CHAPTER 8: WINTER OPERATIONS AND SALT, SAND, AND CHEMICAL MANAGEMENT

Snow/ice removal consists of plowing snow and ice from bridges, roadways, and shoulders. Sanding activities place abrasives on road and bridge surfaces to provide for temporary traction and safer driving. Temperature suppressant chemicals such as magnesium chloride (MgCl), are applied as an anti-icer or de-icer, and for pre-wetting of abrasives, for general winter maintenance. Winter weather and level of service guidelines help determine rates of application for abrasives and winter chemicals. Currently about ten million tons of road salt is used each winter in the United States.(*i*) A 1994 NCHRP report estimated that North Americans spend $20 billion annually on snow and ice control.(*ii*) A more recent report by the New England Transportation Consortium estimated that winter ice control chemical application in the U.S. alone totaled $500 million per year, accounting for one-third of highway winter maintenance expenditures in the United States.(*iii*) More effective use of deicer chemical could result in significant economical and environmental benefits.

While DOTs typically specify and test for heavy metals, pH and nitrogen/nitrates for all products used for winter maintenance and try to avoid overuse of all materials, much of managing the environmental effects of winter operations comes down to management of salt. Salt contamination has become a growing issue for some state DOTs, which have had to purchase contaminated wells and properties and have had to extend pipes to municipal water systems. In Canada, salt has become more heavily regulated by the federal environmental agency; the Canadian Ministers of the Environment and of Health therefore recommended adding road salts to Schedule 1 of Canada's Environmental Protection Act of 1999. In response, Environment Canada proposed management measures to minimize the impacts of road salt on the environment in late 2003.(*iv*)

The Transportation Association of Canada and many DOTs in the United States have begun to develop best practices to minimize salt usage and salt entry into the environment surrounding roads and maintenance facilities. Along with reduced salt usage and the shift to more proactive anti-icing methods, sand usage, water and air quality problems, and roadside vegetation inundation decrease as well. The stewardship practices are compiled to help transportation agencies implement a winter operations program with reduced impacts to the environment from salt, sand, and other chemicals.

The transition to reduced salt usage has been facilitated by great improvements in snowfighting equipment and technology in recent years. Equipment is available to facilitate precise, controlled applications of material, at reduced rates established as a result of extensive research and testing. While much of this new equipment is more sophisticated, durable, and easier to use, the potential benefits can be best realized if maintenance staff are thoroughly trained, material use is closely monitored, and feedback systems are in place. Increasingly, application rates are being tied into sensor based information systems including real time data, weather forecasts, road friction measurements, road surface temperature measurements, and global positioning equipment. As the use of this technology evolves, considerable planning, organization, and evaluation are required to ensure the best use of existing technology.

Some DOTs are also taking a closer look at sensitive areas, for special consideration and/or altered practices. Such areas include: (*v*)

- Spawning streams and those inhabited by federally protected or state listed sensitive aquatic species, especially trout and other listed or candidate fish.
- Those impaired water segments listed on the state's "Section 303(d) List" for Total Maximum Daily Load (TMDL) Plan development and restoration.
- Those receiving direct runoff from treated roads and highways where there would be less than 100:1 dilution;
- Those where a large volume of highway runoff can directly reach small, poorly flushed ponds, lakes and wetlands.
- Those where receiving water temperatures have warmed by the time highway runoff arrives.

This chapter on environmental stewardship practices in winter operations will first identify recommended practices for strategic planning for reduced salt usage, and then look at initiatives by leading DOTs, and practices and accomplishments in specific program areas to achieve such reductions and improve environmental outcomes.

8.1. SELECTING SNOW AND ICE CONTROL MATERIALS TO MITIGATE ENVIRONMENTAL IMPACTS

DOT Maintenance staff generally develop winter management and operation plans that identify sensitive/critical areas, levels of service for roads and methods for maintaining levels of service during winter weather. NCHRP and AASHTO are producing NCHRP 6-16, Guidelines for the Selection of Snow and Ice Control Materials To Mitigate Environmental Impacts, which will be available in 2005. The objective of the project is to develop guidelines for selection of snow and ice control chemicals and abrasives, based on their constituents, performance, environmental impacts, cost, and site-specific conditions. The project will identify and justify methods for measuring the constituents and properties that determine the environmental impacts of the current range of snow and ice control materials, and present this information on available materials and significant properties in matrix format, with purchase specification and quality assurance test protocol for the evaluation of existing and future materials. Environmental impacts to be studied include effects on human health; aquatic life; flora and fauna; surface water and groundwater quality; air quality; vehicles; and physical infrastructure including bridges, pavements, railway electronic signaling systems, and power distribution lines. Guidelines will be developed that incorporate: (*vi*)

- A decision-making process for the selection of snow and ice control chemicals and abrasives, based on their composition, performance, environmental impacts, cost and site-specific conditions.
- The matrix of currently available products and their properties.
- The purchase specification.
- The quality assurance protocol.

For the purposes of this report, NCHRP 25-25(04), impacts of various snow and ice control materials and the background for use of recommended environmental stewardship practices are summarized below.

Impacts of Salt and Chloride-Based Deicers on the Environment

Road-salt use in the United States ranges from 8 million to 12 million tons of NaCl per year according to the National Research Council (NRC); Massachusetts, New Hampshire, and New York report the highest annual road-salt loadings, with Massachusetts the highest at 19.94 tons/lane-mile./yr.(*vii*) Salt usage and impacts on the roadside habitat, water sources, fish and wildlife, and pavement are growing concerns in North America and abroad. Such concerns in Canada prompted the federal environmental agency, Environment Canada (EC), to conduct a comprehensive assessment of road-salt application to determine whether conventional deicers should be considered toxic substances under the Canadian Environmental Protection Act.(*viii*) EC conducted a five-year, comprehensive scientific assessment of the environmental impacts of road salts that contain inorganic chlorides, such as sodium chloride, calcium chloride, potassium chloride, and magnesium chloride. The study found that high concentrations of road salts commonly enter the environment through roadway melt water and through seepage from mismanaged salt storage facilities and snow disposal sites.(*ix*) Although not directly harmful to humans, the road salts can have harmful effects on the aquatic environment, plants, and animals.(*x*)

Much of the salt that is placed on a road during snow and ice control operations eventually runs off with the roadway drainage. While sodium may bond to negatively charged soil particles or be taken up in biological processes, chloride ions are less reactive and can be transported to surface waters through soil and groundwater. Road salts applied to roadways can enter air, soil, groundwater, and surface water from direct or snowmelt runoff, release from surface soils, and/or wind-borne spray.(*xi*) Deicing salt reaches the natural environment in a number of ways:(*xii*)

- Through salting practices in which some of the spread salt lands directly on or bounces onto roadside verges of footways.
- Through salt being thrown to the edge of the road by the action of passing vehicles or by the wind.
- Through dissolved salt running off roads and into drainage systems, which eventually discharge into natural waters.
- Through dissolved salt being splashed or sprayed onto roadside soil, vegetation, and surface waters by passing traffic.
- Through salted snow being blown or plowed onto the roadside by snow blowers or snowplows.

These salts remain in solution in surface waters and are not subject to any significant natural removal mechanisms. Their accumulation and persistence in watersheds pose risks to aquatic ecosystems and to water quality. Approximately 55 percent of road-salt chlorides are transported in surface runoff with the remaining 45 percent infiltrating through soils and into groundwater aquifers.(*xiii*) In the past, salt storage has led to contamination of local soils and watercourses. According to Hogbin, 0.125 to 02.5

percent of the initial weight of an uncovered stockpile is lost per year by leaching for each inch of rainfall on that stock pile.(*xiv*)

While wind deposition has received less attention than other areas of salt impact, study results have shown that roadside exposure to airborne salt was related strongly to the wind direction.(*xv*) Bulk deposition was collected in a field adjacent to highway E4 in SE Sweden and related to wind characteristics and deicing activities on the road; chloride was shown to be transported several hundreds of meters away from the road and the amount of air-borne chloride deposited in the roadside environment was well correlated to the road-salting intensity.(*xvi*)

Salinity and chlorine-impaired streams are present in a number of Midwestern and Western states.(*xvii*) A Nevada DOT-Caltrans study in 1990 concluded that 15 percent of the trees observed along the Lake Tahoe Basin highways within both Nevada and California, were salt-affected, showing evidence of disease, bark beetle infestation, and the effects of four years of drought.(*xviii*) Roadside trees and other vegetation are affected by salt primarily through two mechanisms: 1) increased concentrations of salt in soil and soil water leading to greater root absorption; and 2) salt accumulation by foliage and branches due to vehicle splash and spray and windblown dry salt. Although deciduous trees have no leaves in winter, they can still be affected by salt spray as dormant twigs intercept the salt, which may reach living tissue by entering twigs through leave scars. In contrast to salt taken up by roots, salt spray rarely causes tree death outright, but annually recurring damage tends to keep the crowns narrow, stems thin, and plants short. Trees close to roads are generally the worst affected. Damage is most severe within five meters of the road but there is frequently a distinct injury gradient with distance; damage is minimal about 30 meters from the road. Trees on the downhill side of a road suffer more damage than those on the uphill side. On high-speed roads where salt spray instead of runoff is the major cause of injury, trees on the downwind side of the carriageway have the greatest injury. (*xix*)

CDOT research on the environmental effects of chloride-based deicers found that aodium chloride, magnesium chloride, and calcium chloride may contribute to the mobilization of trace metals from the soil to surface and groundwater, though field evidence is limited. The chloride-based deicers have the potential to increase the salinity of the rivers, streams, and lakes. Since the dilution of deicers from the roadways to nearby streams is estimated to range from 100 to 500-fold, salinity increases are only likely to occur in slow-flowing streams and small ponds. Increased salinity was reported in groundwater at a distance of more than 300 feet from roadways. Damage to vegetation from deicing salts was reported to a distance of 100-650 feet. (*xx*)

Sodium chloride crystals attract birds and mammals, which can contribute to road kills. Sodium-deficient wildlife sometimes travel great distances to ingest road salt. Many animals tend to overshoot their salt deficit and then drink salty snow melt to relieve thirst, which increases salt toxicity in blood and tissues.(*xxi*)

In contrast, magnesium chloride and calcium chloride deicers do not attract wildlife since the main chemical attractant is sodium. Acute toxicity tests show that there is slight oral toxicity of the chloride deicers to small animals.(*xxii*)

Further study of magnesium chloride deicer by the Colorado DOT and the University of Colorado concluded that application of Mag chloride at current rates is highly unlikely to cause or contribute to environmental damage at distances greater than 20 yards from the roadway. Even very close to the roadway, the study found that the potential of magnesium chloride deicer to cause environmental damage is likely much smaller than that of other factors related to road use and maintenance, including pollution of highway surfaces by vehicles and use of salt and sand mixtures to promote traction in winter.(*xxiii*)

Caltrans found that Magnesium chloride, being a liquid, can be applied in a more uniform manner than granular salt, but must be kept in storage tanks.(*xxiv*) 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.(*xxv*)

Colorado DOT's study concluded with the following practice recommendations for Mag chloride: (*xxvi*)

- Mag chloride may offer net environmental benefits if its use leads to a reduction in the quantity of salt and sand applied to roadways as long as concentrations of contaminants remain low and rust inhibitors containing phosphorus are avoided.
- Appropriate specifications for vendors and routine testing can ensure the continued environmental acceptability of magnesium chloride deicers.
- Deicers provided by vendors should be monitored independently by DOTs for chemical characteristics. Any significant changes in processing or source material should be disclosed by the vendor. Independent specifications should probably be developed depending on elevation in the state.

Impacts of Acetate Based Deicers on the Environment

Acetate-based deicers are organic and have different kinds of effects on the environment than the chloride-based deicers. The acetate ions are broken down by soil microorganisms and may result in oxygen depletion of the soil, which can impact vegetation. The acetate deicers also have the potential to cause oxygen depletion in rivers, streams and lakes. Since the dilution of deicers from roadways to nearby streams is estimated to range from 100 to 500-fold, oxygen depletion has been considered likely to occur only in slow flowing streams and small ponds.(xxvii) The aquatic toxicity of Calcium Magnesium Acetate (CMA) to fish and invertebrates is low.xxviii However, the depletion of dissolved oxygen (DO) from the degradation of the acetate component of CMA has been a water quality concern, and studies have shown that CMA decomposition exerted a significant biochemical oxygen demand on receiving waters.(xxix)(xxx)

The acetate deicers Potassium Acetate, Sodium Acetate (NAAC), and CMAK have higher toxicity to aquatic organisms. The use of the acetate deicers results in the decrease of air pollution from the reduction in sand use. However, the solid acetate deicers CMA and NAAC may contribute fine particulates to the air and increase air pollution. The acetate deicers CMA and Potassium Acetate are not harmful to terrestrial vegetation at the concentrations typically used on the roadways. However, NAAC may potentially have an adverse effect on vegetation because of the presence of the sodium ion, which decreases the stability and permeability of the soil. The depletion of oxygen in the soil from the breakdown of the acetate ion can have a negative effect on plant growth. Slight acute oral toxicity to mammals has been reported for the acetate deicers. No studies have been conducted on whether the acetate deicers attract wildlife to roadways.(*xxxi*)

Oregon DOT has decided to tightly control and potentially avoid the use of calcium magnesium acetate (CMA) and potassium acetate (KA) in the following areas:

- Those where receiving waters will not provide 100:1 dilution during the runoff season, or if the runoff occurs in the late season when the receiving waters may have warmed and protected aquatic species are present;
- Those where a larger highway runoff volume can directly reach a small, shallow pond, lake, or wetland, particularly if the receptor is ice covered. A 30-foot vegetation buffer may be adequate;
- Those where there is no vegetation buffer between the road and receiving waters, and the waters should be protected from oxygen depletion. Present DOT standards for vegetative buffers are adequate;
- Those known to have heavy metal concentrations, coarse soils overlying sensitive aquifers, or percolation devices such as French drains and drywells: when CMA or KA is used in any of the above situations due to over riding concerns for highway safety, water quality should be carefully monitored for possible problems.

Caltrans tests of CMA found the compound less effective than salt for deeper snow packs, resulting in a delay in the melting of ice and snow pack, particularly at temperature below 24 degrees F though the consistency of the snow pack was changed such that it was easier to plow.(*xxxii*) CMA can cause respiratory distress and eye irritation for personnel required to handle it, thereby necessitating the use of protective gear. CMA costs over 10 times more than salt and typically requires an application rate 50 percent over that of salt for CMA to be effective.(*xxxiii*)
The National Research Council conducted a study to examine the full economic costs of using salt and CMA for highway deicing. The report, TRB Special Report 235, Comparing Salt And Calcium Magnesium Acetate, defines the true cost of salt; estimates of monetary costs involved in mitigating environmental damage from road salt; and summarizes field performance, infrastructure and environmental impacts, production technologies and costs of CMA.(*xxxiv*) Other studies have investigated the effects of different deicers on concrete deterioration.(*xxxv*)

Impacts of Sand/Abrasives on the Environment

Sand is not a deicer, but has been used for snow and ice control since the early 20th Century. Agencies tend to spread sand many times throughout the winter months, an expensive process that can create large debris deposits on roadways and require road sweeping and subsequent disposal as solid waste. Sweeping picks up only a small percent of the total sand applied during a typical winter. An Oregon DOT study found that 50 to 90 percent of sand applied to pavements remains in the environment after cleanup.(*xxxvi*) The rest remains in the environment, much of it in catch basins or on or around roadways. Much of the sand not retained in catch basins stays in drainage pipes, decreasing their capacity. Abrasives can clog stormwater inlets and sewers, requiring cleanup in urban areas, on bridge decks, in ditches, and where aquatic environments are at risk. The materials may wash downstream and end up in streams and lakes.

Resource agencies have determined that roadway sand contributes to sedimentation in streams and impacts fish and other aquatic resources. Sand has a negative effect on water quality as a result of the increased turbidity caused by the presence of sand particles in water. Sediment impairment is the most widespread cause for waters of the state to fail to meet water quality standards.(*xxxvii*) The increased water turbidity can result in mortality of fish and bottom-dwelling invertebrates that may be covered by the sand. The increased turbidity will also reduce or inhibit photosynthesis in aquatic plants.

Air pollution from particles less than 10 microns in size (PM_{10}) has been documented from winter abrasive use. Vehicle grinding of sand allows fine particulate matter, PM_{10} (or $PM_{2.5}$), to become airborne when dry, and causes river silting during snow melt via surface drainage. Sand used for snow and ice control increases air pollution and has been estimated to contribute approximately 45 percent of the small particulates present in air.(*xxxviii*) A 1995 study documented "The Contribution of Road Sanding and Salting Material on Ambient PM_{10} Concentrations" in Albany, NY; Denver, CO; and Reno, NV, the impacts of wintertime road sanding and/or salting on ambient particulate loadings and found the following: (*xxxix*)

- **Albany.** In 21 6-hour sampling periods, sanding contributed more than 44 percent of the total PM_{10} particulate loading, with a high of 75 percent. Motor vehicle emissions contributed approximately 22 percent and deicing salt was as low as 1 percent, averaging 24 percent.
- **Denver**. In 24 samples analyzed in the study, the sand loading contributed over 59 percent to the ambient PM_{10} levels, with a high greater than 89 percent. Motor vehicles contributed 19 percent and deicing salt just over 1 percent. Shortly after the study was completed, EPA approved the State of Colorado's air quality improvement plan including a new section dedicated to "Improved Street Sweeping" which requires "that any entity responsible for applying street sanding material within the Denver Central Business District shall clean all streets using vacuum sweepers or a more effective technology within four days of each sanding episode."
- **Reno**. In 20 samples analyzed, sand contributed an average of 57 percent to PM_{10}, similar to Denver, with a high of 80 percent. Motor vehicles contributed 22 percent and highway salt approximately 1 percent.

