# Revised Chapter 8, Winter Operations and Salt, Sand and Chemical Management, of the Final Report on NCHRP 25-25(04)

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## 8.0 Introduction

Winter maintenance operations include removing snow and ice from roads through application of anti-icing and deicing products and traction materials, and plowing operations to make the road safe and passible for the driving public. Applying snow and ice control products prevents the bond between ice and pavement from forming or breaks it once it has occurred so that snow and ice is easier to remove with plowing. Approximately 70% of US roads are located in snowy regions, with nearly 70% of the US population living in these regions (FHWA, 2012b). Winter maintenance operations require roughly 20% of state Department of Transportation (DOT) budgets, spending more than $2.3 billion annually.  This equates to approximately 15 million tons of deicing salt used each year (EPA, 2010). More effective use of winter maintenance products and efficient practices could result in significant economic, environmental, and social benefits.

Since the 1960's research in the areas of winter maintenance related corrosion and environmental impacts has occurred, and in the 1990's a shift in winter maintenance practices began to not only consider the initial cost of operations, equipment and products used, but to also consider the cost of the impacts to infrastructure and the environment. DOTs typically specify and test for heavy metals, pH, nitrogen/nitrates, etc. for all products used for winter maintenance and try to avoid overuse of all materials. Managing the environmental effects of winter maintenance operations can be accomplished through appropriate salt management. In Canada, a five year scientific assessment of road salts was conducted and it was determined that sufficient concentrations pose risks to plants, animals, and the aquatic environment. In response a *Risk Management Strategy for Road Salts* was developed to assess the risks associated with road salts and a *Code of Practice* was developed to provide recommendations for road authorities, including preparation of salt management plans that identify actions to improve salt storage, general use on roads and snow disposal practices (Environment Canada, 2007). A working group of members of Environment Canada and the Road Salt Working Group created the first manual titled *Synthesis of Best Practices, Snow Storage and Disposal* composed of current and effective practices used internationally. The manual provides local municipalities with basic guidelines that can then be tailored to fit their site specific needs. The Transportation Association of Canada (TAC) is currently working to update this manual which is heavily cited in this chapter as (TAC, 2003).

**Table 1 Top 10 practices identified by survey respondents.**

| | |
|---|---|
| 1 | Anti-icing |
| 2 | Pre-wetting |
| 3 | RWIS |
| 4 | Brine Production |
| 5 | Staff Training |
| 6 | Monitoring and Keeping Records of Maintenance |
| 7 | Pavement Temperature |
| 8 | Equipment Calibration |
| 9 | Deicing |
| 10 | Material Storage |

DOTs are now seeking out sustainable practices through the use of newer technology to realize cost savings while maintaining the same or better level of service (LOS). Winter maintenance practitioners were surveyed and over 50% stated that technology, tools and methods implemented in the last 10 years was for cost saving purposes and has had the side benefit of reducing the amount of winter maintenance products used. Table 1 provides a list of the top 10 approaches implemented or modified by surveyed practitioners in the last 10 years. The identified practices, or proactive approaches, can be used alone or in conjunction with one another to reduce the amount of winter maintenance products used, lost or wasted.

Reactive approaches which remove deicers following application can be costly to construct and maintain and often shifts the location of the burden of the deicers or abrasives by moving it to a retention pond or off site to a water treatment facility (Fay *et al*., in review). Additionally once anti-icing and deicing products go into solution, removing the products or the associated anions (e.g., chloride ($Cl^-$)) can be challenging, as chloride ions will not break down over time and cannot be easily treated or removed from the environment. For this reason, the standard practice seems to be to simply dilute the solution not remove it.

The transition to reduced salt usage has been facilitated by great improvements in snow fighting 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. Many DOTs are also taking a closer look at sensitive areas, for special consideration and/or altered practices (Montana DOT, 2002; Staples *et al*., 2004; Levelton Consultants, 2007; Fay *et a*l., in review).

This chapter on environmental stewardship practices in winter operations will review the products commonly used in winter maintenance operations and their associated environmental impacts, and strategic planning and practices for reduced salt usage. Initiatives lead by DOTs, and practices and accomplishments in specific program areas to achieve such reductions and improve environmental outcomes are presented throughout the chapter.

## 8.1 Selecting Snow and Ice Control Materials to Mitigate Environmental Impacts

This section describes the use of various winter maintenance products for the prevention of ice bonding to pavement or for ice melting and removal, with a focus on their environmental footprint. Best practices of winter chemical usage are implemented to *apply the right type and amount of materials in the right place at the right time* for snow and ice control. Deicing agents can be found in a wide variety of snow and ice control products used on winter roadways to either prevent the bonding of ice to the roadway (anti-icing) or break the bond between ice and the roadway (deicing). The products (e.g., chlorides) melt ice and snow by lowering the freezing point of the snow-salt mixture. Prior to application onto roadways, liquid products can also be added to abrasives or solid salts to make them easier to manage, distribute, and stay on roadways (pre-wetting). For simplicity, the term *deicer* is used hereafter to refer to all products used for anti-icing, de-icing and pre-wetting operations.

