot apply chemicals before snowfall, it must apply it when the pavement condition is no worse than wet, slushy, or lightly snow covered. Because of a limited fleet, heavy traffic, or some other circumstance, pretreating the road before a snowstorm might be the only way to ensure treatment of all areas before conditions deteriorate.

Product Application: Dry Solid Materials

- Dry solid chemicals can be an effective anti-icing treatment where sufficient moisture or accumulation exists on the pavement. Moisture must be available for two reasons: to prevent loss of material off a dry pavement, and to trigger the solution of the salt. For initial operations, solid chemicals will be effective when applied after sufficient precipitation has fallen, but before snowpack or ice bonds to the pavement.
- NaCl is the solid chemical most commonly used for anti-icing treatments. A mix of solid NaCl and solid calcium chloride ($CaCl_2$) has been used by some agencies, and in some instances straight $CaCl_2$ has been used.
- Guidance is provided for the use of dry solid chemical treatments for three events only: light snowstorm, light snowstorm with periods of moderate or heavy snow, and moderate or heavy snowstorm.
- Course gradations can be a disadvantage. Fine particles have more surface area for an equivalent load weight and will go into solution faster. Their use on a clear or well-plowed road will decrease the time for a solution to form and cover the entire road surface, and therefore be more effective than will large particles.

Product Application: Liquid Chemicals

- Liquids can be used at pavement temperatures below 23º F by increasing the application rate over the levels recommended for 23º F and above.
- If a rapid rise in temperature is forecast liquid chemicals can be applied at temperatures as low as 15° F.

Prewetting

- Apply prewetted solids, either in advance of the storm or as an early-storm treatment. In the latter case, apply prewetted solids onto dry, wet, slush, or lightly snow-covered pavement before accumulation or pack bonds to the pavement. Late applications onto pavements with more than a light covering of slush or snow can result in excessive dilution of the chemical, and should be coordinated with plowing.
- Experience has shown the use of $CaCl_2$ to have an advantage over NaCl because it absorbs moisture from air at a relative humidity of 42 percent and higher. The absorbed moisture keeps the salt crystals on the pavement after much of the water has evaporated or been removed by traffic. Field tests have shown that a 20 percent $CaCl_2$ solution applied to NaCl at the rate of 30 percent by weight of the total mixture is effective.
- Agencies practicing anti-icing have found that 10 gallons of 23 percent concentration of NaCl solution will sufficiently wet a 1 ton of dry chemical of coarse gradation.

When Not to Anti-ice

- Do nothing when traffic and wind (speeds of 15 mph or higher) may be sufficient to prevent accumulation and compaction when the pavement is cold (below 15° F) and new or blowing snow is light and cold.
- If the initial or previous anti-icing treatments have done their job, the pavement temperature is around 28° F and holding steady or rising, and there is no additional precipitation coming down or forecast, there may be no need for further action.

Handbooks and Manuals

Publications by the Utah LTAP and a nonprofit trade association provide practical advice for developing and maintaining an anti-icing program. **Transportation Agency Documents** include Minnesota's 2005 field handbook for snowplow operators, which offers guidance for applying anti-icing materials.

Winter Maintenance Manual, Utah LTAP Center, August 2008.
http://www.utahltap.org/Services/winter2008.pdf
This guide to anti-icing and snow control strategies includes information about product selection, material usage, quality control and application rates.
Recommendations with regard to anti-icing include:

- Anti-icing should be first in a series of strategies for each winter storm.
- Anti-icing is most cost effective on heavy frosts and freezing fogs.
- Liquid chemicals are better than dry solid chemicals for anti-icing.
- Plowing should be used to remove snow and loose ice before anti-icing applications. If snow accumulates before or after applications, plowing directly before the next application will minimize product dilution.
- Anti-icing trucks should be equipped with front-end plows.

The Snowfighter's Handbook, Salt Institute, 2007.
http://www.saltinstitute.org/content/download/484/2996
Originally published in 1967, this 40th-anniversary edition includes sensible salting methods designed to provide the most effective snow and ice control program at the lowest overall cost with the least impact on the environment. Highlights of the anti-icing information that appears throughout the manual include:

Cost Savings

- Research has shown that timely applications of anti-icing materials can cut the cost of maintaining a safe road surface by 90 percent compared to traditional deicing.
- Anti-icing requires anywhere from one-third to one-quarter the material of deicing, making it the most cost-effective option for improving winter traffic safety.

Product Selection

- The handbook defines anti-icing as spraying brine on pavement before the storm arrives.
- Liquid NaCl is the most effective choice for anti-icing above 15° F.
- The most common material in use is NaCl in the form of a brine made from a mixture of rock salt and water. NaCl brine is effective to –6° F.
- Some agencies use $CaCl_2$ or magnesium chloride ($MgCl_2$) in a brine solution, which is effective to –6° F, but these materials are more than six times as expensive than NaCl, and more difficult to handle. Also, $CaCl_2$ and $MgCl_2$ residue on road surfaces can attract moisture at lower relative humidity than NaCl resulting in dangerous, slippery conditions under certain circumstances.
- The proper brine mixture is 23.3 percent NaCl content by weight. This is the concentration at which NaCl brine has the lowest freezing point: –6° F.

Product Application

- Because of the much greater control inherent to the spray process, anti-icing is best applied with full-width stream nozzle systems to maintain a small width of bare pavement to reduce slipperiness. A fan spray is not recommended and care must be exercised during windy conditions.
- Do not apply anti-icer under blowing conditions, particularly in areas prone to drifting.
- Do not apply too much material or the roadway may become slippery.
- Do not apply $CaCl_2$ or $MgCl_2$ to a warm road (above 28° F pavement temperature). It can become very slippery and cause crashes.
- Additional precipitation always results in a dilution of brine at the road surface.

Transportation Agency Documents

Minnesota Snow and Ice Control: Field Handbook for Snowplow Operators, Minnesota Local Road Research Board, *Manual Number 2005-01*, August 2005.
http://www.mnltap.umn.edu/pdf/snowicecontrolhandbook.pdf

Highlights of the handbook's recommendations for anti-icing include:

General Guidelines

- Anti-icing is often effective for heavy frosts.
- Anti-icing works best when combined with accurate road weather information.
- Early application is particularly important for frost or light freezing drizzle.
- Liquids are the most efficient and may be applied days in advance of an event.
- Pretreated salts will work at lower applications (lowest possible setting, less than 100 lbs/two-lane mile) closer to the expected event.

Product Application

- Apply only with stream nozzles to maintain some bare pavement between sprayed areas to reduce slipperiness. Fan spray is not recommended.
- Schedule applications on bridge decks and critical areas if temperature and conditions could produce frost or black ice.
- Consider spot-applications on hills, curves, and intersections if predicted conditions warrant.
- Use the appropriate chemical for the pavement temperature range.
- Application rate guidelines are found on page 24 of the PDF.

When Not to Anti-ice

- Do not anti-ice under blowing conditions, in areas prone to drifting, and anywhere else you would refrain from using salt. Be aware of areas that are prone to wind issues.
- Do not apply before predicted rain.

Precautions

- Reapplication is not always necessary if residual material is present on the surface. The residual effect can remain for up to five days after application if precipitation or traffic does not dilute the initial application.
- Remember that the surface can refreeze when precipitation or moisture in the air dilutes the chemical.
- Do not apply $MgCl_2$ or $CaCl_2$ to a warm road (above 28° F pavement temperature). It can become slippery and cause crashes.
- For the first application or after a prolonged dry spell, apply liquids at half the rate (not half the concentration). On dry roads, liquids tend to mix with oil from vehicles and cause slippery conditions.
- Do not apply too much material or the roadway may become slippery. Always follow application recommendations.

Best Practices

The research below seeks to provide best practices by improving anti-icing application techniques and product selection protocols and recommending quality control practices. **Transportation Agency Documents** include state DOT anti-icing fact sheets and a PowerPoint presentation used to train field commanders on anti-icing strategies.

Evaluation of ODOT Roadway/Weather Sensor Systems for Snow & Ice Removal Operations/RWIS Part IV: Optimization of Pretreatment or Anti-Icing Protocol, Gayle F. Mitchell, Wallace Richardson, Andrew Russ, Ohio Department of Transportation, *Report No. FHWA/OH-2006/24*, November 2006.
http://www.dot.state.oh.us/Divisions/Planning/Research/reportsandplans/Reports/2006/Maintenance/14758_Part_IV-FR.pdf
This study addressed the use of brine as a pretreatment protocol for winter maintenance of roadways. Researchers surveyed state DOTs and county garages in Ohio and conducted field durability studies of various applications of brine on portland cement concrete and asphalt concrete pavements in Ohio. Over three winter seasons, weather events and resulting pavement conditions were documented during pretreatment and during the subsequent events. Extensive laboratory studies supplemented the field investigations.

Findings from the study resulted in the creation of a decision tree that can be used once per day when a significantly updated weather forecast becomes available. Researchers recommend considering the following when **deciding to pretreat**:

- Temperature of pavement, bridge deck simulator, or air at the time of application.
- Timing of the application based on:
  - Forecast
  - RWIS data
  - Estimated traffic counts and peak periods
  - Work schedules
- Residue from prior applications.
- Brine application rate in gallons per lane mile based on:
  - Type of event
  - Condition of pavement
  - Traffic counts
- Truck/equipment settings and calibration for the specified application rate.

Page 399 of the PDF lists the **principles on which the decision tree is based**:

- If there is forecast winter weather likely to affect driving conditions it is desired to have some form of salt on the road, preferably in the form of dried brine.
- If there is no or very little salt residue on the road, pretreatment is recommended, except under the following conditions:
  - Pretreatment would be rendered ineffective by weather conditions.
  - Blowing snow may make pretreated roads dangerous.
- If the decision is made to pretreat, the pretreatment may require an application rate of double the normal value to compensate for circumstances that would otherwise deplete the salt residue below a value likely to be effective. These circumstances include more than 24 hours before the anticipated event with no intervening regular work days, roads that have surfaces on which normal pretreatment rates have been observed to be not effective, and anticipation of sleet or freezing rain.