Last but not least, recent studies have shown sand to be of limited value on icy roads. The Iowa DOT and the Iowa Highway Research Board completed a study on "The Use of Abrasives in Winter Maintenance" and concluded that "… applying abrasives dry is of limited value in providing lasting friction enhancement. This represents a substantial change in current practice. Nonetheless, the results of a variety of studies are unequivocal in finding that abrasives applied to roads where significant traffic travels at high speeds are swept off the road rapidly, remaining in place (and providing friction enhancement) for somewhere between 10 and 100 vehicle passages, at most." The effects of sanding are temporary, whether spread dry or prewetted. Abrasives do little to improve driving conditions on roads with high traffic volume. When dry sand is spread, 30 percent of it immediately scatters. Over time, cars usually displace most of the remaining sand. As few as 8 to 12 vehicles can sweep it from snow covered highway surfaces. Even with light traffic, friction gained from dry sand is quickly diminished.

University of Iowa (UI) researchers have drawn similar conclusions about methods to prewet abrasives with a chemical deicing brine.(*xl*)

Responding to Public Concerns/Complaints Regarding Contamination

If a complaint suggests that a DOT may be responsible or involved in the alleged contamination NYSDOT has recommended the following steps or practices to respond to public concern and address the environmental issue:

- *Site Location.* Locate the contaminated property or area on a map and observe if transportation facilities or major roads or highways are located near the affected site. Sometimes, we observe salt contamination in aquifer areas adjacent to salt storage (including former or temporary) facilities or more rarely, along major highways such as highly traveled State roads or interstates. Salting of smaller or low traffic volume roads generally does not cause significant groundwater contamination.
- *Interview*. Discuss with Regional Transportation Maintenance staff whether salt (or salt/sand mixtures) is or has been stored at or near the affected site. If so, find out if the salt pile is or was uncovered, and for how long. If stored salt is in contact (even occasionally) with rain or surface water, then recommend or perform actions (i.e., cover the pile with tarpaulins when not in use) to avoid such contact. Inadequate salt storage often results in aquifer salt-contamination.
- *Photo, Map, and Background Water Quality Review.* If possible, review historical aerial photos, soil/geological maps, and area background water quality data. Aerial photos may show previous salt piles. Soil/geological maps may suggest the location/orientation of potential geological conduits for the contaminants to migrate in the subsurface. Background water quality data from nearby wells will help in interpreting and deciding whether the water quality results received with the complaint could relate to salt-contaminated groundwater from DOT activities.
- *Inspection.* Inspect affected residences and ask residents for well data (well type and depth, soil/rock type, etc.). Look for water treatment system connections, if any, and identify where the system effluent goes. Typically the effluent discharges to the septic system. Also, inspect any nearby DOT facilities and evaluate past or current salt storage practices or conditions. If uncovered salt-, salt/sand mix- piles, or significant amounts of spilled salt are observed, recommend that regional transportation maintenance staff immediately cover or relocate the piles or remove the spilled salt.(*xli*)

8.2. REDUCING SAND USAGE

Stewardship practice requires the careful review of use of sand in areas with the following issues: (*xlii*)

- PM10 (dust) related air quality problems;
- Potential for in spawning streams, shallow lakes or ponds;

- Sensitive, rare plants near the roadside; and,
- Sand is considered to have a negative impact on aesthetics.

The Montana Department of Transportation (MDT) and the Western Transportation Institute have developed "Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water."(*xliii*) That study and MDT practice recommended the following:

- Identify areas where road sand may be impacting streams adjacent to highways.(*xliv*)
- Wherever possible, a combination of both structural and non-structural BMPs, or best management practices, should be employed to minimize the environmental impacts of winter traction materials. Structural BMPs treat or mitigate highway runoff after it goes off the roadways, and non-structural BMPs reduce the amount of traction materials applied on roadways while maintaining winter mobility and public safety. Strategies can be implemented in the domain of technology, management, or both.
- Strategies may vary, depending on the specific climate, site, and traffic conditions. The crux is selecting an appropriate suite of BMPs that can function most effectively for a given set of conditions.
- Despite the challenges of winter conditions, structural BMPs such as ponds, wetlands, and vegetated swales and filter strips, can still remove high levels of sediment from runoff if designed, sited, installed, and maintained properly.
- The primary non-structural BMPs used to reduce the use and thus minimize the environmental impacts of winter traction materials, include: incorporating environmental staff into construction and maintenance, proper training of maintenance professionals, erosion control, snow fences, snow storage, street sweeping, improved anti-icing and de-icing practices, improved sanding practices, appropriate application rate, and snowplow technologies. Among these, anti-icing strategies, road weather information systems, the Maintenance Decision Support System, and advanced snowplow technologies were highly recommended.

In some areas, MDT is trying to more quickly achieve a bare road, in order to reduce the traction materials needed.(*xlv*)

Since 1989 Caltrans has substantially reduced the amount of traction sand applied to the highways in the Lake Tahoe Basin through a combination of deploying state-of-the-art sanding equipment, operator training, and the employment of anti-icing strategies.(*xlvi*) Caltrans has significantly increased the amount of sand recovery, mainly due to the deployment and use of state-of-the-art vactor and sweeper equipment.(*xlvii*)
The Iowa Department of Transportation and the Iowa Highway Research Board study on "The Use of Abrasives in Winter Maintenance" recommends the following stewardship practices for effective and minimal use of abrasives on the following categories of roadways: (*xlviii*)

- High Speed Urban Roads. For urban streets with posted speed limits above 30 mph, there is no significant value in placing abrasives. Research recommends plowing and applying chemicals to achieve bare pavement.

- Low Speed Urban Roads. For urban streets with posted speed limits less than 30 mph, there is less abrasive dispersion. Abrasives should be limited to parts of the road where motorists must brake, accelerate, or maneuver. Even then, abrasives should be applied only when it will likely take a long time to provide bare pavement.
- Urban Intersections. Urban intersections are relatively low-speed traffic locations. Abrasives could be placed if needed. However, they should be used only when an intersection might be snow or ice-covered beyond a normal period.
- Rural Roads. Both paved and gravel roads can expect to see high-speed traffic. Abrasives will not stay on the road for any reasonable amount of time. Abrasives should be applied on hills and curves only on low-speed low-volume roads. Paved rural roads should be plowed and chemical applied to achieve bare pavement. The recommended gravel rural roads approach should be simply to groom the snow pack.
- Rural Intersections. Again, gravel versus paved roads must be considered. An intersection should be considered "paved" only if all intersecting roads are paved. Road segments where motorists must stop or yield are low-speed traffic locations. Abrasives could be placed if needed. The preferred approach for paved roads is to plow and apply chemicals to achieve bare pavement. On gravel parts of intersections, abrasives may be applied over that part of the road where speeds of less than 30 mph are expected.

8.3. STRATEGIC PLANNING FOR REDUCED SALT USAGE

Increasing numbers of DOTs are evaluating the levels of chlorides in streams adjacent to highways to ensure no impacts to water quality from deicing liquids. Several state DOTs have undertaken strategic planning efforts to reduce salt usage; examples are provided below.

Caltrans Salt Reduction Policy and Implementation

Caltrans implemented a reduced salt-use policy starting in October 1989 that required transportation districts to develop specific route-by-route plans. That policy mandated that "Snow removal and ice control should be performed as necessary in order to facilitate the movement and safety of public traffic and should be done in accordance with the best management practices outlined herein with particular emphasis given to environmentally sensitive areas."(*xlix*) During the first winter, Caltrans reduced salt usage by 62 percent statewide as compared to the previous winter, helped by improved control of the application frequency of deicing salt.(*l*)

NYSDOT's Salt Reduction Strategy

NYSDOT's salt reduction strategy has revolved around "right application at the right time with the right chemical." NYSDOT has employed thorough management controls, keeping track of amount of salt delivered to sheds and the salt used on each beat, and doing calculations afterward to see if the agency is within established guidelines. If not, the first thing they check is the truck; if calibrations are on target, a supervisor has a discussion with the operator. With this system, NYSDOT does not have a problem with operator over-application. Computerized on-board systems allow application at any rate and take into account weather information.(*li*)

PENNDOT District 10 Salt Management "After Action Reviews" and Annual Update of Salt Management Plan

PENNDOT is among the DOTs that have taken the lead in the U.S. in reducing salt usage. PENNDOT District 1 relies on precise application rates to minimize contamination in runoff from anti-icing and deicing operations. All trucks are equipped with thermometers for informed decisions on application rates; equipment operators can make informed decisions on when to spread material because each truck has a thermometer that displays both air and road surface temperature. After every snow event and every shift, PENNDOT operators complete tracking forms and turn those in to the foreman; such "after action reviews" utilize automatic data downloads from spreaders. The foreman and the operator check the application rate and discuss any variances. Summaries are prepared with regard to stockpiles. PENNDOT's universal database from each snow event allows them to evaluate and compare application rates by district and by truck. Information from spreader controllers can be downloaded to a computer or output directly to a printer through a data port on the controller at the end of each shift. This information includes:

- Types and amount of material spread
- Miles spread

Each operator keeps a written log of:

- Routes spread at what time
- Air and road temperatures
- Type of storm

From this database, many different reports can be run. The district has established application rate goals for different types of storms and different temperature ranges. PENNDOT's District 10's Strategic Environmental Management Program Manual details the process and the roles of various stakeholders. (*lii*) Listed in the Appendix is PENNDOT's Post-Storm Salt Management Tracking.

PENNDOT District 10 updates their Salt Management Plan annually, including the following activities: (*liii*)

- Analysis of previous year's winter data.
- Revision of materials application charts and tracking sheets to improve application rates.
- Update of target application rates by snow lane miles by truck and charts to collect actual results.
- Equipment evaluation, calibration, repair, and purchasing plan.
- Update of winter training plan.
- Training of Equipment Operators on application rates.

Ohio DOT Pretreatment, Weather, Decisionmaking, and Routing System

Ohio DOT has a statewide initiative to reduce the amount of salt used to treat snow and ice conditions expanding anti-icing pre-treatment to a statewide level starting in 2002. Storm tracking with the aid of pavement sensors and mini weather stations placed strategically around the state give vital information to the counties to maximize their resources of time and materials. Advances in equipment monitors enable the snowplow truck drivers to be more effective in treating the roads. Optimizing truck routing can save time and money for districts through reduction in the "dead-head time" where a truck must return empty to a yard to refill. The initiative has received high level leadership in the department, from ODOT's Assistant Director and Deputy Director, and affecting District Highway Management, Equipment, and Facilities areas. To date, the initiative has: (*liv*)

- Implemented a material matrix expressing the relationship between pavement temperature and precipitation.
- Determined critical information for operational decision including: surface condition, material freeze point, precipitation type/amount, wind direction/speed, and air temperature.
- Developed a plan to deploy pavement sensors along the interstate system and weather systems at county garages not along interstate system.
- Drafted a plan to display information from weather and pavement sensor on statewide maps.
- Performed research to determine most appropriate pavement sensors to measure freeze point.
- Evaluated computer truck routing software for route optimization. Software modification needed to handle multiple salt locations.
- Established base line parameters for application rates, travel speed, and cycle time for evaluation.
- Developed draft process for long-range planning from the computer truck routing parameters.
- Snow and ice procedures will be included in the new Maintenance Manual being developed.
- Developed equipment evaluation forms and process.
- Developed an equipment matrix listing basic units and auxiliary equipment.
- Testing friction device to monitor surface conditions.
- Purchasing a salinity device to mount on truck to determine surface freeze conditions.
- Evaluating Automated Vehicle Location (AVL) device to track vehicle location, monitor material application, and record operational information.

Remaining goals of the initiative are to:

- Validate material matrix and pre-treatment plan including research for pre-treatment effectiveness.

- Deploy pavement sensors and weather devices statewide.
- Develop enhanced application to display pavement and weather information.
- Coordinate snow and ice operations through Central Radio Center for weather bulletins and condition alerts.
- Implement computer truck routing process and resource planning procedure for equipment and facility location, and staffing.

Transportation Association of Canada Recommended Practices for Developing Salt Management Plans

Given the increased emphasis on salt discharges to the environment in Canada, the Transportation Association of Canada has identified best practices in planning for salt management.(*lv*) Good plans for reducing salt usage and associated environmental impacts should include: (*lvi*)

- **Current baseline/metrics for salt management practice and progress**. A situational analysis may include the following to allow the DOT to measure and track progress in managing the amount of road salt being placed into the environment:

  Examination of On-Road Salt Use:

  - Type and amount of chloride freeze point depressant used (all sources including solids, liquids, and abrasive mixes).
  - Type and amount of non-chloride freeze point depressant used (all sources including solids, liquids, and abrasive mixes).
  - Current application rate for each type of material.
  - Percentage of fleet with pre-wetting.
  - Percentage of fleet with liquid only applications.
  - Percentage of fleet with electronic spreader controls.
  - Number of road weather information systems (RWIS) installations.
  - Number of other surface temperature measuring devices (hand-held or vehicle mounted).
  - Use of dedicated pavement and/or atmospheric forecasting

  Identification of Salt Vulnerable Areas:

  - Locations of salt vulnerable areas
  - Description of winter maintenance practices in the vicinity of salt vulnerable areas (e.g. alternate treatment). Examples of possible salt vulnerable areas include:
    - Groundwater recharge areas
    - Areas with exposed or shallow water tables with medium to high permeability soils
    - Sources of drinking water
    - Salt-sensitive vegetative communities

        - Salt-sensitive wetlands
        - Small ponds and lakes
        - Rivers with low flows
        - Salt-sensitive agricultural areas
        - Salt-sensitive habitats for species at risk

    Evaluation of Sand and Salt Storage Sites:

    - Number and capacity of storage sites
    - Percentage of sand/salt piles covered and type of cover
    - Percentage of indoor loading
    - Management of drainage from sand/salt mix piles
    - Levels of environmental indicators (e.g. chloride levels)
    - Percentage of salt in winter sand
    - Percentage of sites with washwater treatment
    - Existence of a good housekeeping policy, and adherence to the policy

    Snow Disposal Sites: (only necessary in the most snowy regions of the U.S.

    - Number and capacity of disposal sites (permanent and/or temporary)
    - Levels of environmental indicators (e.g. chloride levels)
    - Percentage of disposal sites with water management systems
    - Conformance with existing environmental standards for snow disposal sites
    - Existence of a good housekeeping policy and adherence to the policy

    Training:

    - Training includes such on-the-job elements as preseason "dry runs." Drainage facilities, wildlife crossing structures and other facilities requiring delineation or special treatment in plowing operations should be noted by foremen and equipment operators during dry runs of routes in the fall along with possible obstructions.
    - Percentage and frequency of staff receiving training in best salt management practices broken down into categories (e.g. managers, supervisors and operators)

- **Comparison of current practices to best management practices and document the gaps.** The salt management plan should then focus on closing these gaps. The plan should include preseason, **in-season, and post-season actions** to be taken to reduce the adverse impacts of road salts. It should also include **consideration of equipment, labor, materials, and the local climate**.
- **How general road use of salt, salt use in salt vulnerable areas, and salt storage will be addressed**. Snow storage and disposal sites should be dealt with in regions where this is an issue.

- **Clear tasks, schedules with milestones, budget considerations, and assigned responsibilities** for implementing best salt management practices. The plan will involve prioritizing in many cases. For example, spreaders on the highest salt routes or in proximity to vulnerable areas can be targeted first for replacement, and the most versatile mechanical removal equipment can be stationed where it will help lessen salt loadings.
- **Documented policies, procedures, and guidelines in the following areas,** aimed at introducing best salt management practices with both in-house and outsourced operations.
    - Level of service for each roadway type
    - Salt and sand application rates
    - Managed sand and salt storage
    - Good housekeeping practices for maintenance yards consistent with TAC's Design and Operation of Road Maintenance Yards Synthesis of Best Practices
    - Equipment calibration & re-calibration
    - Training
    - Snow disposal
    - Incorporation of salt management consideration into road design and construction
    - Salt vulnerable areas
- **Monitoring, Record Keeping, Reporting & Analysis**
    - Progress on implementation of the salt management plan can only be confirmed by tracking specific indicators and comparing these to the baseline that was benchmarked at the outset of the program.
    - Each salt management plan should assign responsibility for monitoring and reporting on implementation of the plan. These results should be reported annually to the senior executive responsible for the salt management plan.
    - The monitoring and record keeping system should document and assess the indicators identified in the situational analysis. Where there are new issues or activities being implemented as part of the salt management plan, new monitoring initiatives may be required.
    - Any changes from the baseline established in the situational analysis need to be analyzed to assess the degree of progress being made. The analysis should also take into account the type of winter experienced to ensure that realistic conclusions are being drawn. For example, an increase in salt use may be due to an unusually severe winter rather than the failure of a plan.
    - Similarly, a reduction in salt use may be due to a milder than normal winter rather than the successful implementation of a plan. Therefore the analysis must be sufficiently in-depth to account for these

variances. Where there are known releases to the environment being monitored (e.g. stormwater outfalls, water intakes, water treatment plants, monitoring wells, material storage sites or snow disposal sites), then these data should be included in the annual progress report.