According to a survey we conducted by Fay *et al.* (in review) the most commonly used winter maintenance product is solid salt (NaCl), followed by salt brine and then sand, grit or traction material. Liquid magnesium chloride ($MgCl_2$) and liquid calcium chloride ($CaCl_2$) were selected as being used by approximately 60% of respondents. The two products listed in the other category were - salt/sand mixed with potassium acetate (KAc) and calcium magnesium acetate (CMA) flakes for bridges. For anti-icing, deicing, pre-wetting and dry placement for traction, the most commonly used product was liquid NaCl, solid NaCl, liquid NaCl, and sand/grit/traction material, respectively.

There are primarily five types of products available in North America for snow and ice control on roads, i.e., NaCl, $CaCl_2$, $MgCl_2$, KAc, and CMA. All of these serve as freezing point depressants and have their own characteristics and impacts on the environment. Additives such as agricultural by-products (ABPs) or organic by-product enhancers are also blended with these primary deicers to improve their performances in snow and ice control. Known additives are corn syrup, corn steeps, and other corn derivatives; beet juice-sugared or de-sugared; lignin/lignosulfonate; molasses (usually from sugar cane); brewers/distillers by-product; and glycerin. Abrasives are also often used to provide temporary traction on wintery roads. While improving roadway safety and mobility, the use of these abrasives and deicers can lead to corrosion and environmental costs that should be taken into account (Shi *et al*., 2012).

## 8.1.1 Impacts of Salt and Chloride-Based Deicer on the Environment

Chloride-based salts are the most common products used as freezing-point depressants for winter road maintenance applications. According to a 2007 survey, most state Departments of Transportation (DOTs) continue to rely on chloride salts and abrasives (Fay *et al*., 2008) for winter highway maintenance. NaCl, or rock salt, is the most widely used chemical due to its abundance and low cost (Fischel, 2001). It can be used as rock salt for de-icing, as salt brine for anti-icing, or added to sand or other abrasives to prevent freezing. A near record 20.3 million tons of NaCl were sold in 2007 in the U.S. (Salt Institute, 2008). The Salt Institute suggested application rates of NaCl at 100 to 300 pounds per lane mile (30 to 90 kg per lane km) of solid material, and at 45 to 165 gallons per lane mile (105 to 388 liters per lane km) of 23% liquid salt brine. However, NaCl is rarely used and minimally effective below pavement temperatures of 10°F (TRB, 1991).

Magnesium chloride ($MgCl_2$) brines feature better performance at lower temperatures (Ketcham *et al.*, 1996; Shi *et al.*, 2009a). Laboratory data have demonstrated that relative to NaCl, the use of calcium chloride ($CaCl_2$) for comparable deicing performance at 0 - 10°F within 1 hour would introduce 5 times less $Cl^-$ and 10 times less cations (Brandt, 1973). Field studies have shown $CaCl_2$ to be more effective than NaCl, owing to its ability to attract moisture and stay on the roads (Warrington, 1998). At reasonable application rates, the effective temperature for $CaCl_2$, $MgCl_2$ and NaCl was reported to be -

25°C, -15°C and -10°C, (-13°F, 5°F, 14°F) respectively (Yehia and Tuan, 1998). $CaCl_2$ and $MgCl_2$ are more costly than salt (NaCl), and they can be difficult to handle. Application of $MgCl_2$ or $CaCl_2$ on roads can lead to potentially slippery conditions on the pavement under certain relative humidity circumstances because of their hygroscopic properties (Perchanok *et al.*, 1991; Leggett, 1999).

The environmental impacts of chloride roadway deicers depend on a wide range of factors unique to each formulation and the location of application. According to Ramakrishna and Viraraghavan (2005), the degree and distribution of the impacts in the highway environment are defined by spatial and temporal factors, such as: draining characteristics of road and adjacent soil, amount and timing of materials applied, "topography, discharge of the receiving stream, degree of urbanization of the watershed, temperature, precipitation, dilution", adsorption onto and biodegradation in soil, etc. A recent survey of winter maintenance practitioners found water quality to be of the greatest concern, with air quality, vegetation, endangered species, and subsurface well contamination also mentioned as highly relevant (Levelton Consultants, 2007). Recent research confirm that repeated applications of road salts (i.e., chloride-based deicers) and abrasives or "seepage from mismanaged salt storage facilities and snow disposal sites" may adversely affect the surrounding soil and vegetation, water bodies, aquatic biota, and wildlife (Buckler and Granato, 1999; Levelton Consultants, 2007; Venner Consulting and Parsons Brinckerhoff, 2004).