Pages 400 and 401 of the PDF provide the decision tree in the form of a Winter Maintenance Brine Pretreatment Decision Flowchart.

Improving Winter Highway Maintenance: Case Studies for Connecticut's Consideration, Lisa Aultman-Hall, Scott Zinke, Connecticut Department of Transportation, *CT Study No. 2246-F-06-4*, April 2006.
http://docs.trb.org/01033137.pdf
The goal of this study was to provide a literature-based best practices/case studies review of alternative approaches for winter highway operations in use today or planned within the U.S. or other countries that may be applicable for use in Connecticut.

Anti-icing benefits noted in the report:

- The case studies show that a shift in overall philosophy of winter maintenance from deicing to anti-icing can result in almost complete elimination of sand and some increase in the use of salt.
- Monetary savings will most likely accrue from a significant reduction in spring cleanup.
- Safer road conditions were reported.

- Although NaCl has some negative environmental consequences associated with its use and is a concern of the Environmental Protection Agency, the elimination of or significant reduction in the use of sand will have positive environmental and potentially health benefits.

The authors considered **salts other than sodium chloride**:

- $MgCl_2$ and $CaCl_2$ are commonly used for both anti-icing and deicing because they are effective at lower temperatures, when NaCl does not work.
- Colorado makes use of two forms of $MgCl_2$. One form is used in temperatures above 16° F and the other is used in temperatures below 16° F.
- The form of $MgCl_2$ that is used for the lower temperature range is combined with a corn by-product, which lowers the freezing point of water. Both forms are reported to have little or no negative environmental impacts.
- Researchers suggest the use of calcium magnesium acetate and potassium acetate as viable alternatives to traditional salt. Negative watershed ecosystem and drinking water impacts are significantly reduced with the use of these alternatives; however, these products are considerably more expensive than traditional salt.

Pre-wetting and Anti-icing—Techniques for Winter Road Maintenance, Wisconsin Transportation Information Center, December 2005.
http://epdfiles.engr.wisc.edu/pdf_web_files/tic/bulletins/Bltn_022_prewetting_antiicing.pdf
This fact sheet summarizes Wisconsin DOT's anti-icing guidelines and offers suggestions for preparations, precautions and follow-up activities after a winter storm. (See the State DOT Anti-icing Practices section of this TSR for details of Wisconsin DOT's anti-icing program.)

Synthesis of Information on Anti-icing and Pre-wetting for Winter Highway Maintenance Practices in North America, Katie O'Keefe, Xianming Shi, Western Transportation Institute, August 19, 2005.
www.wti.montana.edu/ForceDownloadHandler.ashx?name=4W0169_Final_Report.pdf
This project synthesizes information obtained from a literature review and agency surveys on the advantages and disadvantages of anti-icing and prewetting for winter highway maintenance. The research indicates that, compared with traditional methods for snow and ice control, anti-icing and prewetting lead to decreased applications of chemical products, reduced use of abrasives, decreased maintenance costs, improved roadway friction, and lower accident rates.

The report addresses **constraints of anti-icing** on pages 47 through 49 of the PDF:

- **Training and management**. Proper training and good management would help agencies select the best tools available for the specific combination of site, traffic and climatic conditions, which may include conventional snow and ice control methods.
- **Equipment costs**. With the addition of new equipment, it is also important that field maintenance crews understand the extent of operations.
- **Reliance on accurate weather forecasts**. Accurate weather forecasts are critical in order to successfully implement anti-icing practices, because such information will guide the timing and amount of chemicals needed for anti-icing operations.
- **Casual slipperiness effect**. The slipperiness effect of anti-icing is caused by chemical residue remaining on the road, which may draw water to the road surface and cause slippery conditions. There have been a few reported instances of this occurring across the snowbelt region; however, not all cases are traced back to winter maintenance chemicals.
- **Material handling**. Handling of liquid chemicals requires additional training; however, most anti-icing chemicals are also used for deicing and training is not considered onerous.
- **Public perception**. Maintenance managers surveyed for the study indicated that the public attitude toward anti-icing is mixed; however, positive responses outweigh the negative.

Recommendations for Winter Traction Materials Management of Roadways Adjacent to Bodies of Water, James Mark Staples, Laura Gamradt, Otto Stein, Xianming Shi, Montana Department of Transportation, *Report No. FHWA/MT-04-008/8117-19*, December 2004.
http://www.mdt.mt.gov/research/docs/research_proj/traction/final_report.pdf
This report summarizes the primary nonstructural best management practices used to reduce the use and minimize the environmental impacts of winter traction materials, including improved anti-icing practices.

Researchers highlight the importance of **training** to a successful anti-icing program on page 56 of the PDF:

> Lack of effective and scientifically based training has hampered progress in the implementation of anti-icing and road weather information system (RWIS) technologies. In order to take advantage of the many new technologies available, a computer based training (CBT) program has been developed by the Snow and Ice Pooled Fund Cooperative Program, and a generic version was distributed in April 2003 to be adjusted by receiving states. (See page 15 of this TSR for more information about AASHTO's Anti-Icing/RWIS Computer-Based Training Program.)

The report makes a series of recommendation for material use:

General Practices

- While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used.
- Deicing typically requires much larger quantities of material than an appropriately timed anti-icing application. However, deicing is still an appropriate technique for roadways with lower priority service levels, and it does not require accurate weather forecasts. Additionally, it can be used in situations when the weather forecasts were inaccurate, or anti-icing was ineffective.
- NaCl, $CaCl_2$, and $MgCl_2$ all contribute chloride to surrounding environments, and this chloride can have detrimental effects. Despite the potential damaging effects of chlorides, the use of chloride-based deicers can reduce the use of sand, cost less if used appropriately, and minimally affect surrounding environments.

Sodium Chloride

- NaCl is rarely used and minimally effective below pavement temperatures of 10° F.
- The primary advantage of NaCl is its abundance and relatively low cost, and the chloride associated with sodium is less toxic to aquatic life than those with calcium and magnesium.

Other Chloride-Based Deicers

- Many DOTs use $CaCl_2$ or $MgCl_2$ in a brine solution for anti-icing. While these chemicals are effective at lower temperatures than NaCl brine, they are also more costly than salt and can be difficult to handle.
- At low relative humidity, $CaCl_2$ and $MgCl_2$ residue on roads can attract more moisture than salt, resulting in dangerous, slippery conditions under certain circumstances. $MgCl_2$ is less corrosive and less expensive than $CaCl_2$, yet remains effective down to –22° F, as opposed to 10° F for NaCl and –60° F for $CaCl_2$.

Alternatives to Chloride-Based Deicers

- Calcium magnesium acetate (CMA) and potassium acetate (KAc) offer attractive alternatives to chloride-based deicers due to their noncorrosive characteristics, benign impacts on surrounding soils and ecosystems, and their lack of adverse human health effects.
- KAc can also offer an alternative to NaCl with fewer detrimental effects on the surrounding environment. KAc is more costly than CMA, yet performs quickly at much lower temperatures, and it is frequently used at airports on runways. A few DOTs have also used KAc for automated anti-icing systems on bridges with various levels of success.
- Biobased deicers, mainly those from agricultural by-products and wastes, are noncorrosive, significantly lower the freezing point, and enhance melting capacity. These products often come from the processing of beet juice, corn, molasses, and other agricultural products.
- Biobased deicers are designed to be biodegradable and environmentally friendly. These products may gradually replace traditional deicers and minimize the negative impacts of snow and ice control activities to the environment.

Page 67 of the PDF discusses **anti-icing pavement technology**:

> A recently developed anti-icing pavement overlay has the potential to greatly reduce the amount of chemicals needed for snow and ice control operations. Research in Michigan has combined an epoxy with an aggregate of limestone that can retain anti-icing chemicals for extended periods. With the overlay, it is difficult to wash off the deicers applied on the surface, and the anti-icing chemicals retained on the surface can prevent ice from bonding to that surface.

Recent tests of this overlay on a bridge in Wisconsin found monthly anti-icing treatments were more than adequate to retain the anti-icing properties. The potential exists for this overlay to receive only one anti-icing treatment each winter season. In addition to reducing the required frequency of anti-icing and de-icing operations, the greatest benefit from this technology will be less reliance on weather forecasting for effective anti-icing.

Role of Performance Specifications in Developing a Quality Control System for Winter Maintenance, Wilfrid A. Nixon, George Kochumman, Ju Qiu, Lin Qiu, Jing Xiong, *Sixth International Symposium on Snow Removal and Ice Control Technology*, June 2004.
See pages 555 through 563 of the PDF at http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.
This paper presents a series of performance measurement tests for anti-icing chemicals and discusses their role in a quality control program. Seven commonly used anti-icing liquids were tested, including:

- NaCl brine (23 percent concentration)
- $CaCl_2$ brine
- CMA
- KAc
- Ice Ban Ultra (20 percent Ice Ban, 80 percent NaCl brine)
- Caliber M-1000
- Mineral brine

Two tests—viscosity and specific gravity— proved to be suitable to be conducted in a maintenance garage when chemicals are received and could differentiate between the seven products tested. Researchers summarize the two tests as follows:

> **Viscosity**
> The method used in this test is specified in ASTM D 445-88. Samples of deicer (diluted to various ratios, if required)—300 ml in volume—were prepared. Suggested chemical to water ratios are 4:0 (all liquid chemical as supplied), 3:1 (three parts chemical to one part water), 2:2, and 1:3. The Ford cup viscometer was mounted on a stand, and a fixed volume of liquid was made to flow under gravity through the capillary of the calibrated viscometer. The time for the liquid to flow was noted. The viscosities at room temperature and temperatures between 0° F to 30° F were noted.
>
> **Specific Gravity**
> A hydrometer was used to measure the specific gravity of a sample. The solution was taken in a graduated funnel, and the hydrometer was suspended into the solution. The readings were read directly from the hydrometer.