- **Management Review**
    - Each year, senior management within each administration should review the results of the previous year's salt management actions to confirm that the plan is achieving the desired results and to adjust the next year's salt management plan to respond to shortcomings and new opportunities. Policies and procedures should be updated prior to the next snow and ice control season and communicated to management and operational personnel.
    - This review should be integrated into the budgetary process to permit timely acquisitions of new equipment and to identify other funding needs, including:
        - Personnel commitments.
        - Review of organizational equipment needs and fleet management strategy, staying current with changes in the business.
        - A transition strategy to shift from the existing fleet to a new fleet that incorporates available technology. To gain experience in new methodology, new equipment may be assigned to preferred "champions" in the organization for demonstrated use on less significant roadways until there is confidence in the new practices.

8.4. STEWARDSHIP PRACTICES FOR REDUCING SALT AND OTHER CHEMICAL USAGE

The minimization of salt related impacts should be one objective of any management strategy formulated for roadway drainage systems. Efficient employment of anti-icing programs and other management systems minimizes the introduction of salt alternatives into the environment.

The Transportation Association of Canada (*lvii*), Oregon DOT (*lviii*), and NYSDOT (*lix*) make the following overarching stewardship practice recommendations for reducing salt usage, included below in addition to practices suggested by recent research. A number of these practices are expanded upon in subsequent sections.

- **Practice anti-icing by promoting a timely response to snow and ice events in order to prevent a bond** from forming between the frozen precipitation and the pavement. This strategy consumes much less material than a de-icing strategy. Anti-icing solution must be applied before snow cover occurs, as otherwise the application may become diluted and brine will not be established between pavement and snow.
- **Evaluate road and weather conditions and trends** to ensure that the proper type and timing of treatment is made.

- **Snow and ice control decision-making should be based on ongoing monitoring of pavement temperatures rather than air temperatures.** Pavement surface temperatures can fluctuate significantly depending upon the time of day, degree of cloud cover, sub-surface conditions (i.e. frost penetration, moisture presence, thermal retention properties, etc.) and type of pavement. Therefore ongoing monitoring of pavement temperatures is important to good decision-making.
- **Plow off snow or slush prior to applying materials to decrease dilution and increase effectiveness of the materials.**
- **Do not overload the material spreader, to avoid spillage.**
- **Control spreading speeds to reduce bounce and scatter.**
- **Control spread patterns to concentrate material where it is most effective** on the road. Solid road salt is usually placed on the crown or high side of the driving surface where a good crossfall and traffic will distribute the resulting brine over the road. When re-applying material, consider the possibility of partial vs. full and spot vs. blanket treatments where appropriate. Wider spread patterns are called for when spreading on deteriorated pavements where an undulating surface or poor crossfall will not ensure adequate chemical migration across the entire road, or when rapid distribution is required to address frost or black ice conditions.
- **Consider alternative treatments** (e.g., plow only, use of snow fencing) which do not involve materials usage where applicable. Non-chemical deicers have the potential to introduce less salt and environmental contamination. Innovative techniques in debonding were explored in SHRP Report H-644, Ice-Pavement Bond Disbonding—Surface Modification and Disbonding, including noncontact and contact methods, additives to alter surface texture, electromagnetic radiation, and abrasive air and liquid jets applied directly to ice pavement interface.(*lx*) In terms of contact debonding technology, SHRP Report H-673, An Improved Displacement Snowplow, describes the research on improving the design of snowplows, as well as design, fabrication, and testing of plows incorporating improvements, toward the effort of decreasing energy consumption during plowing by twenty percent.(*lxi*) Improved Cutting Edges for Ice Removal presents an evaluation of snow plow blade geometry and its effects on the force required to remove ice from a highway pavement surface including prototypes and testing of three different cutting edges.(*lxii*)
- **Alter application methods and rates in sensitive areas**: (*lxiii*)
    - Use CMA on bridges and roads where permitted and during freezing fog in lieu of sanding, when optimum conditions exist, where adjacent water bodies support a 100:1 dilution factor or there is a vegetative buffer between the road and water body and where there is no standing, shallow water.

- Place barriers in site specific locations where appropriate and practical, along streams or direct drainages to route sanding/anti-icing material away from watercourses.
    - Reduce plowing speed in sensitive areas.
    - Stop sidecast sweeping within 50 feet of structures over water, where structurally possible.
    - Identify and creating facilities to capture sanding material where appropriate.
    - Reduce quantity of sand applied where appropriate.
    - Clean inlets prior to first rain as feasible.
    - Modify blade angles or blower hoppers in sensitive areas.
    - Educate DOT maintenance staff on water quality and fishery resource issues.
- **Return unused materials to stockpiles and avoid heavy "end of beat" applications** that empty the load
- **Keep accurate records of materials usage to allow monitoring and improvement of operations.** While it is not practical to monitor all runoff from roadways for chloride levels, transportation agencies should consider monitoring salt vulnerable areas. One municipality worked with their local conservation authority to add chloride monitors to their stream monitoring network.

Shifting to Anti-Icing

Anti-icing is the proactive use of any melting agent to assist melting and resist the formation of a bond between snow and ice and the pavement surface. Highway anti-icing is the snow and ice control practice of preventing the formation or development of bonded snow and ice by timely applications of a chemical freezing-point depressant. It provides a maintenance manager with two major capabilities: the capability for maintaining roads in the best conditions possible during a winter storm, and the capability to do so in an efficient manner with the fewest chemicals and environmental impacts possible.

Anti-icing can involve application to the roadway of liquids, pre-wetted solid granular materials or dry granular material. Thus, anti-icing is not confined to using liquids. Direct liquid applications are efficient since they provide melt action immediately and do not take time to dissolve and form brine. Furthermore, liquids do not depend on the presence of heat from the ground, sunlight or traffic to dissolve (endothermic reaction). The timing of the application is not as critical as with granular materials; the principle is that traffic will help the liquid migrate across the road cross-section and yet not develop into road spray. Liquids can be applied in advance of the start of a storm. 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 (and which will redissolve and reform a brine with precipitation); conversely, hygroscopic brines (such as $CaCl_2$ and $MgCl_2$) will attract moisture and continually wet the road until they are dissipated. The approach to resisting the bond is not to wet the road, but simply to provide enough

chemical to enhance early-storm safety with an application of chemical that stays on the road. The intention is not to “wash” or even fully wet the road with an equivalent chemical loading as that of a granular application. Generally, an equivalent weight of salt applied as a liquid (e.g. dissolved in water) performs better than the same weight of dry granular salt because the liquid is fully retained on the road surface. The cost on a dollar-per-gram basis may be greater for liquid only applications (depending on the liquid used), however the offsetting safety benefits have to be considered.(*lxiv*)
European and Scandinavian experience has shown that as little as 5 to 10 g/m^2 (65 to 130 lb/lane-mile) of salt is needed for preventing salting treatment for frost, black ice, and light snow. There appears to be no consensus among European countries regarding the rate of salt spreading during continuous snowfalls. Estimates of application rates under these conditions range from 10 to 60 g/m^2 (130 to 780 lb/lane-mile). Highway agencies in the United States have found that reducing the conventional application rate to quantities on the order of 4 or 5 g/m^2 (42 or 65 lb/lane-mile) is not generally possible with current equipment that is designed for deicing application rates of 23 to 38 g/m^2 (300 to 500 lb/lane-mile) and higher. Liquid freezing-point depressants offer the advantage of precise and uniform application over a wide range of rates.(*lxv*)

Environmental Benefits and Cost Savings of Shifting to Anti-Icing
According to a study by the Strategic Highway Research Program, experiments at nine state highway agencies, anti-icing treatment requires less chemical use than most deicing procedures and makes it easier to achieve bare pavement conditions.(*lxvi*) As a result, anti-icing can provide cost savings as well as environmental benefits. For example, the Iowa, Missouri, Oregon, and Washington DOTs realized cost savings and the following benefits in test programs: (*lxvii*)(*lxviii*)(*lxix*)(*lxx*)

- Fewer snowplow trips were made. The anti-icing truck only had to make one trip for every three trips made by the larger conventional snow-removal truck.
- Crews experienced less wear on equipment due to fewer snowplow runs.
- When required, plowing was easier and faster. Less time was spent clearing roads. Crews were able to complete snow removal on roads that received anti-icing treatment up to three hours sooner than on conventionally treated roads.
- Fewer chemicals were needed by applying the treatment prior to snowfall. With fewer chemical applications needed, the anti-icing method was better for the environment.
- With reduced costs for labor and chemical use.

Since Boulder began using a liquid solution comprising 29 percent magnesium chloride and 71 percent water in 1993, sand use has decreased by 55 percent. When all costs are considered, using the liquid chemical costs $2,500 per lane mile, as compared to $5,200 for deicing and sanding operations.(*lxxi*) The Center for Geotechnical Engineering Science (CGES) at the University of Colorado at Denver completed a CDOT-sponsored study on ”Environmentally Sensitive Sanding and Deicing Practices” in 1994. The study recommended the formulation of an optimal practice that minimizes the use of sand and increases the use of environmentally friendly chemicals for the purpose of enhancing winter highway traction and maintaining both environmental health and human respiratory health. Implemented since 1994, the shift has had a direct beneficial impact on all issues related to safety, cost, environment, and human health and has improved the Colorado air quality, allowing Colorado to avoid exceedance of the EPA PM_{10} standard over subsequent winters.(*lxxii*) The Idaho Department of Transportation (IDT)'s anti-icing retrofits showed reductions in annual averages of abrasive quantities, labor hours, and winter crashes over five years.(*lxxiii*)

Stewardship Practices to Minimize Anti-Icing Materials Application
Stewardship practices to minimize materials application and release to the environment include the following:

- **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.** The anti-icing chemical solution concentration will decrease as it is diluted with water from either the melting of the snow/ice or falling rain/freezing rain and becomes less effective.
- **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.

FHWA's Manual of Practice for an Effective Anti-Icing Program: A Guide For Highway Winter Maintenance Personnel describes program factors, practice recommendations, and guidance for conducting anti-icing operations during specific precipitation and weather events.(*lxxiv*) Recognizing that the development of the program must be based on the specific needs of the site or region within its reach, FHWA provides the caveat that no short discussion or list of recommendations can completely cover the range of conditions facing agencies continent wide; instead the guide is to be used as a starting point for developing its own anti-icing program, and to modify the recommendations when necessary in order to accommodate local experience, specific site concerns, and agency objectives. The report does present specific recommendations for anti-icing operations for five weather events, from light snow storms to heavy ones, frost, freezing rain, and sleet. Guidance on maintenance actions for each event is provided for several pavement temperature ranges and for initial and subsequent operations. Temperature trend, an important factor, is also indicated. Solid, liquid, and prewetted solid chemical application rates are suggested where appropriate—rates not to be considered as fixed values but rather the middle of a range to be selected by an agency according to its local conditions and experience. Traffic volumes were not found to have a consistent or dominant influence on pavement condition or traction to suggest varying chemical application rates except in the case of frost and black ice, and that category is the only one incorporating traffic as an operational consideration. The guidance presented was based upon the results of four years of anti-icing field testing conducted by 15 State highway agencies and supported by the Strategic Highway Research Program (SHRP) and FHWA, and then was augmented with practices developed outside the U.S., where necessary, for completeness. Steps in initial operation of an effective anti-icing program include: (*lxxv*)

- **Information assembly** upon first notice that a winter storm or frost/black ice event may affect the maintenance area, including weather forecasts, weather radar data, satellite data, local road condition and RWIS data, pavement temperature forecasts, and any RWIS data from areas outside the immediate maintenance jurisdiction that might have already have been affected by the approaching storm. The information must be reviewed to estimate when and where the event will begin, its extent, and severity.

- **Decision** on whether or not to initiate a treatment, when to start it and what type of treatment to apply can be made after the review is made of the information assembled. The decision is based on when precipitation is expected to start, what form it will be, the probable air and pavement temperatures, the anticipated trend of the temperatures, the expected sky conditions, the wind speed and direction, and the intended timing of the treatment.
- **Chemical application.** Either dry solid chemicals, liquid chemicals, or prewetted solid chemicals can be used as an initial anti-icing treatment. Whichever is used, the timing of the application should be consistent with the underlying objective of preventing the formation or development of bonded snow or ice, and should reflect an underlying readiness consistent with a preventive strategy. That is, it should be made in anticipation of or in prompt response to worsening pavement conditions. Applications in advance of snowfall are not necessary for preventing bonded snowpack, but early applications when the pavement condition is no worse than wet, slushy, or lightly snow covered are for the most part necessary for anti-icing success. As this may not always be possible, for example because of a limited fleet or heavy traffic, pretreating the road before a snowstorm may be the only way to ensure that all areas are treated before conditions deteriorate. Chemical application at the right time can reduce chemical usage and environmental effects.

  For snowstorms, initial liquid applications can be made either as a “pretreatment” in advance of the storm or as an “early-storm treatment,” i.e., soon after snowfall has begun and/or when the pavement temperature is dropping toward freezing. A pretreatment can be made well ahead of a storm as long as the storm does not start out with above freezing temperatures and rain, washing the chemical away. In the case of early-storm treatment, the application may be made onto dry, wet, light slush, or lightly snow covered pavement. Late applications onto pavements with more than a light covering of slush or snow can result in excessive dilution of the chemical, and risks failure. These should always be coordinated with plowing. Recommendations for **use of solid and prewetted solid chemicals**, **plowing**, and time when **doing nothing** are most appropriate are also discussed.

Direct liquid applications can be applied over multiple lanes by trucks traveling at higher speeds (than conventional salt spreading) with due regard for traffic. Trucks used for straight liquid applications can range in size, to accommodate frame-mounted or slide-in tanks. Truck configurations may include small trucks with tanks ranging from those used as patrol vehicles (pickups to two-tons) to vehicles used for vegetation spraying or bridge washing in the off-season; larger trucks used for water applications or calcium dust suppression applications in the off-season; and/or full-size, larger capacity tractor trailer tanker units used for long distance hauling in the off season. The application of liquids can be triggered by sensors and sprayed on a road or, more commonly, a bridge deck surface via Fixed Automated Spray Technology (FAST).

A Guide to Selecting Anti-Icing Chemicals and Considering Environmental Impact is available on-line.(*lxxvi*) The purpose of the guide is to specify the key performance measures that are required from an anti-icing chemical, and suggest ways of grading chemicals according to those performance measures. It also provides a method whereby an agency can weight these measures according to the specific needs of that agency, including Freezing Point Depression, Consistency, Environmental Impact, Stability, Corrosion, Handling, and Documentation. SHRP Report H-683, Anti-Icing Study: Controlled Chemical Treatments, developed correlations between meteorologic parameters and chemical effectiveness that can indicate the optimum conditions for a particular anti-icing chemical application.(*lxxvii*)

Road Weather Information Systems (RWIS)

An anti-icing program is only as good as an agency's ability to predict the onset of winter weather events accurately. Understanding and interpreting weather information can be critical to the success of any winter snow and ice removal operation. Knowing when, where and what type of deicing material to use for a particular winter weather event can be a challenge. Knowing where to find the weather information needed to make decisions and what information to use can be difficult.

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. Using pavement and atmospheric sensors and communication systems, RWIS collect and deliver roadway and weather condition data to decision maters in the maintenance garage and even behind the wheel of the snowplow. The data from a system of RWIS sensors along a highway network—especially along trouble spots—help maintenance personnel know when and how fast a winter weather event is approaching. The RWIS data indicate the kind of precipitation likely, where the precipitation will freeze on the roadway, and other information that will help Maintenance forces decide when to apply the minimum amount of chemicals to be effective.(*lxxviii*)

Recent research has found that the use of an incentive-based compensation model built on RWIS results in reduced use of salt compared with a compensation model based on measures to such an extent that the Swedish National Road Association is making preparations for changing the whole compensation system before the next winter season 2004–2005.lxxix

What Are Road Weather Information Systems (RWIS)?

Road weather information systems (RWIS) are networks of weather data-gathering and road condition monitoring systems and their associated communications, processing, and display facilities which provide decision information to maintenance managers. The most visible components of RWIS are the roadside installations of system components. A single site, which may have many sensors, is referred to as a remote processing unit (RPU) station, typically consisting of atmospheric sensors mounted on a tower, sensors embedded in the pavement surface and beneath the surface, and an enclosure which contains data processing capability and communications equipment. Data from the sensors are formatted at the RPU and transmitted to a central processing unit (CPU) where they may be stored, retransmitted to other workstations or locations, or accessed directly. The CPU can be a separate computer or a workstation.