Evaluation of ODOT Roadway/Weather Sensor Systems for Snow & Ice Removal Operations—Part III: Optimization of Salt Brine Pre-Treatment Application Rates and Frequencies, Gayle Mitchell, Christopher Hunt, Wallace Richardson, Ohio Department of Transportation, *Report No. FHWA/OH-2003/008C*, 2003.
http://www.dot.state.oh.us/Divisions/Planning/Research/reportsandplans/Reports/2003/Maintenance/14758-Part%20III-FR.pdf
At the time of this 2003 study, the Ohio Department of Transportation applied 40 gallons per lane mile of 23 percent NaCl brine at a minimum frequency of two times per week when conditions warranted. In order for ODOT to develop the most effective plan for pretreatment, an in-situ study to provide data on decay of brine on pavement receiving traffic was needed. Field studies yielded decay equations that can provide an estimate of brine residual as a function of time and traffic for the type of pavement surfaces investigated in this study. Laboratory tests with the field brine measurement instrumentation provided correction factors for the data.

An example of the study's results for NaCl brine as an anti-icing treatment on asphalt concrete appears on page 147 of the PDF:

> The example indicates the NaCl brine initial application rate required for anti-icing effectiveness for a precipitation event of 0.020-inches with a pavement surface temperature of 20° F (-6.6°C)….the residual required for this event is about 62 g/m2.
>
> When decay by traffic is considered, back calculation must be accomplished as shown in the red box within the figure. For the Figure 145 example, decay resulting from 4,000 vehicles is estimated. Application of the formula results in an estimation of the initial required application of brine of 136 g/m2 NaCl for protection at 20° F. A total bulk dispensing volume of 55.5 gallons per lane mile would be required for the example assuming no additional losses occur.

Syntheses of Best Practices Road Salt Management: 9.0 Winter Maintenance Equipment and Technologies, Transportation Association of Canada, September 2003.
http://www.tac-atc.ca/english/resourcecentre/readingroom/pdf/roadsalt-9.pdf
This best practices overview of the use of anti-icing methods to control snow and ice includes the following recommendations:

- If the application is earlier than the onset of a storm, a NaCl brine will evaporate leaving a salt crystal residue in the surface pores/texture of the pavement, which will redissolve and reform a brine with precipitation; conversely, brines of $CaCl_2$ and $MgCl_2$ will attract moisture and continually wet the road until they are dissipated.
- The purpose of direct liquid application is to enhance road safety over the life of the storm; however the application of any liquid to the road surface, including rainfall, temporarily lessens the friction, and therefore the safety, of the road. The impact of this temporary effect can be minimized by using the appropriate liquid application method.
- Preferred applications make use of pencil-sized streams at 8 to 15.5 inch spacing. This prevents misting or atomizing the liquid that then blows away and fails to reach the road surface. Though the tube must be adequately clamped and will wear from the pavement surface, it better targets the liquid onto the road.

Transportation Agency Documents

This section includes fact sheets from four states that present anti-icing as a best practice to the general public.

Colorado. *Liquid De-Icer Fact Sheet*, undated.
http://www.dot.state.co.us/TravelInfo/DeicerFactSheet.pdf
The environmental, safety and economic impacts of liquid deicers are presented in this fact sheet.

Maine.
Snow and Ice Control, undated.
http://mainegov-images.informe.org/mdot/technical-publications/pdf/snow&icebrochure1a.pdf
This six-page brochure discusses Maine DOT's transition from deicing to anti-icing as a preferred approach to snow and ice control.

Getting the Facts about Salt Brine, 2008.
www.maine.gov/mdot/snowandice/documents/MaineDOT_Salt_Brine_Overview_2008.doc
Maine DOT's use of NaCl brine as a pretreatment and prewetting agent is presented in this fact sheet. The fact sheet notes that Maine DOT uses a $MgCl_2$ blend that contains a lower chloride percentage when temperatures drop below 20° F.

Minnesota. *Mn/DOT Anti-icing Fact Sheet***,** December 4, 2002. See Appendix A.
Highlights from this fact sheet include:

- Preliminary data from an anti-icing trial in Virginia, Minn., shows a savings of about 10 percent or $100 per lane mile.
- Anti-icing saves time. In the Virginia trial, it took 13.75 hours per lane mile using traditional methods and 5.6 hours per lane mile using anti-icing chemicals to achieve the same level of service.
- The anti-icing chemicals that are used in Minnesota include $MgCl_2$, $CaCl_2$, KAc, and NaCl solutions. Bridge systems usually use the first three chemicals given their ability to work at lower temperatures.
- Anti-icing chemicals are specified to be at least 70 percent less corrosive to mild steel than NaCl. Mn/DOT is evaluating corrosion inhibitors that could be used with NaCl brine.
- Anti-icing systems are installed on six bridges and one road in the state.

North Dakota. *Anti-Icing Fact Sheet*, 2009.
http://www.dot.nd.gov/divisions/maintenance/docs/anti-icingfacts.pdf
This fact sheet, intended for the public, describes anti-icing in North Dakota, including the safety benefits of an anti-icing program.

Virginia. *Anti-icing and RWIS for Field Commanders*, Virginia Department of Transportation, Emergency Response Institute, 2008. See Appendix B. (Note that the PowerPoint version of this file contains fairly detailed presenter notes.)

The six sessions in this PowerPoint training presentation include:

- Anti-icing and RWIS: An introduction
- Atmospheric and road weather
- Anti-icing: Chemicals and operations

- Anti-icing: Bringing it all together
- The Scenario Room
- Table-top exercise: Anti-icing

AASHTO's 2004 **Anti-Icing/RWIS Computer-Based Training Program** (see http://www.apwa.net/bookstore/detail.asp?PC=PB.X407) covers similar ground. This two-CD computer-based training is a self-paced, interactive multimedia training program that includes practice and review exercises, links to key definitions, a glossary, a Knowledge Base and related Internet sites. After completing lessons on core anti-icing and RWIS topics, students learn how to put their new knowledge into practice. In the Scenario Room, students battle winter events using tools in a simulated winter maintenance facility to hone their winter maintenance decision-making skills.

Product Selection

Approved products and evaluations of alternative anti-icing chemicals are considered in the documents below. **Transportation Agency Documents** include Michigan's discussion of alternative anti-icing products and Iowa's analysis of salt brine retention.

Approved Product List, Pacific Northwest Snowfighters Association, March 4, 2009.
http://www.wsdot.wa.gov/partners/pns/pdf/PNSQPL.pdf
This list of approved products used in winter maintenance operations is produced by the Pacific Northwest Snowfighters Association. PNS evaluates and establishes specifications for products used in winter maintenance that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness and performance. Products that meet PNS specifications must:

- Pass chemical, frictional, toxicological and corrosion tests.
- Meet environmental and health standards.
- Be at least 70 percent less corrosive than road salt.

Evaluation of Alternate Anti-Icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers—Phase I, Xianming Shi, Laura Fay, Chase Gallaway, Kevin Volkening, Marijean M. Peterson, Tongyan Pan, Andrew Creighton, Collins Lawlor, Stephanie Mumma, Yajun Liu, and Tuan Anh Nguyen, Colorado Department of Transportation, *Report No. CDOT-2009-1*, February 2009.
http://www.dot.state.co.us/Publications/PDFFiles/antiicing.pdf
Researchers aimed to evaluate potassium acetate, sodium acetate/formate-blend deicers, and potassium formate as alternative anti-icing and deicing compounds and compare them to NaCl, salt-sand mixtures, and $MgCl_2$ currently used by the Colorado Department of Transportation. The report includes a deicer composite index that numerically evaluates deicers based on agency priorities or local needs and constraints.

General recommendations from the study include:

- Continue the use of inhibited NaCl and inhibited $MgCl_2$ deicers until better deicer alternatives are identified.
- Explore new technologies to minimize salt usage while maintaining the desired levels of service.
- Optimize the deicer application rate.
- Provide maintenance practitioners with sufficient training/learning opportunities.
- Explore new technologies/methods to minimize the negative side effects of NaCl, $MgCl_2$, and other deicers.
- Routinely clean out liquid holding tanks prior to introducing different liquid deicer products.

Lessons learned by practitioners are highlighted on pages 10 and 11 of the PDF:

- Add water if $MgCl_2$ gets slick.
- Never apply $MgCl_2$ when road temperatures are above 32° F and rising.
- Apply $MgCl_2$ only when it is certain that a storm is on its way.
- Equipment calibration should be done twice per year to ensure that excessive rates of deicer are not being applied.
- Proper training on application rates is important.

Page 196 of the PDF describes the **composite index** proposed in the study:

> As shown in Table 11, the *deicer composite index* for each deicer product is calculated by multiplying the relevant *decision weights* with the *attribute values* indicating where the product's cost, performance or impacts fall in the specific

category or subcategory. These attribute values can be estimated based on an overall examination of the existing literature and experimental data; or in some cases, calculated precisely based on the experimental data. Note that for performance attributes, the attribute values ranged from 1 to 10, with 1 being the worst and 10 being the best. For impact attributes, the attribute values ranged from 1 to 10, with 1 being the most deleterious and 10 being the least.

The deicer composite index calculated for three products evaluated in the study— noninhibited NaCl, inhibited liquid $MgCl_2$, and potassium formate or sodium acetate/formate blend deicers—were 46.6, 57.1, and 46.5, respectively (a perfect product would have a deicer composite index of 100).

The Deleterious Chemical Effects of Concentrated Deicing Solutions on Portland Cement Concrete, Lawrence Sutter, Karl Peterson, Gustavo Julio-Betancourt, Doug Hooton, Tom Van Dam, Kurt Smith, South Dakota Department of Transportation, *Report No. SD2002-01-F*, April 30, 2008.
http://www.state.sd.us/Applications/HR19ResearchProjects/Projects%5CSD2002-01_Final_Report_Final.pdf
This research project investigated the effects of concentrated brines of $MgCl_2$, $CaCl_2$, NaCl and CMA on portland cement concrete. Although known to be effective at deicing and anti-icing, the harmful effects these chemicals may have on concrete have not been well documented.

Researchers found significant evidence that $MgCl_2$ and $CaCl_2$ chemically interact with hardened portland cement paste in concrete, resulting in expansive cracking, increased permeability, and a significant loss in compressive strength.

Recommendations to **minimize the harmful effects of deicing chemicals on concrete structures** include:

- Reduce application of deicing chemicals and maximize effectiveness of each deicing application.
- Use deicing chemicals at the lowest possible concentration levels and preferably less than the amount reported in this study; for example, 20 percent for $MgCl_2$ and 22 percent for $CaCl_2$.
- Consider increased use of NaCl brines wherever possible.
- Consider surface sealers—particularly the use of siloxanes or possibly silanes—at areas of heavy deicing applications to reduce ingress of chemicals.
- Additional testing of CMA is required to determine long-term impacts of this deicing chemical given the mixed results of this research.
- New approaches to freezing point depression of NaCl brines, or new deicing chemicals, should be investigated to allow for use of these brines at lower temperatures.

"Durability of Brine Applications for Winter Maintenance on Asphalt and Portland Cement Concrete Pavements," Andrew C. Russ, Gayle F. Mitchell, Wallace Richardson, *TRB 87th Annual Meeting Compendium of Papers DVD*, Paper #08-2608.
http://pigpen.utc.uic.edu/pigpen/trb/FILES/08-2608.PDF
This research was conducted as part of a longer-term review of road weather information systems and anti-icing techniques with the goal of enhancing Ohio Department of Transportation's snow and ice operations. The subset of the research discussed in this paper focuses specifically on the durability of brine pretreatment applications as determined by direct measurement of salt residue on roads. Experiments on asphalt concrete and portland cement concrete pavements were conducted to determine the lifetime of brine residue from pretreatment.

Findings include:

- Decay of the anti-icing treatment is fairly slow on PCC, with about a third of the salt left after two days. Decay on AC is more rapid.
- On the PCC pavement, the salt level stays above 50 percent after 32 hours, so one can reasonably expect most of the effectiveness of the salt to be retained for that period.
- On the AC pavement, the equivalent value is 17.1 percent; for 24 hours, it is 26.6 percent, just over a quarter of the original application. This suggests that brine pretreatment wears off—or disappears into voids within—asphalt more quickly than it does on grooved PCC. This finding indicates that, for asphalt roads, it is more important that the pretreatment be timed closer to an anticipated winter weather event.
- In cases where pretreatment must be scheduled earlier than the day before the event—such as during regular work hours before a weekend storm event—then a higher application rate may be warranted.

Researchers note that **this study does not address**:

- The retention of $CaCl_2$ residue or other alternative anti-icing chemicals.
- Mixing brine with a small amount—about 10 percent—of corn salt or other agriculturally originated anti-icing compounds. Vendors and users of these mixtures claim that they significantly increase retention of salt residue on the roadway.
- A thorough comparison of zero-velocity brine application equipment to standard brine application equipment.
- How long the pretreatment prevents the ice/pavement bond from forming under winter precipitation, nor whether this time depends on the delay between brine application and weather event.

"Rational Selection of Deicing Materials," *Salt and Highway Deicing Newsletter*, Vol. 44, No. 2 (Spring 2007).
http://www.saltinstitute.org/content/download/326/1814/file/shd-spring-2007.pdf
This article summarizes the findings documented in *NCHRP Report 577*. Results of three examples using the report's decision tool indicated the following:

- When emphasizing cost and performance considerations, NaCl is the preferred product between 22° F and 12° F, after which $MgCl_2$ and $CaCl_2$ are preferred.
- Giving cost, performance, environment and infrastructure considerations equal weight, NaCl is the preferred product between 22° F and 12° F, after which $MgCl_2$ and $CaCl_2$ are preferred.
- When emphasizing environment and infrastructure considerations, all materials have similar scores until temperatures reach below 10° F, when NaCl and CMA lose performance benefits. KAc is the preferred product, though CMA also scores well at warmer temperatures.

Evaluation of Deicer Applications on Open Graded Pavements, Felix C. Martinez, Richard A. Poecker, Oregon Department of Transportation, *Report No. FHWA-OR-RD-06-12*, April 2006.
http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/DeicerAppOpenPavements.pdf
The scope of this research was to study the effects of liquid $MgCl_2$ on open-graded pavements. Four sections on two different highways in Oregon were selected to be skid tested under three conditions: no deicer application, after a deicer application rate of 15 gallons per lane mile, and after a deicer application rate of 30 gallons per lane mile.

The study's only clear-cut conclusion from a limited set of data is that all of the field-measured friction values—baseline and two deicer application levels—were well above FHWA guidelines for pavement friction. The data suggested that the deicer applications had little if any effect on either the open-graded or the dense-graded pavement friction. Given the number of variables that might affect the behavior of the deicer on the pavement, the data were insufficient to conclusively determine whether the friction of the open-graded pavement was affected by the application of $MgCl_2$.

"Mixing It Up in the Fight Against Winter by Blending Liquid Ice Control Chemicals," *Salt and Highway Deicing Newsletter*, Vol. 43, No. 2 (Spring 2006).
http://www.saltinstitute.org/content/download/322/1798/file/shd-spring-2006.pdf
This article highlights a blend of ice control chemicals used by McHenry County, Ill. Transportation Division staff set out to create a cost-effective liquid ice control product that performed well under various conditions and could be used for both prewetting and as a direct application for anti-icing. The product consists of 85 percent NaCl brine (23.3 percent solution), 5 percent $CaCl_2$ (32 percent solution), 10 percent of a sugar beet syrup (55 percent solution), and a small amount of anti-foaming agent. The liquid mix is used to prewet solid NaCl at a rate of 7 gallons per ton and performs satisfactorily at temperatures as low as 2° F.

Agricultural By-Products for Anti-icing and Deicing Use in Michigan, Steven C. Kahl, Michigan Department of Transportation, *Research Report R-1418*, November 25, 2002.
http://www.michigan.gov/documents/mdot/MDOT_Research_Report_R1418_245018_7.pdf
This report summarizes the Michigan Department of Transportation's experience with anti-icing compounds developed from agricultural by-products. Study results indicate that anti-icing practices resulted in lower material costs, lower salt use, and lower accident rates. Specific findings include:

- Application rates for anti-icing were initially 35 gallons per lane mile. With experience, anti-icing methods became more efficient and application rates for anti-icing lowered to 25 gallons per lane mile.
- Agricultural by-product liquids should be used for anti-icing operations and prewetting rock salt, rather than deicing.
- Anti-icing practices maintained bare pavements longer, which bought response time in storm events, up to an hour in some cases.
- Anti-icing practices in 2001/2002 helped to reduce the frequency of winter accidents on I-94 as compared to previous years with similar numbers of storm events.

- Agencies should adopt a benefit/cost methodology to formally track and document the costs and benefits of anti-icing. This can involve the use of TAPER (**T**emperature, **A**pplication rate, **P**roduct used, storm **E**vent, **R**esults) logs, assignment of task-specific time sheet coding, and other means of tracking costs.

Corrosion Effects of Magnesium Chloride and Sodium Chloride on Automobile Components, Yunping Xi, Zhaohui Xie, Colorado Department of Transportation, *Report No. CDOT-DTD-R-2002-4*, May 2002.
http://www.dot.state.co.us/Publications/PDFFiles/MagAutoCor.pdf
Conflicting conclusions arose from this study based on experiments with the deicing salts used in the state of Colorado**.** The inconsistency was attributed to the different moisture conditions and different properties of the two salts under high humidity environment. Depending on service conditions experienced by automobile components, $MgCl_2$ is more corrosive than NaCl under humid environments, and NaCl is more corrosive under immersion and arid environments.

A Guide for Selecting Anti-icing Chemicals, **Version 1.0**, Wilfrid A. Nixon, Anissa D. Williams, *IIHR Technical Report No. 420*, October 1, 2001.
http://www.iihr.uiowa.edu/products/pubvid/pdf/IIHR420.pdf
This guide provides a method to select the best chemical for specific anti-icing needs. Scoring products begins with the weighting of seven categories—freezing point depression, consistency, environmental impact, stability, corrosion, handling and documentation. Grades are assigned to each category and the grade in each category is assigned a numerical value. For categories with four grades—A, B, C and D—the scores are 4, 3, 2 and 1, respectively. Other factors such as cost and availability may influence the final choice; however, the guide provides a simple and effective way to differentiate between chemicals based on an agency's performance needs.

Transportation Agency Documents

Iowa. *Roadway and Bridge Salt Brine Retention Project*, undated. See Appendix C.
A study in 2003/2004 evaluated how long salt brine could be expected to stay on the roadway under varying roadway conditions. Results indicated that salt brine spread on the roadway is influenced by traffic and time. High traffic counts resulted in lower salt retention; all test locations recorded some trace salt on the roadway surface 48 hours after the initial application. Researchers noted that the influence of pavement temperature and humidity levels was more difficult to determine and required further research.

Michigan. *Emerging Technologies in Winter Road Maintenance: Improving Safety While Minimizing Environmental Impacts*, MDOT Storm Water Management Team, Tetra Tech, December 2006.
http://www.michigan.gov/documents/stormwatermgt/MDOT_MS4_Emerging_Technologies_in_Winter_Road_Maintenance_208451_7.pdf
This document includes a discussion of alternative anti-icing products, automated anti-icing spray systems, and surface overlay systems. A case study of the Zilwaukee Bridge includes a discussion of the two anti-icing products used on the bridge since its completion in 1988: CMA and liquid KAc. The report notes that there is no evidence of chloride-induced corrosion. The liquid KAc, which is used to prewet CMA as it is being applied, readily biodegrades and results in little environmental impact.

Anti-icing Technology

Transportation agencies are using surface overlays and fixed automated spray technology to increase the efficiency of their anti-icing operations. Surface overlays absorb and store anti-icing chemicals, while FAST systems are permanent installations of a pump, tank, nozzles and controller that dispense anti-icing chemicals directly onto an area of pavement. **Transportation Agency Documents** include Wisconsin's guidelines for selecting candidate bridges for installation of FAST systems.