Another component of a RWIS is the data processing and display capability used by the maintenance personnel. The actual system configuration depends on the management structure of the maintenance organization. This component can be a computer workstation in a maintenance facility or at a District or Area headquarters. It can also be a portable computer a manager, supervisor or foreman takes home.

- For made from a central office, one workstation with the CPU may suffice.
- If decision making is decentralized, workstations and/or portable computers should be available to the local decision makers for them to access data.

Benefits of RWIS

Data from RWIS are used to determine when and where to apply salt and other materials-commonly called deicing chemicals-that either prevent ice from bonding to the pavement or break the ice-to-pavement bond. The technology helps maintain ice-free roadways, cuts down on labor costs, and reduces chemical use.(*lxxx*)

Sensor-based RWIS has been in use for over 25 years by road and airport authorities around the world. Beyond giving road information and trends, RWIS sites and networks provide information required to develop specific forecasts as well as some service documentation. RWIS supports winter road operations in the following ways: (*lxxxi*)

- An understanding of pavement temperature forecasts and trends can improve the accuracy of decision- making.
- Sensors embedded flush in the pavement, as well as sub-surface, generate data that can be sent back to central locations allowing trends and forecasts to be developed.
- Pavement sensors can monitor pavement temperature, wet/dry status, freeze point of the solution on the road, presence of chemical and concentration (for some chemicals), as well as subsurface temperature.
- Tower-based sensors can also provide real-time information of typical atmospheric conditions such as precipitation, relative humidity, dew point, air temperature, and wind speed and direction.
- Weather forecasting services can use road-based information to provide “road weather” forecasts to help the road maintainer make better decisions regarding snow and ice control.
- Salt use optimization is achieved by more accurate deployment of equipment and application of chemicals.
- Other types of sensors and systems can be added to RWIS to further support road maintainers (e.g. road-imbedded device to measure road friction and snow cover, automated liquid deicer application system―Fixed Automated Spray Technology (FAST), etc.).

- The RWIS can be equipped to perform other beneficial functions. A camera can be attached to provide real-time weather information. A laser device can measure visibility. The intensity and accumulation rate of snow can be measured. And the station can activate changeable message signs to warn drivers of snow, high winds, and other hazardous conditions.

By doing a better job of predicting where and when crews and materials will be needed, agencies are able to reduce usage and expenditures while maintaining level of service. Pilot tests have indicated the potential for wider scale reductions; for example Mass Highway estimated that a complete RWIS could yield savings of $150,000 to $250,000 during a typical Boston winter.(*lxxxii*) NJDOT is equipping all crew supervisors with portable computers so that they can access RWIS and other data at any time and winter maintenance decisions are made by the people most familiar with the roads and weather in a particular area, estimating that the resulting savings in chemical, labor, and equipment costs could reduce snow and ice control expenses by 10 to 20 percent statewide. A fully implemented system was estimated to eliminate at least one chemical application pass per storm.(*lxxxiii*) NYSDOT is stressing pavement temperature not air temperature and in-pavement sensors are beginning to provide this information. At NYSDOT, 10 percent of trucks have units, plus supervisors have hand-held units to estimate pavement temperature.

Strategically placed RWIS stations provide forecasts that are 90 to 95 percent accurate, a rate which is improving with addition of further stations and better technology. In sum, (*lxxxiv*)

- Crew chiefs have a better idea of how much deicing chemicals to apply to the pavements and when, cutting costs and minimizing any environmental impacts.
- Maintenance activities can be better planned and executed. Labor, material, and energy costs are reduced. DOT operations have become more efficient, giving the agency a return on investment of 200 percent to 1,300 percent.(*lxxxv*)
- Road safety is enhanced and the public benefits from faster response to weather-related emergencies.

RWIS Selection, Siting, Use, and Maintenance, Connection to Snow and Ice Control Materials and Methods and Use of Friction Indicators to Minimize Chemical Usage

Additional information about RWIS, their selection, procurement, siting, use, maintenance, and calibration can be obtained in the two-volume SHRP report Road Weather Information Systems Volume 1: Research Report and Road Weather Information Systems Volume 2: Implementation Guide (SHRP-H-351).(*lxxxvi*)(*lxxxvii*) The National Cooperative Highway Research Program (NCHRP) recently completed Project 6-13, Guidelines for Snow and Ice Control Materials and Methods, to help maintenance managers select appropriate strategies and tactics for specific winter storm conditions. NCHRP has distributed the report to state departments of transportation. In combination with the results of NCHRP Project 6-16, Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts—now in progress—the report will provide a complete winter maintenance handbook for managers. Supplementing RWIS data with real-time friction measurements may be useful for managers allocating resources for snow removal as a storm is occurring, and NCHRP

Web Document 53, Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility, provides practical insights. NCHRP Project 6-15, Testing and Calibration Methods for RWIS Sensors, in progress, will assemble best practices and produce practical guidelines to ensure the reliable operation of RWIS sensors in the field.(*lxxxviii*) Together, these resources and the RWIS tools below can help maintenance managers optimize road safety and minimize chemical usage.

Road Information and Temperature Assessment

Maintenance decisions should not be based on a rigid, automatic basis but rather on the assessment of a need. In contrast to prescribing that chemicals be applied, or plow runs be made every hour or two or other fixed interval, decision on treatment need can be based on a number of information sources, including the visual observations of precipitation/weather and pavement conditions from patrols and from operators, an indication or the measurement of chemical concentration on the pavement, and the measurement of frictional resistance to sliding.(*lxxxix*)

Real-time knowledge of the pavement surface state is necessary for making an informed decision on treatment: the pavement temperature, whether it is wet or dry, and some indication of the concentration of a freezing-point depressant. The most important is pavement temperature, as the solubility of all chemicals varies with temperature. Lower temperatures bring about less solubility. An ice-control chemical must form a solution in water in order to depress the freezing-point. The pavement temperature will determine if it will form an ice-melting interface at the pavement surface. Air temperature is less important at the critical time of application and immediately following since there is usually a lag between air temperature change and the response of the pavement surface. Nonetheless, the air temperature trend is important to track because pavement temperature will usually follow the air temperature within a few hours depending on the difference in the air temperatures, the amount of solar radiation, wind, and the characteristics of the road. Remote measurement of amount and type of precipitation will guide the maintenance manager in deploying available resources most effectively. It is not unusual for part of a region to be receiving freezing rain, another part snow, and still another no precipitation. Using the most appropriate chemical and application rate for the condition, scheduling only plowing, or choosing to do nothing can all be informed decisions based on road and weather information.

Pavement Sensors and Thermal Mapping

Pavement sensors accomplish this monitoring and warning function. In addition to their real-time monitoring function, pavement temperature sensors can be used to generate a forecast of pavement temperature trend and warn when it will drop below freezing. This warning can occur several hours before the event, providing sufficient time to plan operations and avoid unnecessary costs.

In addition to measuring temperature most pavement sensors give a relative value of the chemical concentration on the sensor surface based on conductivity measurement. It will serve as a guide to whether some chemical remains on the road and help in making the decision whether or not to retreat. Another capability is available on some of the newest types of pavement sensors: measurement of the freezing-point of the solution on the detector. Its value lies in warning of the refreeze of a chemical treatment which has been diluted by melted snow or ice.

Thermal mapping, or thermography, is the process of determining thermal profiles of road surfaces using infrared sensors. Thermal mapping profiles can be used to infer pavement temperatures between sensor locations where the temperatures are known. An extension of this process is to forecast temperatures along the roadway based on the forecasts of temperatures at known points. The measurements are typically made in the early morning hours, when there is the least change in the pavement temperature during the measurement process. They are also made under different atmospheric conditions, since the radiation balance at the surface is related to the atmospheric conditions, including cloud cover, wind speed, and precipitation. A variation of thermal mapping is called road climatology. Additional data are acquired when measuring pavement temperature, including air temperature, relative humidity, and climatological characteristics of the pavement environment. The additional data are input to a short-range (up to 4 hour) forecasting model for pavement temperature.

Thermal mapping of highway segments has been conducted in several States, including Washington, Nevada, and Minnesota. The data from thermal mapping have assisted in siting RPU stations, forecasting pavement temperatures for locations where no RWIS sensors exist, and for developing snow- and ice-control strategies. Other potential locations for thermal mapping include those areas where anti-icing operations are used, where reduced chemical areas exist, or where a significant number of different microclimates exist in a given area. Thermal mapping may also point to representative RPU locations that can eliminate the need for one or more sites. Better routing or allocation of maintenance resources and personnel is possible based on thermal mapping. The data can allow staging of responses to only those road segments expected to be below freezing. It can also indicate certain areas or locations that may not need attention. Research has indicated that thermal information from the road environment can be obtained using relatively inexpensive hand-held radiometers. Vehicle-mounted instruments for measuring pavement temperatures are already used by some State highway agencies.

There is some thought that thermal mapping should be considered when variations of pavement temperature greater than 5 degrees C (9 degrees F) are possible, or when the road elevation changes more than about 200 m (650 ft) over the segment length of interest. These “rules of thumb” are for general guidance and have not been validated by research data.

Infrared Thermometers (IRTs)

Decisions about material application are improved when information about the current road surface temperature is available and the temperature trend is known.

Infrared thermometers (IRTs) are portable devices that can be used to determine the current road surface temperatures while mobile along the road network. Both hand-held and truck-mounted versions are available; with the mounted versions measuring ambient air temperature as well. Truck-mounted versions allow continuous monitoring of the road surface while the vehicle is moving down the road. The data can be recorded and transmitted as part of the data stream of a GPS/AVL system (see

Operational Support Equipment later in this document). IRTs need to be checked and calibrated to confirm their accuracy and to be confident in the reading.

Road Surface Traction/Friction Measurement

Decision about material application can be improved by having better information about the current friction level of the road surface. Devices that measure the degree of friction on the road surface have the potential to eliminate the unnecessary use of salt on roads with adequate traction. In some cases friction sensors are mounted on the spreader vehicles and used in conjunction with on-board mounted pavement temperature measurement equipment to automatically control the application rate of snow and ice control chemicals. Several DOTs and suppliers are conducting research on affordable and convenient measurement methods.

Measurement of friction was used successfully in the SHRP and FHWA anti-icing projects. An agency may find it reasonable to establish this as a technique used during patrols. There are many devices for measuring friction. Skid trailers are commonly used for the measurement of the coefficient of friction, but for various reasons related to safety and equipment deterioration, they are not normally used on snow-covered pavements. Specialized vehicles incorporating a fifth wheel, which measures the increase in force when braked at a controlled slip rate, are available, but high cost has limited their use mainly to airports. A low-cost device was used in both the SHRP and FHWA test programs because it can be installed in most any vehicle and can produce reliable measurements. It gives a direct readout of friction coefficient when the vehicle is hard-braked from 65 km/h (40 mph). Its repeatability is acceptable for treatment analysis and decision support purposes, provided the device is calibrated and operated in accordance with the manufacturer's specifications. Because it requires hard braking, however, it is not suitable for use in heavy traffic.

A 2004 TRB paper on the Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility presented the results of NCHRP Project 6-14, which evaluated the feasibility of using friction indicators as tools for improving winter maintenance operations and mobility. As part of the project, information was collected and reviewed regarding the use of friction indicators for winter maintenance operations decision-making, operations performance evaluation, and motorist information. In addition, short-term and long-term implementation scenarios were developed in which friction measurements could be used to improve winter maintenance safety, operation, and mobility. The study also found that analyzing information collected from low-cost and reliable friction measuring devices and other data, such as pavement temperature, traffic, and weather conditions, could be useful for allocating snow-fighting resources in real-time. The information gathered suggested that a traction-control system is the most promising technology for practically and safely measuring friction in winter conditions, followed closely by deceleration and slip devices. Forecasting surface friction based on models that relate data such as temperature and traffic was also identified as a promising technique for improving winter maintenance operations, but further research is needed in this area.(*xc*)

Residual Chemical Measurement

The availability of chemical concentration indicators appears to enhance the timing of subsequent applications by providing indications of the dilution of the chemical. After a storm event has passed and the road has become bare and dry, there often is a residue of chemical on the road surface which can be activated with the next precipitation event. The concentration of salt contained in roadway slush is the determinant of the freeze point temperature of the slush. It is helpful for decision-makers to know the residual salt concentration on the road. An RWIS road sensor will provide this information, enabling a manager to time the reapplication of chemicals so that the operation is complete before the freezing-point of the brine on the pavement surface starts to climb and, especially, before it reaches 0^{o}C (32^{o}F). Where decision makers have confidence in these data, they can be used as a basis for establishing cycle times of the repeat applications for different conditions.

Portable salinity sensors are available, although their high cost makes widespread use unlikely. Existing salt concentration meters permit only point-to-point measurement and are, therefore, not suitable for road management that relies on longitudinally continuous concentration measurement. These existing methods of measurement require that field personnel stop the vehicle and manually take measurements on the pavement. Consequently, this method is not convenient and is also dangerous for field personnel. The New England Transportation Consortium has been working on development of a method and prototype for the continuous measure of deicer concentration.(*xci*) Another tool on the horizon is a “chemical presence” sensor that can measure the chloride concentration of road spray in a vehicle’s wheel well.

Nowcasting

Nowcasting refers to the use of real-time data for short-term forecasting. It relies on the rapid transmittal of data from RWIS installations, radar, patrols, and any other information source for making a judgment of the probable weather and pavement condition/temperature over the next hour or two. Nowcasting is one important tool for making the decision of when to call in personnel. Mobilization timing may vary among sites, therefore the frequency of weather information updating required for a nowcast will also vary with the site. Nowcasts can be provided by a weather service or performed by the maintenance manager. Specially trained maintenance managers in some highway agencies already perform this duty using the necessary information available from a variety of sources.

Traffic Information

Vehicles can affect the pavement surface in several ways: tires compact snow, abrade it, displace or disperse it; heat from tire friction, engine, and the exhaust system can add measurable heat to the pavement surface. Vehicle tires also bounce a proportion of applied chemicals off the pavement. These positive and negative impacts on the effectiveness of anti-icing treatments should be considered in the decision-making process. The traffic information most important for making operational decisions is the variation of traffic rate throughout a 24 hour period.

Patrols

There is no substitute for visual observation of weather conditions and conditions of the pavement surface. Observations remain an important tool for making operational decisions even when an agency has access to and experience with new technology such as RWIS. Use of patrols for this purpose can be highly effective. Though the State or local highway patrol can fulfill this role, trained maintenance personnel are better prepared to judge the severity of conditions and to make or recommend corrective action.

ITS Standards for RWIS

An Introduction to Standards for Road Weather Information Systems (RWIS) describes three categories of standards (here as guidelines, recommended procedures, protocols, and other practices) that formalize some of the processes involved in deploying and maintaining RWIS sensors: siting standards, calibration standards, and communication standards. While the standards are not mandated, agencies are encouraged to use the introduction as a starting point to learn about RWIS standards and to consider how they might use these standards to reinforce their own RWIS operations. The ITS standards program has produced a number of weather-related standards, including the Environmental Sensor Station standard for road weather information systems (RWIS), weather elements in the Advanced Traveler Information Systems standards, as well as a number of other standards.(*xcii*) There are many examples of the use of ITS to improve transportation system operation under adverse weather conditions, including closed-circuit television (CCTV), RWIS, 511 (the national traveler information number), road closure notification/diversion coordination, dynamic message sign (DMS) advisories, variable speed limit (VSL) technologies and enforcement, in-vehicle devices, sensor/detection systems and other field devices, signal control systems, land closure/ direction change systems, smart work zones, and highway advisory radio (HAR). Recommended practices for ITS deployment include the following: (*xciii*)

- Make sure that area jurisdictions have compatible equipment, can share data, and have similar operating standards and procedures.
- Use technology to make sure the right equipment and the right people are at the right place at the right time and for the right reasons.
- Deploy systems so that they can prove their benefit in specific, quantifiable ways.
- Evaluate their effectiveness – from both a cost and benefit perspective – to demonstrate value to the traveling public and to relevant stakeholders, including elected/appointed officials.
- Seek both short- and long-term wins from technology deployment.

Future projects, including the Vehicle Infrastructure Integration (VII) initiative, the Infostructure, and the Integrated Network of Transportation Information (INTI), hold great promise in providing better weather information via ITS applications in the not too distant future.(*xciv*)

Road Weather Management Decision Support

As identified by the FHWA Road Weather Management Program two problems stand out in RWIS: 1) There are consistent complaints that weather information, and the road-condition predictions dependent on it, remains insufficiently timely, accurate, and relevant, and 2) RWIS remains a profusion of disparate environmental information sources, incompatible in communications protocols, and information formatting.(*xcv*) In 1999, FHWA sponsored the Surface Transportation Weather Decision Support Requirements (STWDSR) project, which defined the decision maker, not the information sources, as central.