Evaluation of the Cargill SafeLane Surface Overlay, Michael M. Sprinkel, Daniel S. Roosevelt, Gerardo W. Flintsch, Edgar de León Izeppi, David W. Mokarem, Virginia Department of Transportation, *Report No. VTRC 09-R8*, February 2009.
http://www.virginiadot.org/vtrc/main/online_reports/pdf/09-r8.pdf
Cargill's SafeLane surface overlay is constructed with epoxy and broadcast aggregates, which is typical of multiple-layer epoxy overlays that are used to provide a skid-resistant wearing surface for bridge decks that protects the decks against chloride intrusion. Cargill indicates that the limestone aggregate used in the SafeLane overlay is unique in its ability to absorb and store liquid deicing chemicals that are applied to the surface of the roadway.

The purpose of this research was to compare the SafeLane overlay and the Virginia Department of Transportation modified EP-5 epoxy concrete overlay based on an evaluation of their construction, initial condition, and effectiveness in preventing frost, ice and snow formation on the surface of the roadway. The evaluation indicated that the SafeLane overlay can provide a skid-resistant wearing and protective surface for bridge decks. The study was not able to determine the performance of the overlay with respect to providing a surface with less accumulation of ice and snow. Researchers note that there has not been sufficient time to evaluate chloride penetration into decks with SafeLane overlays in Virginia.

Comprehensive Evaluation of Bridge Anti-icing Technologies, Alaska Department of Transportation and Public Facilities, Jing Zhang, Deben Das, Rorik Peterson, Doug Goering, *Report No. INE/AUTC 07.06*, January 2007.
http://www.dot.state.ak.us/stwddes/research/assets/pdf/ine_autc_07_06.pdf
This report provides technical recommendations for viable and economical anti-icing and deicing technologies for the Knik Arm Bridge (Knik Arm is the northernmost branch of Cook Inlet).

Researchers concluded:

- For anti-icing and deicing chemicals, NaCl mixed with $CaCl_2$ and $MgCl_2$ should be given high priority due to their excellent low-temperature applicability and extremely low cost.
- Thermal methods examined by researchers include electrically conductive concrete, electrical resistive heating, geothermal heat pumps, infrared heating, microwave and radio frequency power, and solar and wind power.
- A combination of the chemical method with a fixed automatic spray technology and the thermal method is suggested to be the best approach based on cost-effectiveness criteria.

Vehicle-Based Technologies for Winter Maintenance: The State of the Practice, Xianming Shi, Christopher Strong, Robb E. Larson, David W. Kack, Eli V. Cuelho, Nabil El Ferradi, Aswinkumar Seshadri, Katie O'Keefe, Laura E. Fay, Western Transportation Institute, *Project No. 20-7(200)*, September 2006.
http://www.transportation.org/sites/sicop/docs/Vehicle-Based_WinterMaintenance_Final%20Report.pdf
Prepared in connection with NCHRP Project 20-7(200), this report synthesizes information obtained from a comprehensive literature review and agency surveys on the state of development of advanced winter maintenance technologies. Of these technologies, researchers note that automatic vehicle location systems, road surface temperature measuring devices and FAST systems are the only ones that have matured and become fully operational, while others are still in the development and testing phases.

Researchers' conclusions related to FAST systems include:

- Experience with FAST systems in North America and Europe has revealed a mixed picture. Several studies have indicated reductions in mobile operations costs and significant reductions in crash frequency, resulting in favorable benefit-cost ratios. However, there have been a variety of problems related to activation frequency, system maintenance and training.
- North American transportation agencies consider FAST to be an evolving technology, and are not planning significant new installations of FAST in the near future.
- Installing a FAST system is complex, and the challenges are often site-specific. Difficulties appear to be expected during their operation, particularly in areas related to software, system activation, and the pumping system.
- Evaluations show that FAST systems can be cost-effective if their locations are carefully chosen and the system is supported with reliable environmental sensors.

A Synthesis to Improve the Design and Construction of Colorado's Bridge Anti-Icing Systems, Gordon T. Bell, Wilfrid A. Nixon, Robert D. Stowe, Colorado Department of Transportation, *Report No. CDOT-DTD-R-2005-19*, April 2006.
http://www.dot.state.co.us/Publications/PDFFiles/fast.pdf
This study was designed to develop a state-of-the-art specification for statewide use of FAST in Colorado. Results from a survey document sent to more than 50 agencies using FAST system technology, global Internet search results, personal interviews, and documented reports indicated that new specifications for FAST systems should be established. The research and recommendations in the report provide details for the planning, design, installation, and testing of future FAST system projects.

Researchers' observations begin on page 47 of the PDF and include:

- Researchers note significant challenges in achieving fully automated operation of a FAST installation.
- Use of a particular ice control chemical in FAST installations does not appear to be required. While it has been assumed that KAc should be used to avoid problems with corrosion, experience with other chemicals indicates that, if suitable care is taken to keep equipment clean, corrosion is not an issue.

- Preventive maintenance was not conducted on the majority of FAST sites, except for an annual draining and flushing of the system at the start of the summer. Researchers recommend a more aggressive preventive maintenance program.
- Researchers recommend that all facilities should be aboveground.

State-of-the-Art Fixed Automated Spray Technology, J.R. Waldman, *Sixth International Symposium on Snow Removal and Ice Control Technology*, June 2004.
See pages 379 through 390 of the PDF at http://onlinepubs.trb.org/onlinepubs/circulars/ec063.pdf.
This paper provides a concise overview of FAST. The author cites several advantages of FAST over conventional methods of winter maintenance, including:

- Just-in-time applications of anti-icing chemicals provide the greatest benefit to preventing the pavement–ice bond while reducing the labor and material required for winter maintenance practices.
- System activity monitoring can alert agency staff to weather and pavement conditions in the geographical area of the system.
- Reapplication to prevent refreezing conditions can be automated.
- Efficient use of more costly nonchloride anti-icing chemicals that minimize damage to the highway infrastructure is permitted.

A Bridge Deck Anti-icing System in Virginia: Lessons Learned from a Pilot Study, Daniel S. Roosevelt, Virginia Transportation Research Council, *Report No. FHWA/VTRC 04-R26*, June 2004.
http://www.virginiadot.org/vtrc/main/online_reports/pdf/04-r26.pdf
The purpose of this study was to evaluate fixed automatic anti-icing spray technology for bridge decks and become familiar with the construction, maintenance and operations issues involved with such systems. The study evaluates a number of design options for delivery of a liquid chemical to the deck to determine the effectiveness of the options.

Findings include:

- FAST effectiveness is dependent on surface temperature, the amount of chemical dispensed, and the timing of application. FAST must be supplemented with plowing and coordination of subsequent applications of chemicals after the initial application.
- Although FAST can be designed to place chemical anywhere, only chemical placed at locations where traffic travels is effective as a bond breaker.
- Based on the literature review, active sensors produce a more accurate brine freezing point determination over a wide range of chemicals than do passive sensors.
- Preventive maintenance of the system is essential to maintaining the life of the system.

Transportation Agency Documents

Wisconsin. *State Highway Maintenance Manual. Winter Operations – Equipment: Bridge Deck Anti-icing Systems; Guideline 36.55*, October 1, 2002. See Appendix D.
This document presents Wisconsin's criteria for selecting candidate bridges for installation of FAST systems.

Prewetting

Many anti-icing programs make use of dry solid materials that are typically prewetted before application. The documents highlighted below consider various prewetting strategies.

Michigan. *Analysis of the Benefits of Bulk Pre-Wetting Solid NaCl with Several Different Liquids*, Russ Alger, Jan Haase, Research Report RC-1473, January 2006.
http://www.michigan.gov/documents/MDOT_RC-1473_161865_7.pdf
The purpose of this project was to study the prewetting characteristics of several liquid deicing chemicals using a standard laboratory melting test and solid NaCl. Application rates of six, eight and 10 gallons per ton were compared at temperatures of 15° F, 20° F and 25° F. Researchers concluded that there is no benefit to increasing the amount of liquid added to salt piles from six to 10 gallons per ton. Solid NaCl and the 23 percent NaCl brine tested in the study displayed good melting ability at the temperature ranges tested.

Transportation Agency Documents

Maine. *Comparison Tests of Liquid Calcium and Salt Brine: A Controlled Experimental Evaluation of Rock Salt Pre-Wetting Liquids*, October 2003.
http://www.maine.gov/mdot/transportation-research/pdf/Report0303.pdf
This research evaluated the use of liquid calcium as a prewetting liquid in an effort to determine if there is a performance advantage in the melting action. Results indicated that liquid calcium rapidly encourages melting at eight gallons per ton; however, at colder temperatures liquid calcium did not help significantly, precisely when it would be expected to perform better than NaCl brine. In this experiment liquid calcium did not provide enough increase in performance to justify the additional expense for routine use, unless the initial gain during the first five to 10 minutes is critical.

Equipment

This section addresses evaluation and modification of salt spreaders and the use of equipment used to apply liquid deicing chemicals.

Transportation Agency Documents

Iowa

Anti-icing Equipment: Recommendations and Modifications. See Appendix E.
This document offers information on:

- Improvements that can be made to increase the efficiency of brine makers.
- A formula to determine how much storage is required to meet current and future anti-icing/deicing needs.
- Standardization of fittings and connections to limit the need for adapters.
- An evaluation of on-board equipment to deliver liquid chemicals for prewetting and anti-icing.
- Retrofitting and proper application of pumps, spray bars and nozzles.
- Tracking resources with on-board material control units.

Liquid Applicators to Combat Snow and Ice in Iowa DOT. See Appendix F.
This document includes photos and descriptions of equipment used by the Iowa Department of Transportation to support the use of liquid deicing chemicals.