More than 100 types of operational information needed for winter road maintenance decisions (at the fourth or lower level of a taxonomy) were defined, which could in turn be divided broadly into four types: Resource status, weather, weather-related road condition, and other road information. The “environmental” information on weather is just part of what is needed. For road-maintenance purposes, weather is usually a predictor of the road conditions that are the immediate interest, and there is a large inferential gap between the two, is primarily due to the fine-scale climactic differences of road versus atmosphere and to the different dynamics and time constants of the atmosphere versus road heat-energy and mass transfers.(*xcvi*)

The basic decision problem is to choose an alternative with the best, but uncertain, impact on the goals. The uncertainty comes in part from the uncertain causal relationship between a control action that is chosen and its execution by resources in the transportation systems. The true transportation outcomes under winter weather threats are almost always the result of joint decisions among maintenance agencies, other road operating agencies (e.g., traffic management), and road users. All decision-support information acts causally on a decision at the central time, and all uncertainty comes from flawed observation of data in the past and flawed translation to the central time. As all decisions have risk, or uncertainty in the outcome measures of the alternatives, maintenance managers request reliability indicators or “worst case” values for their information.(*xcvii*)

The development of a prototype winter Maintenance Decision Support System (MDSS) is part of FHWA’s Office of Transportation Operations (HOTO) Surface Transportation Weather Decision Support Requirements (STWDSR) initiative. The objective of the MDSS effort is to produce a prototype tool for decision support to winter road maintenance managers. The MDSS is based on leading diagnostic and prognostic weather research capabilities and road condition algorithms, which are being developed at national research centers. Several candidate road weather technologies currently exist at national laboratories, but the new technologies needed to be integrated, refined, and tailored to address road maintenance weather issues. The project will also identify new and focused research that must be conducted to address specific winter maintenance decision support needs not addressed by current technologies. The project began in 2001, with work with state DOTs on the development of a prototype MDSS, which is moving into demonstration and evaluation of selected prototype components in an operational environment. The MDSS project goal is to develop a prototype capability that: (*xcviii*)

- Capitalizes on existing road and weather data sources.
- Augments data sources where they are weak or where improved accuracy could significantly improve the decision-making task.
- Fuses data to make an open, integrated and understandable presentation of current environmental and road conditions.

- Processes data to generate diagnostic and prognostic maps of road conditions along road corridors, with emphasis on the 1- to 48-hour horizon (historical information from the previous 48 hours will also be available).
- Provides a display capability on the state of the roadway.
- Provides a decision support tool, which provides recommendations on road maintenance courses of action.
- Provides all of the above on a single platform, with simple and intuitive operating requirements, and does so in a readily comprehensible display of results and recommended courses of action, together with anticipated consequences of action or inaction.

Precision Application to Manage and Reduce Chemical Applications

Acquisition of precision application equipment is a large cost center for winter maintenance operations, and often requires a business case or justification for the purchases. Thus, the objectives of applying new technology to winter maintenance operations are: (*xcix*)

- Reduction in accidents
- Return on investment
- Reduced chemical usage and improved environmental stewardship

Benefit-cost analysis performed by Iowa researchers demonstrated that integration of the newer emerging technologies in the concept vehicle met the business case, reducing accidents, increasing mobility, reducing adverse environmental impacts, and generating positive economic effects.(*c*) DOTs are also ordering and using multi-purpose equipment; for example, slide-in equipment, used for winter maintenance, gives plow trucks the capability to carry a variety of products to better match the environmental concerns within an area.(*ci*)

Mechanical removal of ice and snow can be facilitated by preventively treating roadways with road salts. Such pre- or early-storm applications will often minimize the overall amount of road salts required to achieve the desired surface friction level. Reacting to a snow and ice event and applying road salts after a bond has formed requires additional salt to be used; proactively treating the road surface just prior to the event, or just as it commences, can prevent a bond, simplify the mechanical removal and expedite the achievement of bare pavement.

Some transportation agencies choose to leave a small amount of snow on the road before salt is applied in order to keep the salt from bouncing or being blown off the road surface by passing traffic or wind. This can increase the amount of salt required to "de-ice" or melt the snow packed on the road, and is not as efficient in retaining salt on the road as other methods (e.g. slower spreading speeds, pre-wetting, "zero-velocity" spreading, etc.) General overviews of technology available and disadvantages and advantages of their use are summarized below from the Transportation Association of Canada and a TRB Report on Snow Removal and Ice Control Technology. (*cii*)(*ciii*)

Spreaders, Spread Patterns, and Spreader Controls

The total amount of salt used for winter maintenance is significantly influenced by the characteristics of the spreader equipment.

- Spreader controls should be capable of delivering several precise application rates.
- The application rate should be consistent whether the spreader is full or nearly empty, regardless of material variations, or temperature changes.
- When purchasing new equipment, transportation agencies should require test results from suppliers to confirm that the equipment will achieve precise application rates under all conditions.
- Spreaders must operate in a severe environment of low temperatures, high moisture, poor visibility, and corrosion, often with limited maintenance. Controllers must be easy to load, and simple to operate.
- Ideally, a spreader should be adaptable for other tasks, or the hopper should be easily removed so the trucks can be used for other operations during the summer.
- Hoppers must be constructed so that all sand and salt can be easily removed from the body.
- Spreaders should be fitted with screens to ensure that frozen clumps of material or other contaminating material that would jam the chain/conveyor mechanism are not loaded into the spreaders.
- Cab shields should be fitted to assist in loading the spreaders to ensure that all loaded salt enters the box, and material is not spilled over the truck.
- Spreaders should be manufactured from a material that will resist corrosion. Special chlorinated rubber primers and epoxy-based primers will increase coating life. Stainless and galvanized steel, and fiberglass bodies are available but can be relatively expensive. High strength, low alloy self-coating steel, used with good surface preparation and special primers has been proven to provide a cost effective body life of up to fifteen years. Manufacturers also supply spreader bodies constructed of fiberglass. These bodies are lighter and thus provide increased payload possibilities, but are also more expensive than steel.
- Electrical wiring for controls and lighting, and hydraulic components must be enclosed in vapor proof, or sealed systems.
- Neoprene spinners are frequently used to improve durability and spreading efficiency.

Spread Patterns

Salt and sand application methods can be modified to meet differing requirements.

- Salt use sometimes can be reduced by applying the salt in concentrated locations (e.g. windrowed on the crown), rather than being spread uniformly or broadcast across the entire road surface.
- In most cases solid or pre-wetted salt should be applied in a continuous narrow windrow along the centerline of the road. The concentrated mass of material

minimizes the tendency of the material to bounce or be blown off the road by passing traffic. Salt going into solution drains down the crossfall of the road, and can migrate under packed ice and snow; a uniform section of road is then bared off initially along the center of the road to provide two-wheel stability for traffic. Application in a windrow is achieved without using the spinner, by dropping the material from a chute. Windrowing on the centerline will not work if the crown of the road is not consistently on the centerline, or the road surface is badly deteriorated which could cause the salt brine to pond in some areas. Centerline application is also not appropriate if the entire road surface is slippery and immediate de-icing is required. In these situations, higher salt application rates may be needed across all traffic lanes.

- Application ahead of the drive wheels can provide improved traction under the drive wheels of the spreader vehicle. Application close to the driver's cab also enables the driver to monitor the application to ensure that material flow has not been impeded.
- Hopper Spreaders

Conventional hopper spreaders provide good control of material application and dependable service. However, they are the least versatile for other operations during the off-season. New hopper designs, including rear-discharge, slide-in units with a longitudinal agitator bar and belt conveyor, are gaining popularity, particularly for pre-wetted applications.

Tailgate Spreaders and Reverse Dumping of Dual Dump Spreaders
The primary limitation of tailgate spreaders is the inconvenience of raising the dump box and the possibility that the box will not be raised high enough to ensure that sufficient material is dumped in the hopper to provide consistent delivery. The rear discharge restricts the operator view of the operation and ability to ensure that the material is being discharged at the right location. The vertical clearance and the upward and rearward shift of the center of gravity when the box is raised can cause instability and is a safety concern in some areas.
Dual dump spreaders were developed to overcome problems identified for tailgate spreaders while still providing a multi-purpose spreader that could be used year round. They function as regular rear dumping bodies when not being used to apply winter maintenance materials. Disadvantages of this spreader are the high weight compared to a regular dump truck, and the need to raise the body while driving to move the material to the front of the truck. This reduces the truck's stability and care is required by the operator to ensure that sufficient material covers the cross conveyor at the front to maintain a precise application rate. The pivots have been a source of failure and replacement is expensive.

Multipurpose Spreaders
Multipurpose spreaders incorporate most benefits of the other spreaders. A recent design makes use of a U-shaped box to ensure that no material hangs up in the box and that all material can be easily removed from the box at the end of the shift. Material is either discharged in a windrow using a chute for concentrated action, or spun across the lane using spinners. The spreader provides precise application rates and all the advantages of

distribution in front of the rear wheels. Cross conveyors are easily removable during the summer so that there is no tare weight penalty. The units are lightweight and provide year round use, and the body can be easily switched to carrying construction materials (simply by installing a pan or tray across the floor conveyor). As these units can carry substantial loads, care must be exercised to ensure that adequate truck components, axles, springs, and wheels are specified to carry the load. This is particularly important on combination units that are also equipped with snow plows.

Rear-Discharge Spreaders

Based on the premise that no salt particle should be placed dry onto the road surface, and that fine salt is the gradation of choice for prompt dissolving and melting, certain spreader design characteristics cater better to liquid and fine salt use in prewetted applications. The salt must be of a fine gradation in order for it to retain the brine moisture content and fine salt does not travel as easily on certain chain-type conveyor systems. These spreaders allow a “high-ratio” salt application rates up to 255 liters per ton of salt, or at a ratio of 30:70 liquid-to-solid by weight. This requires a large capacity of liquid onboard and adequate pumping capability that may not be possible or practical on a conventional retro-fitted unit. They are either frame-mounted or slide-in, rear-discharge v-hoppers can stand on self-contained stilt legs in the maintenance yard, and remain tarped until needed. Pre-wetting liquid can be applied directly on the spinner, that is designed to spread the material across a given area of the road cross section. Areas that only have access to coarser salt may find that the liquid component must be reduced since saturation can be achieved with less liquid.

Electronic Spreader Controls

All spreaders require an accurate electronic controller to ensure that the appropriate application rate is achieved. Simple hydraulic circuits, used to maintain a steady application rate, are still in use in many transportation agencies. This equipment starts to exceed the desired application rate as soon as the truck speed drops below the design speed and an excessive salt application is then dumped on the road. Early models of the electronic controllers were not dependable and required extensive maintenance. The new models are improved but can still require patience.

Modern spreaders use electronic groundspeed spreader controls to provide consistent, accurate application rates. The truck speed is monitored from the truck’s speedometer drive, and the spreader output is adjusted to maintain a steady output at the set rate per kilometer. Both open loop and closed loop systems are available to monitor material flow and provide increased accuracy of the spread rate (closed loop systems provide confirmation of the actual application rate). Electronic controllers automatically increase the output rate if a second spinner is actuated (if so equipped) to treat truck climbing and turning lanes. With some electronic units, calibration settings can be applied electronically using infrared controls.

Manufacturers can now provide units that record, for printing, information about the amount of salt used, the time it was used, and the associated application rate, for analysis and control by the transportation agency. Information that is captured and logged can include: amount and type of material applied, gate position, run time, blast information, average speed, spread width/symmetry, etc. Units are also available that incorporate global positioning systems (GPS) for automated vehicle location (AVL) and to identify where the material was discharged (either generating a passive history or a live transmission). There is currently no industry standard format in place for this information reporting; it is difficult to compare and combine the information from the units supplied by the various manufacturers.

Rearward Casting Spreaders (*including Ground-Speed and Zero-Velocity Spreaders*)
With normal spreaders, a high percentage of the dry salt applied to the road bounces off the road due to the combination of the impact of the granules hitting the pavement, and the speed of the spreading vehicle. Most transportation agencies now theoretically constrain their spreading speed to avoid wasting salt due to the scatter effect at higher speeds. In practice however, speeds of 40 km/hr and more are not uncommon. If salt could be applied at higher speeds, combination units would be much more productive as the unit could apply salt at plowing speeds. This would allow for safer operating condition since trucks could move at the speed of traffic. Casting material rearward has shown potential for salt use reduction by increasing the percentage of applied salt that is retained on the road, and in the required location on the road. This is a concept by which the salt is discharged rearward at exactly the same speed as the spreading vehicle is traveling forward. The two velocity components cancel each other causing the salt to drop on the road as if the spreading vehicle was standing still.
To-date, the available equipment has experienced some operational problems such as material caking, uneven discharge and mechanical complications (fan/blower) under certain conditions. One manufacturer makes use of a shielded-spinner at the mid-chassis discharge location, discharging at a point just beyond the width of the rear wheels where the material is “flung” rearward. Another manufacturer used a high-speed blower to discharge the salt rearward. This results in a large cloud of salt that can be hard to control and may be affected by side winds. Also, the spreader units may not suitably handle pre-wetted material or finer sands. Though useful for salt applications, there is no good way to spread sand with these spreaders. Modifications are being developed and it is anticipated that further refinements will enable transportation agencies to reduce application rates and increase application speeds using this concept.
Ground-speed spreaders and prewetting are recommended to permit high-speed spreading of salt in a windrow patter on bare pavement. Equipment manufacturers and material suppliers have attempted to overcome these problems by using spreaders designed to place the material on the road at zero velocity or in a controlled location, and through the application of small quantities of deicing liquids to the dry material before it is applied. The specialized spreading equipment is referred to generically as ground-speed spreaders, and the application of liquid deicer is referred to as prewetting. Prewetting did not significantly improve material placement over dry salt at a spreader speed of 34km/h and is therefore not recommended as a means of reducing material loss during spreading at current operating speeds. At 60km/h, prewetting made a small but significant improvement over dry rock salt in material placement using a centerline chute and a ground-speed spreader, and it is therefore recommended as a means of reducing material loss during salt spreading at high speeds.(*civ*)
Zero Velocity Spreaders can optimize the use of deicing material through the controlled distribution of the material. The material is dispensed at the same velocity of the forward

motion of the equipment. This helps reduce bounce and whip off allowing more of the material to remain on the pavement, saving up to 40 percent in de-icing material and reducing salt runoff to the surrounding environment. The zero-velocity spreader applies material in such a way that the material lands at a velocity that is zero relative to the road surface. The spreaders, which mix and spread liquid and solid deicers, use technology that enables plow trucks to apply chemicals at speeds as fast as 35 miles per hour, which increases efficiency and safety in terms of the speed differential between plows and traffic. In 1994 and 1995, Iowa was the FHWA test site for the zero velocity spreader, at that time a new concept in roadway chemical spreaders. Mn/DOT tested eight zero-velocity spreaders that same season and discovered savings of 30 percent or more. Even in 1995 when the spreader was priced at around $10,900 compared to $2,000 to $2,500 for a common spreader, tests indicated that material savings compensated for the increased cost.(*cv*)

At PENNDOT, during the 1995-1996 winter season, the use of 4 trucks equipped with the system resulted in average material savings of about 50 percent and a cost savings of about $2 per mile per truck. In 1997-1998, PENNDOT purchased 95 additional ZVS units and another 150 units in 1998-1999, equipping all of Pennsylvania's Interstates and limited access highways with ZVS. The systems were expected to pay for themselves in about 1½ years. PENNDOT also equipped every new dump truck with a ground speed control salt spreader system known as the AS2 system, an on-board computer adjusts the discharge rate of salt and anti-skid material according to the speed of the truck. The truck's operator inputs how wide the material needs to be spread and the desired tons of salt and anti-skid material to be used per lane mile. At intersections or other areas that may require a heavier application of salt, the operator may use a "blast button" for a preset number of seconds.(*cvi*)

Pre-Wetting Solid Materials to Minimize Bounce

Applying liquid melting agents or pre-wetted salt can prevent or clear frost more quickly than solid salt. Pre-wetting is a commonly used practice to improve retention and keep salt on the road by reducing the effects of bouncing, blowing and sliding of the salt or sand particles. This technique uses salt brine, liquid calcium chloride or other liquid chemical to wet the salt or salt as it is spread on the road. Pre-wetting also enhances the melt action of the chemical present by speeding the dissolving of salt and the formation of brine.

Spraying stockpiles and truck loads has also been termed pre-wetting or "pre-treating", but this practice is not as practical since the granules are not uniformly coated, the liquid may drain out of the solid material and the performance on the road is not consistent throughout the route. Therefore, pre-wetting should be done by spraying the salt as it is discharged from the chute, or at the spinner. A straight liquid will avoid the endothermic cooling effect that solid salt can have on pavements. Practical considerations relate to the gradation of the salt being wetted, the maximum liquid to solid ratio that can be mixed, the amount of mixing action, caking/clumping concerns, etc.

Pre-wetting is commonly considered to have the following benefits:

- The deicing effect of the salt spread onto the highway surface is achieved more quickly, with time lag significantly reduced or even eliminated.

- A significant proportion of the salt spread by dry spreading techniques ends up o the channels of the highway or on the highway verge because of particle bound and the action of traffic. It is also claimed that this may well increase the longevity of the salt action on the highway surface, with a direct result of possible reductions in salting frequency.
- It is claimed that significant reductions (on average one-quarter, but up to one-third) in the overall amount of salt use can be realized.
- Because less salt can be used, and more of it stays o the road surface, pre-wetting techniques can lead to significant environmental benefits compared with traditional dry salting techniques.
- Damage to concrete structures is likely to decrease with high-purity prewetted salt although a calcium chloride wetting agent may cause more damage than a sodium chloride one.