Maine

Evaluation of 6 Modified Salt Spreaders, Problem Solving 07-1, July 2007.
http://www.maine.gov/mdot/transportation-research/pdf/report0701f.pdf
In the summer and fall of 2006, the Maine Department of Transportation began a retrofitting process on six of their conventional salt spreaders. The intent of the retrofit was to modify the spreaders to allow for a 70 percent granular salt/30 percent NaCl brine application. MaineDOT's previous experience with the Schmidt STRATOS Spreader showed promise using this combination of materials. Study conclusions included:

- Four of the five locations reported a savings of salt when using the 70/30 mixture. The average savings per mile when combining the five locations was 76.6 pounds, or 7.8 percent.
- With the exception of one location, crews using the 70/30 mix indicated that it outperformed the typical treatment of six, eight and 10 gallons per ton. All crews indicated that the mix did a better job of minimizing bounce and scatter.
- Crews considered treating the roadway early, at the outset of a storm event, critical.
- A heavier first application, followed by smaller subsequent applications, appeared to work best when using the 70/30 mix.
- Four of the five locations believed that the belt-over-chain delivery system was far superior to the chain delivery system typically found in MaineDOT hoppers. Crews indicated that the belt systems virtually eliminated the issues of uneven material distribution commonly experienced with the chain system.

Evaluation of the Schmidt-STRATOS Spreader, Technical Report 05-1, July 2005.
http://www.maine.gov/mdot/transportation-research/pdf/report05-1final.pdf
In the fall of 2004, the Maine Department of Transportation entered into an arrangement with Schmidt International to evaluate Schmidt's STRATOS material spreader. The scope of this evaluation included a focus on several features of the STRATOS, as well as determining if the recommended 70 percent granular/30 percent liquid combination was a viable option for typical storm conditions encountered within the state of Maine. Additional evaluations are required to determine the accuracy of the metering equipment, whether multiple-lane treatment is a viable option, and whether anti-icing techniques can be conducted using the STRATOS.

State DOT Anti-icing Practices

Summary

Twelve state DOTs provided documents describing anti-icing operating practices and procedures. Highlights of key program elements include:

Application Timing

- Anti-icing is a proactive approach to snow and ice control that helps prevent snow and ice from bonding to the pavement. As such, it is not surprising that many state guidelines specify that anti-icing be conducted before precipitation occurs. Michigan adds another caveat, recommending that anti-icing operations begin only after the first snow event that requires snow removal operations. The initial snow removal operation of the season provides a “scrubbing” of the road surface, allowing oils and other contaminants to be cleaned from the roadway before application of anti-icing materials.

- Several state guidelines note that anti-icing operations should be conducted during normal working hours and low-volume traffic periods. In North Dakota, anti-icing applications can be made up to 72 hours in advance of a storm event, though application as close to the event as possible is a best practice. New York’s guidelines indicate that straight liquid chemical applications can be made up to three days prior to the onset of a winter weather event if the chemical is allowed to dry on the pavement surface.

- Application of liquid chemicals is advised when pavement temperatures are at or above a specific temperature. Half of the states with guidelines that specify a threshold temperature use 15° F as that threshold; three states use 20° F, and one state specifies 23° F.

- Many states recommend pretreating bridges or other icing-prone locations in advance of a storm. The most common pretreatment frequency is twice per week. Some states schedule pretreatment; for example, Illinois’ usual operation is to pretreat bridges on Tuesdays and Fridays during the workday.

Product Selection

- Programs vary widely with regard to choice of preferred materials. While some programs make use of solid, liquid and prewetted chemicals, as well as abrasives, other programs prefer liquid agents. Wisconsin’s guidelines indicate a preference for liquid chemicals, citing greater effectiveness and less waste of liquid agents as compared to solid materials.

- When states specify the solution of salt brine used in their operations, the solution most often specified is 23.3%.

- The anti-icing programs we reviewed use the following liquid chemicals: sodium chloride, calcium chloride, magnesium chloride, calcium magnesium acetate, and potassium acetate. Alternatives to sodium chloride are often recommended for lower pavement temperatures.

- Some states recommend the use of abrasives at specific locations or when surface temperatures drop below 10° F to 15° F.

Application Rates

- Program guidelines vary in their specificity with regard to application rates. Some provide application rates based on weather conditions; others provide a general guideline. While some states provide a maximum or minimum, others provide ranges. Ranges vary, from a low of 10-30 gallons/lane mile noted in Montana’s guidelines, to a high of 40-80 gallons/lane mile in North Dakota’s recommendation for anti-icing in freezing rain or heavy snow.

- Many states specify application rates for frost events, with recommendations ranging from 10-15 gallons/lane mile to 40 gallons/lane mile.

Prewetting

- Most states using solid materials in their anti-icing programs recommend prewetting. Recommendations for adding liquids range from 8 to 15 gallons per ton of dry material.

- Salt brine is often used as a prewetting agent, though calcium chloride, magnesium chloride, and agricultural deicers are used for very cold temperatures.

- Indiana's guidelines note that an exception to required prewetting is application on wet slush, where there is sufficient moisture already present to produce a brine. Kansas' guidelines take a different approach to slush, cautioning that heavy slush dilutes applied chemicals and should be plowed prior to application of anti-icing agents.

When Not to Anti-ice

- Many states note that anti-icing is not advised in windy conditions—with wind speeds of 15 mph or higher—when loose snow is present.

- Temperature is a common contraindication for anti-icing. Some states use a pavement temperature of 32° F; others use 38° F as a threshold at which further action is not required.

- States caution against anti-icing during heavy snow due to the rapid dilution of chemicals or prior to predicted rain events.

Precautions

- Michigan's guidelines note that use of calcium or magnesium chloride is not recommended for scheduled anti-icing of bridges. These materials can accumulate and, in the event that no frost or snow events occur, result in excessive application.

- Pavement slipperiness associated with the use of calcium or magnesium chloride under certain conditions is noted in Minnesota's guidelines, with temperatures above 30° F and humidity levels greater than 40% considered problematic.

- Some states recommend caution for applications after periods of no precipitation. Wisconsin's guidelines call for reduced application rates; in Minnesota, a review for buildup of oils and rubber residues on the pavement surface is recommended before anti-icing operations begin.

Equipment Considerations

- The importance of equipment calibration is frequently mentioned as a critical element of an effective anti-icing operation.

- States recommend streamer, drip or pencil nozzles; fan nozzles are not recommended.

- Recommendations for nozzle spacing range from 8 to 10 inches.

- Speeds recommended for spraying liquid chemicals range from 40 to 50 mph.

- Some states recommend the use of drop tubes for application speeds over 20-25 mph.

Residual Effect of Application

- Advice on the retention of residual chemicals ranges from three to four days on higher-volume freeways to up to one week.

Illinois	
Guidelines for Liquid Chemical Application for Snow and Ice Control for Illinois' Total Storm Management Program, September 24, 1998. See Appendix G.	
Application Timing	• Use liquids in quantities appropriate for conditions and pavement temperatures above 20º F. • The usual operation is to pretreat on bridges on Tuesdays and Fridays during the workday.
Product Selection	• Either dry solid chemicals (which are not recommended on dry pavement), liquid chemicals, or prewetted solid chemicals can be used as an initial anti-icing treatment. • Four chemicals have been used for liquid anti-icing treatments: sodium chloride (NaCl), calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), and potassium acetate (KAc). NaCl and $CaCl_2$ are the most commonly used snow and ice chemicals in Illinois. CMA and KAc have been used for unique situations (e.g., in environmentally sensitive sites or at very low temperatures). • NaCl is the solid material usually used when applying prewetted chemicals. • Applications can be made at temperatures as low as 10º F with NaCl brine, and 0º F or below with $CaCl_2$, if temperature moderation is forecasted.
Application Rates	• Using NaCl brine at the rate of 30-50 gallons/lane mile can delay the need for adding additional liquids or the application of prewetted solids at the beginning of the storm. • NaCl brine applied to bridge decks can prevent preferential icing (frosting) conditions. The liquid is applied at the rate of 30-50 gallons/lane mile at speeds up to 50 mph.
Prewetting	• The prewetting of a solid chemical such as NaCl will enhance the chemical's performance by 30% to 50%. • Depending on conditions, prewetting will allow lower, yet effective, application rates; 100 lbs/lane mile of NaCl prewetted with 15-20 gallons of NaCl brine per ton may be adequate. • Most of the time 10 to 20 gallons per ton of dry NaCl will achieve good success using either a 26% or 23% solution depending on whether an on-demand NaCl brine system or brine stored in tanks is used.
When Not to Anti-ice	• When the pavement is cold (below 20º F) and new or blowing snow is light, traffic and wind (speeds of 15 mph or higher) may be sufficient for preventing accumulation and compaction in tire tracks. • If the initial or previous anti-icing treatments have done their job, the pavement temperature is around 28º F and holding steady or rising, and no additional precipitation is occurring or forecasted. This is especially true when the pavement temperature is above 32º F and steady or rising.
Precautions	• The use of liquids is not recommended during either a freezing rain or sleet storm because of the large quantity needed to retain an effective concentration. • The use of dry solid chemicals is not the best choice except when there is sufficient moisture on the pavement to initiate the brine process immediately. • Abrasives are not ice-control chemicals, and will not support the fundamental objective of anti-icing when applied either straight or in a mix with chemicals. Because of this and evidence they are generally ineffective when used routinely in anti-icing operations, using abrasives should not be a customary operation in an anti-icing program except for low pavement temperature conditions.
Equipment Considerations	• All equipment should be calibrated before winter operations begin. • Streamer nozzles ¼ inch or more in diameter are recommended.

	• When liquid chemicals are applied during windy conditions, adjusting the sprayer closer to the pavement can be successful in avoiding loss and more closely achieving the desired application.
Residual Effect of Application	Depending on traffic and weather conditions, residual chemical on bridges can prevent frosting conditions for up to one week on low-volume roads or three or four days on higher-volume freeways.