While pre-wetting may provide significant potential for reductions in salt use, it can increase the complexity of the required equipment and controller. Pre-wetting requires additional equipment. Storage tanks for the liquid(s), or brine making equipment are required, along with pumps to load the spreaders. The on-board liquid capacity and loading time are factors to consider. Additional maintenance is required such as ensuring that the liquid filters, lines and nozzles are purged and the equipment cleaned at the end of the storm to prevent clogged lines and seized equipment. Prewetting is not universally acclaimed. A University of Iowa study found that prewetting at the stockpile had little effect on the ability of the abrasives to remain on the pavement surface when delivered and that prewetting while loading or final prewetting at the truck spinner was found to help keep salt and other chemicals on the road surface when first delivered but may do little to help material stay on the road.(*cvii*) Brine is a method that has mixed reviews. While brine has uses les salt, melts faster, and dries road surfaces faster than prewetted salt, maintenance areas must have equipment for spreading prewetted salt, as brine is not suitable for use during heavy snowfalls. If the road surface is very wet or precipitation is ongoing, there is a risk that the brine will be excessively diluted and the liquid will refreeze.(*cviii*)

The Transportation Association of Canada outlines the following recommended practices for pre-wetting: (*cix*)

- Adjustment of the spray nozzles is critical. Tests by one state department of transportation showed that they never achieved more than 60 percent coverage of the salt. The remaining 40 percent of the pre-wetting liquid was effectively being applied directly on the road. Also, as the wetting agents are corrosive, it is important that corrosion resistant nozzles and non-contact pumps are used to ensure dependable performance.
- Utilize the latest research on optimum liquid application rates; extensive testing is currently being performed.
- The application pumps on the spreaders should be regulated by ground speed controllers to ensure the correct liquid application rate is maintained under all conditions.

A recent study on the possibility of decreasing the use of salt by changing the spreading method found that saturated brine (20 percent) is spread more evenly across the road than prewet salt, and more salt from the brine is still present on the road 2 hours after spreading as compared with prewet salt. Several statistical analyses were carried out, giving a useful picture of the amount of residual salt on the roadway and indicating that more salt from brine than from prewet salt is active on the roadway and that degradation of residual salt is crucially affected by high traffic intensity.(*cx*)

Fixed Automated Spray Technology (**FAST**)

Areas that experience a high number of frosting or black ice events each winter season have traditionally required a significant amount of labor and road salt to manage properly. Maintaining material on the road to deal with frosting events can be difficult and expensive on roads with higher traffic volumes. Applying the material just prior to an anticipated event is ideal. Fixed, automated liquid anti-icing spray systems, called FAST systems, have been developed to help organizations better manage these demands and place the right material, in the right amount, in the right place and at the right time. Fully automated FAST systems have been developed that use sensors embedded in the roadway and mounted on bridge towers, elevated ramps, or intersection approaches. Site mounted computer hardware and software and nozzles embedded in the roadway or the parapet wall automatically apply liquid anti-icing chemical to the road surface just prior to a forecasted icing event.

The information in the remainder of this section has been previously profiled by AASHTO, FHWA, and TRB in relation to "Smart Bridges."(*cxi*)

Brooklyn Bridge Anti-Icing/Deicing System Paves the Way for Others

The New York City Department of Transportation developed a fixed anti-icing system that is comprised of a control system, a chemical storage tank containing liquid potassium acetate, a pump, a network of PVC pipes installed in roadside barriers, check valves with an in-line filtration system, 50 barrier-mounted spray nozzles, and a Dynamic Message Sign (DMS). The DMS displays warnings to alert motorists during spray operations. A Closed Circuit Television (CCTV) camera allows operators to visually monitor the anti-icing system. Each self-cleaning nozzle delivers up to three gallons (11.4 liters) of chemical per minute at a 15-degree spray angle. This angle minimizes misting that could reduce visibility. Two nozzle configurations were implemented to investigate different spray characteristics. On both sides of one bridge section, nozzles were installed 20 feet (6.1 meters) apart for simultaneous spraying. On another section, sequential spray nozzles were mounted on only one side of the bridge. Due to concerns about bridge deck integrity, nozzles were barrier-mounted rather than embedded in the road surface. System operators consult television and radio weather forecasts to make road treatment decisions. When anti-icing is deemed necessary, "ANTIICING SPRAY IN PROGRESS" is posted on the DMS and the system is manually activated to spray potassium acetate on the pavement for two to three seconds, delivering a half-gallon per 1,000 square feet (1.9 liters per 92.9 square meters). Operators then review forecasts and view CCTV video images to monitor weather and pavement conditions. If there is a 60 percent or greater chance of precipitation and pavement temperatures are predicted to be

lower than the air temperature, maintenance crews are mobilized to supplement anti-icing operations with plowing to remove snow and ice.
An analysis of maintenance operations found that bridge sections treated with the anti-icing system had a higher level of service than segments treated by snowplows and truck-mounted chemical sprayers. Road segments treated by the anti-icing system have less snow accumulation than sections treated conventionally, improving roadway mobility and safety in inclement weather. The system was most effective when chemical applications were initiated at the beginning of weather events. If potassium acetate was sprayed more than an hour before a storm, vehicle tires dispersed the chemical necessitating subsequent applications. The system also improves productivity by extending the life of bridges and minimizing treatment costs associated with mobilizing maintenance crews, preparing equipment, and traveling to treatment sites on congested roads, in addition to minimizing salt runoff to the environment. The DOT would like to expand the anti-icing system by integrating a Road Weather Information System (RWIS) with the control system, the CCTV camera, and the DMS to improve treatment decision-making. A wireless or fiber optic cable communication network is envisioned for connectivity of these elements. Deployment of the system on the entire Brooklyn Bridge and on other local bridges is also anticipated.(*cxii*)

Guidelines for Prioritizing Bridge Deck Anti-Icing System Installations
A 2003 report for the Mid-America Transportation Center and the Nebraska Department of Roads (NDOR) developed guidelines for prioritizing bridge deck anti-icing system installations. This research was undertaken with the objective of developing a decision-support tool that can aid NDOR with the prioritization of bridges for installation of automatic anti-icing systems. Based on a literature review on automatic bridge anti-icing systems was conducted, factors considered important in the installation of automatic anti-icing systems included accident history, bridge alignment, weather, traffic, and bridge distance from maintenance yard. The factors were included in a database and decision-support tool that assisted NDOR in narrowing the list of candidate bridges for NDOR. Some of the sources and GIS layers included were: NDOR bridge inventory, NDOR accident database, archived weather data from the High Plains Regional Climate Center and the National Weather Service, Nebraska streets database, Nebraska rivers and streams database, and NDOR maintenance yard data.(cxiii)

Calibration
Regardless of the spreader or Fixed Automated Spray Technology chosen, the service provider must have faith that the application rate settings are indeed accurate. Spreaders should be calibrated to avoid the over-application of de-icing agents or abrasives and use no more than is necessary for snow and ice control.

- A calibration policy should be established to assure the material settings are correct. Preferably, if application is by weight, then calibration should also be by weight. Calibration checks or recalibration should take place several times during the season:
    - Calibration should occur after repairs.
    - Calibration should occur when distribution calculations show a discrepancy between theoretical and actual.

    - Calibration spot-checks on units in the fleet should be scheduled throughout the season.
- Operators should be able to easily track fuel and material usage.
- In order to apply the proper amounts of anti-icing, de-icing and/or traction enhancing materials, spreading equipment should be calibrated for both solid (typically salt) and liquid (typically salt brine, calcium chloride, magnesium chloride or IceBan/MAGic) applications.
- To ensure proper placement of materials, equipment affecting the spread pattern should be adjusted to match the required use. Critical system components include the automatic ground speed controller, the flight chain or belt, the gate opening, the chute, the liquid nozzles (if applicable), the spinner and the deflectors.
- Maintenance districts should calibrate their equipment regularly and train their operators so they understand the reasons behind pre-treating application practices and quantity of materials to be applied under specified conditions. Training presentations should be available at each District. Presentations should be showing the exact details on how calibration is performed and should be reviewed each year before beginning calibration.
- Because of the adverse conditions under which snow and ice equipment operates, periodic checks should be made to confirm proper settings. Calibration is necessary to find out how much salt and/or abrasives are discharged at each auger setting.
- All truck and spreader combinations, both Department owned and rented, should be calibrated every year. Calibration should be completed prior to the snow season. Calibration can be done using sand or other abrasive materials if the truck is used on routes where salt is not spread. Department personnel should calibrate non-municipal rental trucks equipped with spreaders.
- Those servicing state roads under lump sum agreements typically are responsible to calibrate their own equipment. Department personnel may assist with their calibration programs if requested.
- As part of calibration all Department trucks should have their augers and spinners mechanically restricted. Augers are to be restricted to spread no more than the maximum amount of material approved for the route or routes to which that the truck is assigned.
- Spinner speeds should be restricted so that no spinner will spread more than a ten-foot width of material when the truck is stationary.
- Records should be kept for each piece of equipment. Calibration information for each spreader is stored electronically on a laptop computer. If any controller is replaced, calibration information can be downloaded to the new controller as a starting point to recalibrate.

Operational Support Equipment

Accurate records should be maintained of the locations of de-icing agents and abrasives application and the quantities of de-icing agents and abrasives used. Various types of equipment support the winter maintenance program either by helping manage the operations by generating useful data or by supporting the service delivery itself. Equipment is available to assist with meeting the following necessary functions for environmental stewardship and effective minimization of materials application:

Material Usage Monitoring

Loader Mounted Electronic Weighing Equipment

Loading extra material onto a spreader can lead to overloading or the temptation to over apply the salt. In the past, operators tended to load a little extra salt as there was no exact method of determining the amount of material loaded, and they did not want to run out without completing the route. Overloaded trucks also contribute to contamination in the area of the salt storage facilities. Salt heaped above the side boards is thrown off the trucks as they negotiate curves to exit the yards.

- With electronic scale control systems operators can more precisely load the right amount of salt. This device is a relatively inexpensive, durable, and accurate weighing device consisting of a transducer load cell mounted to the loader bucket arm. These devices can measure a predetermined load size for the scheduled route (length of route X application rate + a limited contingency amount for bridge decks, intersections, etc.). Models are available that will record with the loader in motion so that the loader operation is not impeded.
- The units will record the amount loaded for future printing and analysis. Though the equipment can be overridden, it provides the operators with a mechanism to accurately measure and control the amount of material loaded on the spreaders.

Truck Scales

Weighing the trucks as they enter and leave the maintenance yard is one way of determining the material loaded and the resulting spread rate for the serviced route. This function can be automated with a weigh-in-motion pad that tracks the equipment movement and can serve to reconcile the data from the spreader controller and other documentation.

Liquid Meters

Pump meters will likely be used to measure delivered brine, but not likely be on each pre-wet unit.

- A meter should be in place at the brine supply facility, whether the source is hauled brine or manufactured brine, in order to track loading times and quantities.
- A cross reference should be incorporated in the electronic log to identify the truck loaded for future reference.

Automated Vehicle Location (AVL)

- Tracking equipment movements along with the services provided is possible via proven GPS receivers/ transmitters and software.

- This electronic record can be actively followed real time or can be passively recorded for later analysis.
- AVL can support a route optimization exercise, to rationalize the number of trucks required and thus the expected salt to be used on the roads serviced.
- This equipment can provide operational support to greatly enhance the monitoring of salt usage, to demonstrate prudent usage and to correlate with the achievement of the required level of service.

Material Loading and Handling
Sand and chemicals should be stored and handled in a manner to minimize any contamination of surface or ground water. Care should be taken to prevent runoff from chemical tanks or chemical treated stockpiles. Covered storage for dry chemicals is preferred.

Avoiding Contaminants to Materials

- As noted by Oregon DOT, chemicals and sanding materials should be free of contaminants known to cause water quality problems. Some of these include: Arsenic Barium Cadmium Chromium Fluoride Lead Mercury Nitrate Selenium Other heavy metals Hydrocarbons.

Bulk Salt Handling by Loaders

- Extensive environmental contamination has been identified in the area of salt storage yards. Much of this contamination results from poor salt handling practices.
- Conveyors are available which are designed to allow salt trailers to dump directly into the conveyor for movement into the storage facility.
- Loaders used to fill spreader vehicles are often fitted with buckets that are too large for the spreader hopper bodies, resulting in spillage. Though they have a slower production rate, smaller buckets are available for most loaders. Side dumping bucket attachments can also be used to provide quick precise loading.

Bulk Material Conveyors

- Whatever equipment is used for moving salt, it should provide a way of tracking the flow so the quantities can be reconciled.
    - Pre-loaded drop-hopper loaders meter salt into spreader trucks.
    - Overhead silos can be pre-filled with salt to similarly meter salt into spreader trucks.
    - Pneumatic handling equipment can handle fine material that is used for either direct application onto the road or for blending with sand.

Sand/Salt Blend Mixers

- Ideally, blended winter sand stockpile are put up in favorable, dry conditions. Relatively dry sand stored indoors should not require more than 1-2 percent salt by weight; more moisture in the sand may require more blended salt (up to 5 percent), but the purpose still is to keep the sand free-flowing, and not to support melt action.

- Traditionally, blending took place on the apron to the storage shed, with several buckets of sand spread level, followed by one bucket of salt trickled on the surface; the resulting blend was loaded in the dome, and the process was repeated. Though highly inefficient, it was also highly inaccurate, and produced sporadic result on the pavement surface. Equipment to support high-production stacking and uniform, light blends now involves a form of dual-auger pugmill or a twin conveyor feed. In either case, two supply lines are metered to an accurate ratio and the final conveyor stacks the completed mixture.

Brine Production Equipment

- The concentration should be checked with a hygrometer to measure the specific gravity of the solution. The percent of saturation is determined by reference to specific gravity charts for the specific solution temperature.
- Water supply flow rates are a critical factor. Production sites may require cisterns to ensure adequate water supply where well production rates are poor.
- Manufactured salt brine can be pumped directly into tanks mounted on the spreaders or transferred to holding tanks at the maintenance yards.
- Stored brine will normally stay in solution as long as there is not evaporation or a drop in temperature below eutectic.
- Corrosion inhibition requirements can complicate the brine manufacturing process.
- Additives such as rust inhibitors may complicate long-term storage, in which case agitation or recirculation could be considered.

Brine Delivery Equipment

- Sampling containers and a refractometer or hygrometer should be available for sampling and testing the concentration.

WisDOT's Winter Maintenance Concept Vehicle (*Wiscplow*)
The Wisconsin Department of Transportation (DOT), in cooperation with eight Wisconsin counties, embarked on a 4- to 5-year effort to implement advanced technologies in winter maintenance vehicles. The effort equipped winter maintenance vehicles are equipped with differential Global Positioning System (DGPS) receivers and numerous additional sensors that collect environmental data (e.g., pavement and air temperature), equipment status data (e.g., plow up/plow down), and material usage data (e.g., salt application rate). These data are telemetered to a dispatch center and recorded on magnetic media for later downloading. Data are transmitted and recorded as often as every 2 seconds. A geographic information system (GIS) application, dubbed "Wiscplow," was developed and initially deployed for testing within participating counties, combining vehicle data with manually entered data (e.g., storm durations, vehicle configurations, and labor and equipment cost rates) and with spatial data representing roadway centerlines attributed with functional class, number of lanes, patrol

sections, and route systems. Outputs include reports on computed performance measures (e.g., cycle time and hourly average salt application rate by patrol section and storm) and decision management tools (charts, graphs, and maps) showing relationships among performance measures (e.g., salt application rate versus pavement temperature by patrol section and storm).(*cxiv*)

Winter operations performance measures and decision management tools were identified, defined, developed, and refined in an iterative process, with state and county transportation decision makers, that included a series of meetings, communications, and two workshops.(*cxv*) Concerning material usage, Wiscplow can generate up to 19 performance measures and chart relationships among them. Sample performance measures include average pounds of salt per lane mile for each operator and event, hourly average for each patrol section of gallons per lane mile of anti-ice liquid, tons of salt used for each event and patrol section, and cubic yards of sand used for all events for each patrol section. Sample charts include average pavement temperature, salt, and sand application rates by patrol section for a winter storm event and seasonal cumulative salt use on each patrol section. Concerning equipment usage, Wiscplow can generate performance measures such as cost for each attachment unit for each event and patrol section, cycle time for each patrol section and storm, and total operating distance, season-to-date, for each attachment unit. Charts of relationships among these measures include production rates for equipment units by roadway class and cumulative operating hours for units of an attachment class. Concerning labor, Wiscplow can generate labor hours per lane mile for each patrol section and storm and percentage of labor costs attributed to clean-up for each storm. The map display can be queried and attributes displayed for roadways, patrol sections, and each data point in a vehicle track, including operator name, time, air temperature, pavement temperature, vehicle speed, front plow status, right-wing status, left-wing status, and scraper status. The user can scroll down to see material application rates, on which patrol section and route the vehicle is traveling, and the route measure of the vehicle's location. Ultimately, Wiscplow is intended to help transportation agencies at multiple levels (i.e., central office, districts, and counties) to measure performance of winter operations. (*cxvi*)

Monitoring, Recordkeeping, and Decision Support in Maintenance Management Systems

Evaluating Treatment Effectiveness

In addition to evaluations of chemical residue, friction, and changing temperatures during a storm, it is beneficial for the personnel of each maintenance area to conduct a post-storm evaluation of the treatment effectiveness. This can help identify areas needing improvement and changes that can be made in the treatment strategy. A post-season review of treatment effectiveness is likewise helpful. It can help identify where changes are needed in equipment, material, and route configurations, and can begin a process of engineering an anti-icing program to fit the exact needs of a site or agency. It can also help identify where changes in personnel procedures and training are needed to improve the effectiveness of the winter maintenance program.

Advanced ITS technologies are expected to automate winter operations performance measures and provide them in real-time to snow-fighting supervisors. The idea is to measure outcomes like roadway friction rather than just outputs like the time and amount of salt applied. Field studies of roadway friction measurement have been done at the NASA Wallops flight facility, and in Iowa, Minnesota and Michigan. There has also been an ongoing, coordinated study in Norway.(*cxvii*)

The data logging and reporting capabilities of loader scales, electronic controllers and GPS/AVL systems can assist transportation agencies in more accurately tracking their salt use. Progress in implementation of best salt management practices can be measured in improvements to the fleet. Monitoring and record keeping should include:

- Type and amount of winter materials being placed.
- Percentage of fleet equipped with electronic spreader controllers.
- Percentage of fleet equipped with pre-wetting.
- Percentage of fleet equipped with direct liquid application.
- Percentage of fleet calibrated annually.
- Percentage of staff trained in equipment use.

Decision management tools allow managers to visualize relationships among performance measures and make well-informed decisions on their business practices.

Environmental Performance Measures for Winter Operations

In 1997, Pennsylvania DOT began developing an environmental management system, to provide a comprehensive approach to integrating environmental considerations throughout the agency's complex operations. Over the last two winters, Engineering District 10 maintenance staff have developed and implemented procedures and tools to help them curtail the amount of anti-skid, anti-icing and de-icing material used while still exceeding customer expectations for safe and efficient winter travel. Preliminary survey results indicate that District 10 staff saved more than 3,000 tons of material agents using their improved procedures. By reducing their use of materials District 10 staff not only saved more than $100,000 but also significantly reduced the impact on vegetation and groundwater.(*cxviii*)

PENNDOT Strategic Environmental Management Program Maintenance Performance Measures pertaining to winter operations and snow removal were:

- Salt Usage per Snow Lane Mile (lbs) 250 lbs.
- Percent of Material (salt, skid) Deliveries with Penalty <10 percent

Non-Environmental Performance Measures for Winter Operations

The Wisconsin Department of Transportation sponsored a synthesis report which investigated major transportation and municipal Web sites in the U.S. and Canada for working methodologies for measuring the efficiency and effectiveness of winter operations, and found the following initiatives of interest.

The Municipal Performance Measurement Program (MPMP) is a new initiative designed to provide Ontario taxpayers with useful information on service delivery, and municipalities with a tool to improve those services over time. The program requires municipalities to measure their performance in nine core municipal service areas, including Roads. The Ministry suggests that municipalities use the following formulae to measure their performance in winter road services:

- Operating Costs for Winter Control—operating costs for winter control maintenance of roadways, divided by total lane kilometers maintained in winter, equals total cost per lane kilometer. This is a measure of "efficiency," to determine operating costs for winter control maintenance of roadways per lane kilometer. The objective is efficient winter control operation.
- Condition of Roads—number of paved lane kilometers rated as good to very good, divided by total number of paved lane kilometers tested, multiplied by 100. This is a measure of "effectiveness," to determine the percentage of paved lane kilometers where condition is rated as good to very good. The objective is to provide a paved lane system that has a pavement condition that meets municipal standards.
- Winter Event Responses—the number of winter event responses that meet or exceed municipal road maintenance standards, divided by total number of winter events, multiplied by 100. This is a measure of "effectiveness," to determine the percentage of winter event responses that meet or exceed municipal road maintenance standards. The objective is to provide appropriate winter response.

In its report to the Ministry, one of the municipalities—Middlesex—cited the following factors that can influence the results of the performance measurements: severity of the winter (amount of snowfall, incidents of icy conditions); levels of approved service; length of road system (in particular length of major arterial roads within the road system); and proximity to an urban center.

Winter Road Maintenance Ministry of Transportation Ontario (MTO) Tools for Monitoring Maintenance Activities and Performance is focusing on three categories of technology/practices for monitoring maintenance activities and performance. Information can be used to establish data on effects of material applications and rates of application. Under a partnership with Transport Canada, the device is also being tested on airport runways.

- On-board data recording systems incorporating global positioning systems (GPS) have the capability to identify where equipment is working at any time and the location where material is spread.
- Information from these systems can be used to ensure adherence to operational policies such as application rates and spreading speeds. For real-time scenarios and historical data collection, the information provided (equipment activity) is directly related to RWIS information (road conditions).
- Road surface condition monitoring equipment measures friction of driving surface during winter conditions.

The Aurora Project - Decision Support System for Winter Maintenance: Feasibility Demonstration has defined three measures of effectiveness for testing purposes:

- Elapsed time between material application and bare pavement (defined as 10 percent snow cover);

- Rate of clearing (rate of change of snow cover from time of material application until snow cover is 10 percent);
- Binary measure where effective is defined as: snow cover is reduced between t0 and tx, , where t0 is time of material application and x is 30 minutes, one hour, or two hours.

Comparisons should account for differences between test cases due to: air or surface temperature, drifting, initial snow cover, traffic, sunlight and prior applications or retention of salt on the surface between applications. Variables have been introduced to account for each of these. Two types of analysis have been used thus far: sorting of data into similar conditions, and multi-variate linear regression. Sorting analysis is a more straightforward approach but requires a large database because sorting into similar conditions for several variables results in small samples for each relevant action.

The UK Performance Audit Method for Winter Maintenance proposes verification statistics that can also be used to measure the performance of highway agencies and private consultants or whoever decides when roads should be salted, in response to a need for a simple performance audit method that measures the consequences and value of correct and incorrect decisions to salt roads. A type 1 error is defined as when roads should have been salted but were not. A type 2 error is when roads were salted when they need not have been. Up to now these checks have been applied to the forecast providers only.(*cxix*)

The Federal Highway Administration is forging ahead in developing performance measures for the new National Transportation System. Among the parameters of interest to snow fighters for which measures are being developed are:

- Speed (miles per hour, transit time, ton-miles per hour, dollar-miles per hour, and passenger-miles per hour);
- Reliability (standard deviation of freight speed, percentage of "on-time" deliveries); "service quality;"
- Response times for various emergencies;
- Various measures of access such as convenience, comfort and personal security;
- Crash fatalities and injuries and property loss;
- Tons of airborne particulate matter;
- Wasted motor fuels and various measures of financial cost.

Performance-Based Assessment of Winter Maintenance Using Level of Service (LOS) can be evaluated using a wintertime pavement condition index (PCI), a set of eight road surface descriptions that can be used to help identify appropriate material application rates to be used during different snow and ice control strategy/tactic combinations for various storm types, pavement conditions, cycle times or traffic flow levels. The performance-based assessment technique allows agencies to determine not only how well they are doing relative to the LOS goals: it provides a mechanism for determining the need for additional resources or improved technology.(*cxx*)

Utah made efforts to develop a measure of winter maintenance efficiency that accounts for labor, equipment, and material costs, as well as storm severity and duration, for an established number of land kilometers of given service levels. The expenditures are normalized by the lane kilometers in the maintenance facility's service area and a storm severity index.(*cxxi*)

In 1996, the Washington State Department of Transportation implemented a system of performance measures and service levels for highway maintenance activities known as the Maintenance Accountability Process (MAP). Initially, the MAP did not include service levels for snow- and ice-control activities based on field measurement, as it does for the majority of other maintenance activities. To gain similar benefits for snow- and ice-control activities, a pilot project that included performance measures, services levels, and field measurement protocols was developed and implemented. Two performance measures were used: the amount of roadway traction provided at the time of a field measurement, and the time taken to regain bare pavement after the end of a snowfall event.(*cxxii*)

Bringing It All Together: Michigan Vehicle Retrofits and Management System Partnership

Four road maintenance agencies and a regional transit authority worked together to implement a management system for maintenance vehicles in southeastern Michigan. The Southeast Michigan Snow and Ice Management (SEMSIM) partnership formed in 1998 to maintain over 15,000 road miles in the region. Partners include the City of Detroit Department of Public Works, the Road Commission for Oakland County, the Road Commission of Macomb County, the Wayne County Department of Public Services, and the Suburban Mobility Authority for Regional Transportation. The SEMSIM maintenance vehicle management system consists of snowplow systems, a communication system, and central systems. Snowplow systems include sensors on snowplows to record air temperature and pavement temperature., automated controls, and in-vehicle devices. Vehicle status sensors monitor the position of each snowplow (i.e., location, direction and speed), plow position (i.e., up/down), and material application (i.e., salt on/off, application rate). Each maintenance vehicle has automated application controls. Computerized salt spreaders automatically adjust the application rate based upon the speed of the snowplow. In-vehicle devices integrate display, text messaging, and data communication capabilities. These devices include interfaces to snowplow systems and Global Positioning System receivers, which are used for automated vehicle location. The regional transit authority's 900 MHz radio communication system transmits environmental and status data from in-vehicle devices to the transit management center. A Local Area Network, an Integrated Services Digital Network and multiple dial-up telephone lines are used to transmit data from the management center to central computers accessed by both maintenance managers and transit dispatchers.

Central computers display a map-based interface that maintenance managers view to identify weather threats, track snowplow locations, monitor treatment activities, and plan route diversions if necessary. Each maintenance vehicle appears on the map with a color-coded trace indicating where plows have been and what treatment has been applied (e.g., spreading salt, plow down). Text messages from managers, such as route assignments, may be displayed to drivers on the in-vehicle devices. With these devices, drivers can send messages to managers, as well as view temperature measurements and salt gauge. The maintenance vehicle management system can be used to plan treatment strategies, monitor real-time operations, and conduct post-event analysis. Post-event analysis provides maintenance managers with statistics (e.g., driver hours, truck miles, material applied) that can help reduce the costs of future winter maintenance operations. Environmental data from the plows also serves as decision support for transit dispatchers, who utilize this information to make scheduling and routing decisions during winter storms.

The system has helped SEMSIM improve agency productivity and has enabled managers to identify the most efficient treatment routes, reduce equipment costs, and share resources. Automated salt application controls minimize material costs. The system also improves roadway safety and mobility by allowing the partners to assess changing weather conditions and quickly respond to effectively control snow and ice. Although each agency had different types of snowplows, with dissimilar equipment, and diverse operational procedures, this project has facilitated interagency communication that benefits both the public and partners. The SEMSIM partners can collectively procure equipment and services at lower costs than individual agencies, and the partners developed specifications, issued a request for proposals, and contracted with a private vendor to furnish and install system components. Additionally, the partners have agreed to allow snowplows to cross jurisdictional lines to assist one another with road treatment activities when necessary. The transit authority allowed the partners to use excess capacity in their radio communication system. After initial testing proved the system's benefits the system was expanded to equip 290 additional vehicles after evaluation proved the system's benefits. The system hardware and software have been improved and a web-based communication system established. The University of Michigan enhanced central software by designing an application that will automate snowplow routing. As conditions change, the central software will calculate the most efficient routes and automatically notify drivers via in-vehicle devices.(*cxxiii*)

8.5. WINTER OPERATIONS FACILITIES MANAGEMENT

Materials Storage

Sand and chemicals should be stored in a manner to minimize any contamination of surface or ground water. In general:

- As previously discussed, all known runoff receptors should be inventoried and protected.
- Care should be taken to prevent runoff from chemical tanks or chemical treated stockpiles. Stockpiles of winter materials should be maintained according to best management practices.
- Covered storage for dry chemicals is preferred.
- All usage of sand and chemicals should be continuously and accurately recorded.
- Vehicle washwater should be managed as well.

Environmental stewardship practices for operation of maintenance facilities and maintenance of stockpiles are reviewed in Chapter 6 on Facilities.

Management of Snow Disposal Sites

Site Security and Environmental Controls

- The sites should be secured to avoid illegal dumping, prevent unauthorized access, by both humans and animals, for safety reasons and to permit safe efficient operation of the site. Security and environmental considerations include:
    - Delineation of the site boundary using perimeter fencing with appropriate signage and a gate with controlled access.
    - Provision of adequate lighting for operations, with the lights focused away from adjacent land uses.
    - Provision of low permeability berms (with or without trees) around the site to prevent uncontrolled offsite release of meltwater. These berms and additional landscaping can also mitigate noise, litter, and visual impacts.

Site Management

- Ensure that a single individual is assigned responsibility for the operation of the site and is accountable for its operation and environmental performance.
- Litter control:
    - With any snow removal and disposal operation a significant amount of small, lightweight debris will be collected and dumped along with the snow. This litter is blown around by the wind and can be a problem both on and offsite.
    - Staff should collect litter regularly to prevent it from blowing onto adjacent properties.
    - The installation of a net or fence around the perimeter of a snow disposal facility can help contain the litter within the site.
    - All debris in the snow storage area should be cleared from the site prior to snow storage.
    - Collect and dispose of onsite litter, debris and sediment from the meltwater settling area in accordance with local waste management legislation.
    - All debris in the snow storage area should be cleared from the site and properly disposed of no later than May 15 of each year.
- If a municipality provides locations for private contractors to deposit snow, they should require disposal according to these recommendations.
- Control emissions (drainage, noise, dust, litter, fumes) to prevent offsite environmental impacts.

Pile and Meltwater Management

- Efficient flow of meltwater to the collection area should be maintained.

- Placing snow in high, compact masses with steep sides all around minimizes the exposure of accumulating sediment on the snowfill surface to seepage and flow.
- Placing snow in a single snow mass rather than several isolated masses reduces exposure of sediment to up-gradient meltwater sources. Sites can also be operated to take advantage of aspect, with snow placed as compact masses at northernmost down-gradient locations so that a snowfill will preferentially recede from uphill to downhill. This practice will reduce exposure of down-gradient sediment to meltwater flows as the sediment settles to the pad surface in the final stages of melt (and becomes most vulnerable to erosion).
- Rutting caused by heavy trucks should be kept to a minimum or repaired quickly.
- Fast flowing, high volume channels of meltwater should not be allowed to develop near the piles, to avoid excessive erosion and rutting of the driving and snow pile surface. Sheet flow of meltwater under and near the piles is preferred.
- Avoid blowing, pushing or dumping snow into the watercourse.
- Place hauled snow over the full width of each swale. Sequence placement of snow starting at the downslope side and working upslope.
- Maintain snow in a compact mass with steep sides.
- Maintain setback from all containment berms and from the discharge end of V-swales.
- Maintain pad vegetative cover and re-grade only to ensure V-swale functionality.
- Restrict access and prohibit off-season traffic and on-snow storage uses.

Monitoring
All parties involved should recognize that snow disposal sites will have an impact on the environment. Most activities should be focused on minimizing or mitigating the impacts. Monitoring aids in the determination of the extent of the impacts, the effectiveness of the mitigation measures taken, and potential adjustments that can be made.

- Baseline condition (benchmarking) of site and surrounding area for future monitoring comparisons should be completed prior to the site being commissioned. Contaminant levels recorded once the site is operational will have to be compared to levels prior to the site opening to give a true indication of any environmental impacts.
- Contamination levels may be monitored at various points around the site and surrounding area. Various factors can effect the number and location of monitoring points including - urban vs. rural location, intensity of site use, size of site, and local requirements.
- Where warranted some or all of the following locations may be monitored:
    - Beneath the site (ground water and soil).
    - Above and around the site (where air quality is an issue).
    - In the snow being dumped.
    - In the melting snow piles.

- In the collected meltwater.
- At the discharge site and in the discharged melt water.
- Upstream (for comparison) and downstream of the discharge site (in the receiving area or mixing zone).
- In the ground water downstream or downflow of the discharge site.

- There are numerous potential contaminant levels that can be monitored. Important contaminants from a salt management perspective include chlorides, sodium, pH, - metals, Total Petroleum Hydrocarbons (TPH), and suspended solids.

Site Operation

- The efficiency and remaining capacity of the meltwater collection and treatment areas need to be monitored. Over time the collection and treatment ponds will silt-up reducing their capacity and ability to handle the meltwater. Regular removal of the material that has settled out will significantly extend the life of the areas.
- The stability and condition of the snow storage and driving surface. If the surface deteriorates significantly a site may become unusable until major repairs are done.