Indiana	
Use of Liquids for Winter Operations, March 2004. See Appendix H.	
Application Timing	• Apply initial treatment prior to precipitation. • Only use NaCl brine when pavement temperature is 15º F or above, and expected to remain 15º F or above. • Once precipitation begins to fall, continue treating road while plowing off accumulated snow. • A proactive bridge anti-icing routine is recommended.
Product Selection	• NaCl brine is the preferred anti-icing and frost-prevention liquid material. • Use NaCl brine with 23.3% to 24% salinity (23.3% is optimum). Brine with higher or lower salinity has a lower freezing point and is less effective.
Application Rates	• For anti-icing, use an application rate of 40-60 gallons/lane mile. • For frost prevention, use an application rate of 20 gallons/lane mile.
Prewetting	• Typically dry NaCl should be prewetted before application. One exception is on wet slush where there is sufficient moisture already present. In this case, dry NaCl may be acceptable. • NaCl brine is the prewetting liquid of choice. During very cold temperatures, $CaCl_2$, magnesium chloride ($MgCl_2$) or agricultural deicers may be used more effectively. Normally, liquids are added at 8 to 10 gallons per ton of NaCl. Some agencies have had success by increasing this rate to 20 gallons or more per ton.
When Not to Anti-ice	• When the pavement temperature or the air temperature is within 2° of the dew point. • When a storm event begins as rain, then changes directly into snow or ice. • When loose snow is present on the ground next to the roadway and the wind speed is 15 mph or greater.
Precautions	• Stop applying NaCl brine if the pavement temperature begins to drop below 15°F. • If significant accumulation begins to form and is not easily plowed or melted off, stop applying NaCl brine and begin treating the road with granular NaCl. • Prepare ahead for holidays, long weekends, and rush hours where a quick response with brine application may be inhibited.
Equipment Considerations	• Streamer nozzles are used on all equipment; fan nozzles are not recommended. Typically spray one lane at a time. • If possible, spray at 45 mph or less. • The recommended spraying sequence for three or more lanes per direction is to start with the inside lane and work out. For two lanes in each direction, start with the passing lane, then spray the driving lane.

Iowa	
Brice, undated. See Appendix I. **Instructional Memorandum, Snow and Ice Control: Chemicals and Abrasives**, September 18, 2006. See Appendix J.	
Application Timing	The key is to place the brine on the roadway surface prior to a precipitation event. This action helps prevent the snow and ice from bonding to the pavement.
Product Selection	• The ideal concentration is 23.3%. • The percentage of NaCl in the brine solution is one of the keys to success with the use of brine. Too much NaCl and the freezing point goes up; too little and the freezing point also goes up. • In general, NaCl (liquid or dry) should not be used with pavement temperatures of 15° F and falling. NaCl may be applied if pavement temperatures are expected to rise to 15° F or above. • Straight winter abrasives may be used at locations such as stop signs, railroad crossings, hills, curves and bridges, and at other locations as deemed necessary.
Application Rates	• Use liquids for traditional anti-icing of roadways or bridges at 40-50 gallons/lane mile. • The recommended application rate for liquid NaCl used for anti-icing is a minimum of 50 gallons/lane mile. • The recommended application rate for liquid NaCl used for frost treatment on bridge decks is approximately 40 gallons/lane mile.
Prewetting	• Use liquids for traditional prewetting of dry material at 10-15 gallons/ton. • The recommended application rate for liquid NaCl used for prewetting is approximately 10-20 gallons/ton. • The recommended application rate for liquid KAc used for prewetting is approximately 20 gallons/ton. • $CaCl_2$ in liquid, flake or pellet form may be added to rock salt or mixture. The application rate is 8 gallons of liquid, 38 pounds of flake or 30 pounds of pellets per ton of rock salt or mixture.
Precautions	Caution should be used when applying liquids to the roadways when winds are expected to exceed 15 mph and loose snow is present.
Equipment Considerations	Most current units are designed to anti-ice a single lane and possibly the shoulder, and are equipped with streamer nozzles to minimize the impact to traffic. All have been successfully used in different environments. Fan nozzles are not recommended for new systems.

Kansas	
Guidelines for the Use of De-icing Chemicals, undated. See Appendix K.	
Product Selection	• NaCl can be applied in solid, prewetted or liquid brine forms. NaCl brine should be stored at 23% concentration by weight (85% saturation) as measured by hydrometer. • Chemicals, abrasives and/or chemical abrasive mixtures may be used, as necessary, to help prevent ice and snow pack conditions.
Prewetting	Prewetting NaCl has been shown to keep the material on the road surface in heavy traffic and helps activate the NaCl when there is not already sufficient moisture present to start brine action.

Precautions	• Liquid chemicals should be used with caution when cold pavement (less than 15° F), high winds (greater than 15 mph), and dry snow are expected. • Brine may cause blowing snow to adhere to the pavement. • Slush should be plowed prior to application of chemicals. Heavy slush will dilute applied chemicals to the point that they are not effective.
Equipment Considerations	Spreader trucks should be operated at a speed that is consistent with the results of calibration tests. When spreading solid chemicals, speeds should not exceed 25 mph.

Michigan	
Anti-icing Guidelines: Guidelines for Use with Calcium or Mag Chloride & Agricultural By-Product, undated. See Appendix L.	
Application Timing	Anti-icing operations should not begin until after the first snow event that requires snow removal operations to be performed. This will provide a "scrubbing" of the road surface, allowing oils and other contaminants to be cleaned from the roadway.
Product Selection	These guidelines apply to $CaCl_2$, $MgCl_2$ and agricultural by-products.
Application Rates	• The general application rate is 20-30 gallons/lane mile, starting with 25 gallons/lane mile to see how it works. • Do not go above 30 gallons/lane mile; more in this case is not better. • Bridges for frost application: 10-15 gallons/lane mile. • Ramps or stops at intersections: 10-15 gallons/lane mile; more may make it slippery.
When Not to Anti-ice	• When road surface temperatures are at 38° F and rising. If surface temperatures are rising during an application, the operation should stop and then resume when temperatures are below the 38° F mark. • If the forecast indicates wind and drifting conditions.
Precautions	• Applications with surface temperatures over 38° F may cause slippery conditions. • Shut off application at the ramp's halfway point when anti-icing off-ramps and on-ramps. This will stop "drizzling" at stops or double applications on freeways, which results in excessive application. • Do not overlap routes when anti-icing. While this is done during snow removal operation, it can increase the application rate and may cause slippery conditions when anti-icing. • Use of $MgCl_2$ or $CaCl_2$ is not recommended for a scheduled mode of anti-icing for bridges. When these materials are used in this manner, they can accumulate and, if no frost or snow events occur, cause an overapplication situation.
Equipment Considerations	Spray bars should use ¼-inch streamer nozzles with 10-inch spacing. Drop tubes are recommended for application speeds over 20 mph.
Residual Effect of Application	Anti-icing may be done any time prior to a predicted winter storm event. The products tested and used have remained effective for up to one week.

Minnesota	
Guidelines for Anti-icing, January 2006. See Appendix M. **Chemicals Used by Mn/DOT**, undated. See Appendix N.	
Application Timing	• Schedule regular applications twice per week on bridge decks and critical areas or on black ice and routes prior to events. • Preferred times are during low-volume traffic periods.
Product Selection	• NaCl brine, liquid corn salt and $MgCl_2$ can be used. In rare instances solids may be used. • Apply $MgCl_2$ when pavement temperature ranges from –10º F to 30º F. See Appendix N for other chemicals that may be applied at different pavement temperatures. • The only chemical that can be mixed with NaCl brine is liquid corn salt (it comes in a 50% concentration and can be cut to 10% or 20% for prewetting and anti-icing).
Application Rates	$MgCl_2$ / NaCl Brine Regularly scheduled applications: 15-20 / 20-35 gallons/lane mile Prior to frost or black ice event: 15-20 / 20-35 gallons/lane mile Prior to light or moderate snow*: 15-20 / 20-50 gallons/lane mile (* used as bond-breaking agent)
Prewetting	NaCl brine, liquid corn salt and $MgCl_2$ can be used for prewetting material.
When Not to Anti-ice	• Prior to predicted rain. • During heavy snow (1 inch/hour events). Heavy snows will cause the rapid dilution of chemicals and require frequent reapplication of liquid. During this time a snowfighter may need to switch to deicing methods. • Under blowing or drifting snow conditions. • After the bond between the snow and the pavement has occurred.
Precautions	• Use caution with higher rates of application. • Refreezing of bridge deck or pavement surfaces can occur if the applied chemical is significantly diluted or pavement temperature decreases. Need to know the lowest working temperature of an applied chemical to determine minimum freezing point depression. • Pavement slipperiness with the use of liquid $MgCl_2$ and $CaCl_2$ is possible after application under certain temperature and humidity conditions; for example, temperatures above 30° F and humidity levels greater than 40%. • Anti-icing chemicals on a dry pavement or bridge deck may cause blowing snow to stick and create slippery conditions. • Corrosion inhibitors that reduce material corrosion to 70% less than NaCl are to be used with liquid $MgCl_2$ and $CaCl_2$. • If no significant precipitation has occurred within seven days, check to see that a buildup of oils and rubber residues on pavement surfaces and bridge decks is not present before application. These residues may become slippery after application of liquid anti-icing chemicals.
Equipment Considerations	• Eight holes minimum. • Solid stream. • Bar height should be 12-14 inches.
Residual Effect of Application	Residual effect can remain for up to five days after application if precipitation does not dilute the initial application.

Missouri	
Operator's Guide for Anti-icing, July 2004. See http://epg.modot.mo.gov/index.php?title=133.5_Operator%E2%80%99s_Guide_for_Anti-Icing.	
Application Rates	See 133.5.3.6, Tables for First Priority Continuous Treatment Routes, for specific application rates for light snow, moderate or heavy snow, frost or black ice, freezing rain and sleet.
Prewetting	Prewetting is the practice of applying NaCl brine to dry NaCl before it is placed on the pavement, and should be done at 10-15 gallons/ton. Liquid $CaCl_2$ may be used for prewetting NaCl at temperatures below 15° F.