Record Keeping

The following list includes items and issues for which records should be kept:

- General site information:
  - Number of snow disposal sites and their capacity.
  - Percentage of snow disposal site with run-off collection and/or treatment system(s).
  - Percentage of snow disposal sites with a monitoring program (groundwater, surface soil, etc.).
- The volume of snow dumped and when it was dumped.
- An estimate of the melt rate. Can use estimate of volume of snow left, flow into meltwater collection and treatment system or discharge volume. A record of basic atmospheric data is useful in helping to determine the melting rates.
- Debris volume and type. Some sites have instituted a lost and found so residents and businesses can retrieve items such as mailboxes, garbage cans, signs, etc.
- Contaminant monitoring records (point data, trends, levels, etc.). Benchmark and contaminate monitoring data may need to be kept on file even after the site has been decommissioned. Monitoring records may be subject to periodic audits and third party reviews and need to be kept appropriately.
- Maintenance and operation records.
  - Regularly review site operations and look for ways to improve efficiency of dumping, pile management and melting.
  - Look for ways to reduce debris and litter by tracking type and source.

8.6. TRAINING FOR SALT MANAGEMENT AND WINTER OPERATIONS

As noted by the Transportation Association of Canada, successfully salt reduction strategy requires changes in procedures, practices, equipment, and acceptance of new approaches by managers, supervisors, and operators. For this reason, effective training programs must demonstrate the value of new procedures and ensure that personnel are competent in delivering the new program. This can be a significant shift for long-time winter snow and ice control operators, where the past standard of a job well done has been to see how much salt they can put down during their shift: "More is Better" or "When In Doubt – Put It Out."

Over applying sand and salt is as much a decision-making problem as it is a technical one; plow operators can make good decisions with old equipment and they can make terrible decisions with state-of-the art equipment.(*cxxiv*) If an operator is using too much sand and salt, saving salt should be as simple as dialing in a lower application rate. To counteract the pressure to overuse salt, it is necessary to provide plow operators with the skills and tools to make good application rate decisions including standard application rate guidelines, based on pavement temperature, calibration, and equipping the plow trucks with infrared pavement sensors or some other means of accessing real-time pavement temperatures may enable the operators to follow these guidelines. Organizing five minute meetings and discussing application rates before and after snow and ice events may give operators the chance to learn about application rates from each other.(*cxxv*) MnDOT developed a performance-based program for reducing application rates called "Salt Solutions" that provided operators with tools and systems for making better application rate decisions. Application rates dropped when the entire organization actively supported the operators in making better decisions and the agency took the time to measure and reward improved performance.(*cxxvi*)

As the Transportation Association of Canada notes, traditionally, equipment-related training focused on equipment maintenance and the safe operation of the vehicle and a plow operator could be forgiven for only plowing, just as a spreader operator might only spread. As equipment evolved, so did specific training on the differences between vehicles, which covered the spreader controller features and how to change settings, etc. These aspects of staff training are still essential to the safe and effective use of equipment. Further equipment-related training, however, should emphasize the impact of the operator's decisions made along the route, the range of settings and methodologies available to the operator, and tie these to her/his roles as a "snow and ice controller" and "decision-maker." Equipment training is integral with other winter maintenance topics such as the science of salt and record keeping. With today's understanding of best practices for snow and ice control and with the more sophisticated equipment that is available, operators need to understand that "decision-making" means choosing to spread when appropriate, and – equally important – choosing not to spread when it is not required. It is important to choose to plow the accumulated snow and slush, and important to not prematurely plow salt-laden slush before the salt has done its job. To ensure operators are confident in their duties and in using the assigned equipment, operators should have training in such equipment-related topics as: (*cxxvii*)

- Route familiarization (preferably during daylight).
- Pre-season driver training.

- Spreader calibration.
- “circle-check” procedures.
- Spreader controller operation.
- Brine equipment operation.
- Equipment washing procedures.
- Minor equipment repair.
- Good housekeeping practices.
- Record keeping.
- Use and interpretation of pavement sensor data and forecasts.
- Infrared thermometer use.
- Agency policies.

The following equipment-related learning goals should be included in a training program:

- Understand the concept of putting out the right material, in the right amount, at the right time, and leaving it there long enough to do the job.
- Understand how the electronic controller and gate settings on each spreader must be set to achieve the specified application rate.
- Understand how to calibrate each spreader to ensure that the right amount of material is being spread.
- Understand how to recognize when re-calibration is necessary.
- Understand the importance of timely plowing.
- Understand how to efficiently plow each beat/route.
- Understand the role and effective placement of snowdrift control devices (structural snow fences, snow ridging, agricultural stubble, living snow fences).
- Understand how to fill spreaders and anti-icing units with liquid chemicals.
- Understand the health, safety and environmental precautions that need to be taken when handling liquid chemicals.
- Understand how to measure brine concentrations.
- Understand the components and purpose of RWIS installations.
- Understand how to properly mount a truck-mounted IRT so as to ensure accurate readings.
- Understand that IRTs are for measuring temperature trends not exact temperatures.
- Understand precautions about handling and using IRTs.
- Understand the importance of proper record keeping and how to complete the required documentation on equipment maintenance and salt use.

Training will necessarily include such on-the-job elements as preseason “dry runs.” Drainage facilities, wildlife crossing structures and other facilities requiring delineation or special treatment in plowing operations should be noted by foremen and equipment operators during dry runs of routes in the fall along with possible obstructions.

It is not likely that all staff will need the same level of training. The amount of training and the level of detail of training that is required by specific personnel will vary. For example, managers may not need to know how to calibrate a spreader or to plow a road in order to carry out their responsibilities. They should however understand the importance of an effective calibration program and what equipment is needed to optimize salt use. Operators that do not make salt application decisions may not have to understand much about the decision support systems. However, they need to understand salt application policies, the chemistry and application of salt, the environmental issues, good housekeeping practices at maintenance yards, record keeping, equipment operation and relevant decision-support information. Training needs vary among employees. New staff will need the full training program; determining competency among a range of staff and experience levels is more complex and often requires data gathering and testing and feedback in the course of work.

Trainers should assemble a bank of local case studies, local photos and examples to reinforce learning goals. Training opportunities should not be limited to formal classroom settings. Trainers should be aware of the workplace schedules, inclement weather policies, shift changes and shift downtime for example and take advantage of these windows of opportunity to present training modules. Depending on the regular duties of the staff there are also opportunities to provide training in informal tailgate sessions or in post storm debriefing sessions.

The Transportation Association of Canada set out the following learning goals and best practices related to winter operations and salt management training.(*cxxviii*)

Salt Management Policy

- Understand the definition and importance of level of service and that the goal is to achieve the prescribed level of service.
- Understand the organization’s Operating Policies and their application to winter operations.
- Understand the organization’s Salt Management Policy.

Principles of Ice Formation

- Understand slippery road conditions are a result of water being cooled below its freezing point on the road surface.
- Understand the sources of moisture on the road include dew, rain, and snow.
- Understand dew point and what conditions will lead to dew forming on the road surface. Understand what conditions will lead to frost and black ice forming on the road surface.
- Understand the importance of pavement temperature in making snow and ice control decisions.
- Understand why bridges freeze first.

Science of Freeze Point Depressants

- Understand the concept of a freeze point depressant.
- Understand that chemicals are used to prevent or break the bond between snow and ice.
- Know the chemical composition of rock salt, and other chemicals used by the transportation agency.
- Understand that brine rather than the solid chemical melts the snow and ice.
- Understand the phase diagram for the chemicals that are used in the organization.
- Understand the implication of chemical concentrations greater than the eutectic concentration.
- Understand the criteria for the selection of de-icing chemicals.
- Understand the relationship between chemical concentrations and freeze point.
- Understand that dry chemicals and pre-wetted chemicals take time to work.
- Understand that a change from a solid to a liquid requires heat and can rapidly cool a road surface.
- Understand the testing requirements and risks associated with the introduction of new snow and ice control chemicals.
- Understand the principle of refreeze.

Material Use

- Understand the role of traffic and crossfall of the road in forming and distributing brine.
- Understand when to windrow and when to spin a pre-wetted solid.
- Understand how to treat special areas such as bridges and culverts, super-elevations, intersections, hills (crests, sags, inclines), bus stops and high wind conditions.
- Understand that chemical should not be applied to dry pavement where drifting snow is not sticking.
- Understand when to use and not use specific chemicals, taking into account pavement temperatures, forecasts, time of day, humidity, traffic volumes etc..

Brine Production and Use

- Understand the procedure for making snow and ice control liquids from solid chemicals.
- Understand the importance of quality control and chemical concentration.

Pre-Wetting

- Understand the benefits of using pre-wetting chemicals and abrasives.
- Understand the difference between proactive anti-icing and reactive de-icing.

- Understand how dry materials are pre-wetted.
- Understand that salt and sand can bounce or be blown off the road and that this product loss can be reduced by pre-wetting.

Anti-Icing

- Understand the concepts of liquid anti-icing.
- Understand the benefits of a proactive anti-icing approach.
- Understand how to fill spreaders and anti-icing units with liquid chemicals.
- Understand the health, safety and environmental precautions that need to be taken when handling liquid chemicals.
- Understand how to measure brine concentrations.

Plowing

- Understand the timing of plowing operations so that chemicals are not plowed off the road prematurely.
- Understand the importance of timely plowing.
- Understand how to efficiently plow each beat/route.

Road Salt and the Environment

- Understand that chlorides are mobile in the environment.
- Understand that road salt may attract some wildlife to the road, potentially increasing the hazard of animal/vehicle collisions.
- Understand that high salt levels can harm vegetation and agricultural crops adjacent to the roadway.
- Understand that high salt levels can harm animals including fish living in streams, wetlands and lakes.
- Understand that it is desirable to only use enough chemical to achieve the prescribed level of service.

Maintenance Yards

- Understand that all salt and sand/salt blends should be covered to minimize salt loss.
- Understand that salt spillage is wasteful and can be harmful to the environment.
- Understand the salt-handling activities that result in wasteful releases of salt to the environment.
- Understand how these salt-handling activities should be carried out to prevent the wasteful release of salt to the environment.
- Understand that timely yard maintenance and repairs are necessary to control salt loss.
- Understand maintenance yard salt cleanup procedures that must be followed.

Snow Disposal

- Understand how to manage the snow pile to facilitate melting.
- Understand the measures to be used to control nuisance effects (noise, dust, litter).
- Understand how to monitor and record chloride, metal, pH, TPH and suspended solids in meltwater discharges.
- Understand how the snow disposal system has to be managed to be cost-effective and to reduce environmental and social impacts.

Managing Snow Disposal Sites

- Understanding how to manage the snow pile to facilitate melting.
- Understanding the measures to be applied to control nuisance effects such as:
    - Noise from trucks and equipment.
    - Visual impacts such as dirty snow piles and vehicle and site lights from nighttime dumping.
    - Dust.
    - Litter and debris.
- Understanding how to monitor, and record the chloride, metals, pH, Total Petroleum Hydrocarbons (TPH) and suspended solids in the meltwater discharges.
- Understand how the snow disposal system has to be managed to be cost effective and to reduce environmental and social impacts.
- Understand the importance of proper record keeping and how to complete the required documentation on snow received and quality of meltwater being discharged.

Record Keeping

- Understand the importance of timely and accurate records.
- Understand the importance of good records for mounting a due diligence defense in the event of a lawsuit.
- Understand how to complete the organization's activity/ storm reports.
- Understand the importance of recording actions and inactions and the rationale for each.
- Understand the importance of knowing the beat/route and what it takes to properly maintain it to the prescribed LOS.

Spreaders

- Understand the concept of putting out the right material, in the right amount, at the right time, and leaving it there long enough to do the job.
- Understand how the electronic controller and gate settings on each spreader must be set to achieve the specified application rate.

- Understand how to calibrate each spreader to ensure that the right amount of material is being spread.
- Understand how to recognize when re-calibration is necessary.

Drift Control

- Understand the role and effective placement of snow drift control devices (structural snow fences, snow ridging, agricultural stubble, living snow fences). More information on snow fence and berm design is included in Chapter 3-10.

Weather Forecasts

- Understand the kinds and sources of weather information.
- Understand how to read a weather forecast.
- Understand what can affect local weather conditions and why weather might vary from one location to another.
- Understand lake effect snowfalls.
- Understand that wind chill does not significantly affect absolute road temperatures but does affect the rate of cooling.
- Understand when a forecast could be wrong.

Wind

- Understand that a wind of 15 km/hr is needed to drift snow.
- Understand how wind changes can signal an approaching or passing storm.

Weather Tracking

- Understand how to monitor weather conditions and anticipate changes.
- Understand how to read a radar image and use the information in decision-making.

Weather and Decision-Making

- Understand how weather forecasts can be used in making snow and ice control decisions.

Pavement Temperatures

- Understand the concept of heat balance and how it can affect pavement temperatures.
- Understand how to read a pavement condition forecast.
- Understand how pavement condition forecasts and real time information can be used in making snow and ice control decisions.

RWIS and IRTS

- Understand the components and purpose of RWIS installations.

- Understand how to read and interpret RWIS data.
- Understand how to properly mount a truck-mounted IRT so as to avoid erroneous readings.
- Understand that IRT's are for measuring temperature trends, not exact temperatures.
- Understand why odd readings might be obtained (e.g. interference, out of calibration, acclimatization, buried utilities, shading etc).
- Understand precautions about handling and using IRTs.
- Understand the role of pavement crossfall in snow and ice control and when to windrow and when to broadcast chemicals.
- Understand the importance of pavement surface temperature on snow and ice control decision-making.
- Understand how to track pavement temperature trends.
- Understand what factors can affect pavement temperatures and how knowledge of these factors can be used to predict temperature changes.
- Understand how to treat different pavement conditions during different types of weather events. Also, good pavement design can help improve road salt performance, minimize usage for the same or better level of service and safety, and thus reduce environmental impact.
- Monitor pavement temperatures to assist in making decisions. This can be done when mobile using hand held or truck mounted infrared thermometers. Road Weather Information Systems can provide a surface and subsurface pavement temperature at a fixed location, and can support the generation of a pavement condition forecast as well as real-time pavement condition information.
- Record pavement temperature trends in daily logs, along with pavement conditions, weather conditions and winter treatment strategy.
- Test pavement temperature monitoring equipment at least annually to ensure that they are operating correctly. Inaccurate equipment should be recalibrated, repaired or replaced.

Trainings should be scheduled for each fall, close to the onset of the snow and ice control season and should include seasonal and contracted personnel. While this season of the year prevents the actual plowing of snow, it does not preclude training and testing on such items as; trucks, grader and loader operation, mounting and adjusting the plow, familiarity with plow and spreader control, driving skills involving turning and backing, and clearance judgment with the plow mounted. This type of training can be given by Equipment Operator Instructors.

Some transportation agencies have included testing and a minimum passing grade in their training programs. In the absence of any industry certification standards this type of internal agency certification may be advantageous to those transportation agencies wanting to provide an assurance of minimum competency levels.

PENNDOT "Smart Salting" Training and Snow Academy

PENNDOT's training program is incorporated with winter planning, which starts in April with after action reviews, equipment repairs, route identification, and route assignments. In the fall, PENNDOT conducts dry runs, marks hazards, and familiarizes operators. Foremen have to sign off that equipment operators have done this. Training for Winter Operations includes "Levels of Service," presented by the leader of the local organization. The training addresses mission, vision, customer service philosophy, priority roads, intervals of service, peak travel times, local directives and changes, alternative resources—temporary operators, etc. A "Smart Salting" module covers material testing, sampling, salt specs for current year's content and other elements, including how to read lab reports. The training program and standards are presented as putting the operator in charge of his own destiny; by adhering to internally developed procedures, PENNDOT staff attends to these issues so the state environmental agency doesn't have to. One quarter of the workforce attends a two day Snow Academy yearly. All other employees receive one day Snow Academy refresher training. Trucks are equipped with ground speed controlled spreaders, which allow precise control of material application rates at any speed or engine rpm with "electric over hydraulic" controls and load-sensing hydraulic pumps. Training occurs on this equipment as well. All spreaders are calibrated each year.

NSYDOT Salt Sensitivity Training for Stormfighters, and Snow and Ice Guidelines

NYSDOT has had to work to educate and train their workforce, the public, and even the police. The Department has implemented training to teach that "the way we've always done it" is not acceptable; the Department wants to get the most bang for the buck AND do an effective and safe job. NYSDOT found their decision to dedicate more resources to training is bearing fruit and raising consciousness among staff. One class is "Salt Sensitivity for Stormfighters." The agency teaches where all the applied salt and brine go; 55 percent goes back into surface drains, 45 percent goes into the ground and affects roadside vegetation. Liquid brine has led to salt reductions but increased mowing, as salt retards growth. NYSDOT trains designers for considering snow and ice as well; i.e. enough road to store the snow, roads built on a slight berm, for snow to blow across, road geometrics, design of living snow fences, identification of drainage features and roadside water quality receptors, and use of raised markers, roundabouts, turnabouts, and curbing. Maintenance environmental specialists focus on erosion control and spill containment year round. NYSDOT has developed Snow & Ice Guidelines primarily for managers, with application rates, storage of materials, etc.; it is currently being revised and will be out in 2005. NYSDOT has another version for operators, NYSDOT's Snow and Ice Operators Manual, that reviews application rates, how to plow, when to use chains or not, how to put on plow wings, etc. The Department is certifying operators and one-person plowing and providing a certification for calibration. NYSDOT encourages many employees to get this training because it gives them a better appreciation for application rates. Promotional opportunities are tied to these certifications for Category 3 operators.

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