Montana	
Past and Current Practices of Winter Maintenance at the Montana Department of Transportation, December 31, 2003. See http://www.mdt.mt.gov/publications/docs/brochures/winter_maint/wintmaint_whitepaper.pdf.	
Application Timing	• Use liquid temperature suppressant chemicals (salt brines, acetates, chloride and nonchloride solutions) in warmer surface temperatures of greater than 15° F. • When surface temperatures drop to less than 10-15° F, use prewetted abrasives.
Product Selection	• A 22% solution of liquid $MgCl_2$ is used for anti-icing at surface temperatures of more than 10° F. • A 30% solution of liquid $CaCl_2$ was tested in three locations in 2003-2004. New blends have increased performance and capacity and reduced corrosion.
Application Rates	10-30 gallons/lane mile depending on conditions, temperatures and desired outcomes.
When Not to Anti-ice	In windy areas or during rain events.
Precautions	NaCl is a poor performer on snow and ice when used in temperatures much less than 25° F.

New York	
Highway Maintenance Guidelines: Snow and Ice Control, April 2006. See Appendix O.	
Application Timing	• Pretreat pavement or bridge decks and other icing-prone locations in advance of a storm anywhere from several hours to several days in advance of the event. • Liquid chemicals should only be applied as an anti-icing strategy when pavement temperatures are 20° F or higher. • Straight liquid chemical applications can be made up to three days prior to the onset of a winter weather event if the chemical is allowed to dry on the pavement surface. • Anti-icing can be done by applying conventional solids and prewetted solids on low-speed, low-volume roads.
Product Selection	• $MgCl_2$, with or without organic-based enhancers, and NaCl brine are more desirable products for use in the pretreatment of pavements. • NaCl brine is most effective at a 23% solution. • Liquid $MgCl_2$, liquid $CaCl_2$, KAc, CMA, and a variety of proprietary formulas that contain anti-corrosion inhibitor and agricultural by-products are also available. Although generally higher in cost than NaCl brine, they can be more effective at lower temperatures.
Application Rates	See pages C-4 to C-8 of the guidelines for tables that specify application rates for black ice, freezing rain, sleet, light snow, and moderate or heavy snow.

When Not to Anti-ice	• In conjunction with plowing operations at very low temperatures or when plowing blowing and drifting snow at very low temperatures. • If pavement temperatures are much above freezing. Above 38° F and at high humidity, liquid chemicals will not properly dry on the surface and can result in hazardous slippery conditions.
Precautions	• Liquid $CaCl_2$ is not the most desirable choice for the pretreatment of pavement. Due to problems with this chemical leaving pavement slippery under certain conditions, caution must be exercised if this chemical is used. Special care is necessary to not overapply, maintain effective spray pattern, and monitor pavement temperatures to ensure that the material will dry quickly. • On very rare occasions, too much material (liquid chemicals other than NaCl brine) can result in hazardous slippery conditions before the material has fully dried. • Application of NaCl brine at lower temperatures would require excessive application rates and may be prone to rapid refreeze.
Equipment Considerations	• Liquid deicing chemicals can be applied directly to pavement using an adequately sized slide-in tank or tanker truck with a spray bar. • Liquid chemicals should be distributed on the pavement using streamer or pencil nozzles that lay strips of chemical about 10 inches apart, leaving untreated pavement between the strips. The use of pencil or streamer nozzles will reduce the potential for any unintended slipperiness. • For straight liquid applications, spreading speeds can be between 40 and 50 mph on dry pavements when doing pretreatment applications. Speeds will be lower based on conditions when spraying during a storm. • Liquid spray units must be calibrated at the beginning of each snow and ice season. This can be accomplished by collecting liquid at the spray bar over a premeasured distance.

North Dakota	
North Dakota DOT—Dickinson District Anti-Icing Flow Chart, undated. See Appendix P.	
Application Timing	• While operators can anti-ice up to 72 hours in advance of a storm event, the best practice is to anti-ice as close to the event as possible. • Anti-ice when pavement temperature is 15° F and rising, or between 30° F and 35° F.
Application Rates	• Frost: 40 gallons/lane mile. • Freezing rain: 40-80 gallons/lane mile. • Heavy snow: 40-80 gallons/lane mile.
When Not to Anti-ice	• When there is the potential for blowing snow. • When temperatures fall outside acceptable ranges.

Ohio	
Materials Application Guidelines, October 8, 2008. See Appendix Q. **Snow & Ice Pre-treatment Guidelines**, undated. See Appendix R.	
Application Timing	• Pretreat priority routes and any identified trouble spots with liquid material for black ice, unexpected winter events, frost control, and forecasted winter events when conditions warrant. • Roadways should be dry and rain should not be forecasted for the next 24 hours. • Make certain that sufficient time exists for pavement to dry before pavement temperature falls below 20° F. • Ensure that sufficient material residue is not already present on the pavement. • Apply on dry pavement when the pavement temperature is above 32° F and a drop in temperature is imminent, or when the pavement temperature is 20° F to 32° F and remaining in range.
Product Selection	• 23% solution of NaCl brine. • Spinner application of NaCl brine or $CaCl_2$.
Application Rates	• Recommended application rate is 20-40 gallons/lane mile. • Spinner application of NaCl brine or $CaCl_2$ of 8-10 gallons/ton.
When Not to Anti-ice	When there is the potential for blowing snow.

Wisconsin	
State Highway Maintenance Manual. Winter Operations—De-icing Agents and Abrasives: Application Rates—Anti-icing; Guideline 35.25, October 1, 2005. See Appendix S. **State Highway Maintenance Manual. Winter Operations—Operations: Anti-icing Technique; Guideline 32.35**, October 1, 2005. See Appendix T. **State Highway Maintenance Manual. Winter Operations—Equipment: Liquid Anti-icing Spray Systems; Guideline 36.15**, October 1, 2002. See Appendix U.	
Application Timing	• Apply when the pavement temperature is at or above 23° F or the pavement temperatures are forecasted to rise or stay above 23° F. • At a minimum, anti-icing should be conducted prior to forecasted frost, freezing fog or black ice events on bridge decks or pavement trouble spots. • Anti-icing operations typically should be conducted during normal, nonovertime working hours in periods of low traffic volume. • Time initial anti-icing agent applications to prevent deteriorating conditions or development of packed and bonded snow. • If anti-icing is performed prior to a snow event, re-application may be necessary to prevent refreeze. It also may be necessary to switch to a deicing mode. • Treatment for frost or black ice incidents can be scheduled twice per week during the typical frost season. Applications in anticipation of a possible frost incident or snow event on a Saturday or Sunday may be made on a preceding Friday. • Applications for forecasted frost events should normally be made 12-18 hours prior to a predicted frost or snow event, depending on the material used.
Product Selection	Liquid agents are the preferred material for anti-icing treatments. Liquid agents work more effectively than solids for anti-icing, and there is also less waste with liquid applications.
Application Rates	• Frost: Liquid deicer (20-30 gallons/lane mile) or prewetted NaCl (50-150 lbs/lane mile).

	• Black ice: Liquid deicer (30-40 gallons/lane mile) or prewetted NaCl (50-150 lbs/lane mile). • Sleet: Liquid deicer (20 gallons/lane mile is recommended; 30 gallons/lane mile is maximum) or prewetted NaCl (200-400 lbs/lane mile for four lanes and greater; 100-300 lbs/lane mile for two lanes). • Freezing rain: Liquid application is not recommended; prewetted NaCl (200-400 lbs/lane mile for four lanes and greater; 100-300 lbs/lane mile for two lanes). • Light snow (less than ½ inch/hour): Liquid deicer (30 gallons/lane mile is recommended; 40 gallons/lane mile is maximum) or prewetted NaCl (100-200 lbs/lane mile). • Moderate or heavy snow (greater than or equal to ½ inch/hour): Liquid deicer (40 gallons/lane mile is recommended; 50 gallons/lane mile is maximum) or prewetted NaCl (100-300 lbs/lane mile). • Treat ice patches, if needed, with prewetted NaCl at 100 lbs/lane mile.
Prewetting	• While applying prewetted NaCl prior to an event can technically be considered anti-icing, liquid agents work more effectively than solids. • See **Application Rates** above.
When Not to Anti-ice	• When the pavement temperature is below 20° F or if forecasted to fall below 20° F. • When winds are more than 15 mph. • When anti-icing agents have the potential to cause snow to stick to the roadway under blowing and/or drifting snow conditions. • Prior to forecasted rain or freezing rain events. • After the bond between snow and the pavement has already occurred. • Liquid agents should never be applied to an icy or snow-packed surface.
Precautions	• Refreezing of the surface can occur when rain or snow or moisture in the air dilutes the liquid anti-icing agent remaining on the surface and reapplication of the anti-icing agent has not occurred. • Application rates should be reduced when anti-icing after extended dry spells with no rain or snow events, especially during the late fall or early spring seasons when pavement temperatures are in the 45° F to 50° F range and humidity is in the 45% to 55% range. • Application of a liquid on a bridge deck or pavement surface containing a buildup of oil-based residuals and/or rubber residuals may produce a slick surface.
Equipment Considerations	• Use of a following vehicle for traffic control may be necessary when traffic volumes are high. • Calibrate liquid anti-icing equipment at the beginning of every winter season. • Recalibrate equipment that has been transferred to another truck, modified or repaired. • Drip or pencil spray nozzle heads are preferred over fan-type nozzle heads to minimize the drifting of liquid anti-icing agents from the bridge deck or pavement surface. • Consider using drip or pencil spray nozzle heads with drop rubber tubing extensions that reach the surface when truck speeds will exceed 25-30 mph. • Spray nozzles should be spaced such that the pavement is not saturated at the time of application. • When possible, wind flaps should be installed on either side of the spray bar to minimize drifting of the anti-icing agent.
Residual Effect of Application	Residual materials from liquid anti-icing agents can remain on the surface for up to four days after application if not diluted by rain or snow.

Note: To request a copy of this TRS that includes Appendices A-U, pages 33-519, please contact Research Services, 651-366-3780, research@dot.state.mn.us