There is a need to better understand and assess the environmental impacts of road salts, in an effort to conduct sustainable winter operations in an environmentally and fiscally responsible manner. The damaging impacts of road salts depend on site-specific conditions and concentrations of pollutants in the receiving environments. Levelton Consultants (2007) refined an environmental pathway model to illustrate the deicer footprint on the environment, including: soil, ground and surface waters, and vegetation.

Known issues associated with the use of chlorides as deicers are increased salinity in adjacent waterways and soils, infiltration of cations ($Na^+$, $Ca^{2+}$, $Mg^{2+}$, etc.) and chloride anion ($Cl^-$) into soils and drinking water (TRB, 1991; Jones *et al.*, 1992; Mason *et al.*, 1999; Kaushall *et al.*, 2005), and degradation of the environment along the roadside (Bryson and Barker, 2002; Miklovic and Galatowitsch, 2005).

Chlorides are readily soluble in water and difficult to remove, and thus concerns have been raised over their effects on water quality, on aquatic organisms, and on human health (TRB, 1991; Environment Canada, 2010). The chloride salts applied on winter roads can migrate into nearby surface waters and impact them via various pathways. Godwin *et al.* (2005) found that the $Na^+$ and $Cl^-$ concentration of surface waters in Mohawk River Basin had increased by 130% and 243% from the 1950s to 1990s while other constituents had decreased or remained the same, likely attributed to the estimated 39 $kg/km^2$ (54 $lbs/mile^2$)-day application of deicing salt on roads within the watersheds. Generally, the highest salt concentrations in surface waters are associated with winter or spring thaw flushing events (Stevens, 2001; Ramakrishna and Viraraghavan, 2005). In addition to direct influx of road runoff into surface waters, chloride salts applied on winter roads can also percolate through roadside soils and reach the water table, thus posing an environmental risk for groundwater (Defourny, 2000; Albright, 2005). Research has shown that 10% to 60% of the NaCl applied to roads enters shallow subsurface waters and accumulates until steady-state concentrations are attained (Environment Canada, 2010). Improper salt storage has caused problems with well water and reservoir concentrations. Wells most likely to be affected are generally within 100 ft down-gradient of the roadway in the direction of groundwater movement (TRB, 1991). Watson *et al.* (2002) reported that Cl concentrations exceeded the U.S. EPA secondary maximum contaminant level of 250 mg/L for drinking water (EPA, 2006) at seven wells down gradient from the highway during late winter, spring, and summer samplings. The Cl limit was exceeded only in water from wells with total depth less than about 10 ft below land surface. Na concentrations in water periodically exceeded the EPA drinking-water equivalency level of 20 mg/L in both the uppermost (deicer affected) and lower one-thirds of the aquifer. The most common anti-caking agent used in deicers contains trace amounts of cyanide, which may add additional toxicity and impact aquatic organisms and present an environmental concern for the domestic water supply (Fischel, 2001).

Salt and other chloride-based deicers can pose an environmental risk for soils, as the salt concentrations in roadside soils have been found to positively correlate with the rate of salt application (Jones *et al.*, 1992). Cunningham *et al.* (2008) found that in an urban environment $Mg^{2+}$ from $MgCl_2$ deicer application was the most abundant cation in soils adjacent to roadways even though NaCl was the most frequently used deicer. The $Na^+$ was found to rapidly leach from the soil, decreasing toxicity to plants but increasing input to adjacent waterways. Green *et al.* (2008) found the use of chloride-based deicers to affect ammonification, possibly by increasing soil pH and by nitrification in roadside soils.

The elevated $Na^+$ concentrations in soil tend to displace naturally occurring $Ca^{2+}$, $Mg^{2+}$ etc. and disperse the organic and inorganic particles in the soil pores, reducing soil permeability and aeration and increasing overland flow, surface runoff and erosion (Public Sector Consultants, 1993; Defourny, 2000; Fischel, 2001; Ramakrishna and Viraraghavan, 2005; Nelson *et al.*, 2009; Environment Canada, 2010).

Salt and other chloride-based deicers can have detrimental effects on plants, in particular, roadside vegetation (NDOT, 1990; Bäckman and Folkeson, 1996; Fischel, 2001; Wegner and Yaggi, 2001; Environment Canada, 2004; Cekstere et al., 2008; Trahan and Peterson 2008; Munck et al., 2009). Roth and Wall (1976) suggested that roadside vegetation is subject to environmental stress and the elevated salt concentrations "can only further impair natural balances and accentuate this stress". Road salt exposure due to spray within 33 to 65 ft of the road was demonstrated to cause a greater severity of foliar damage than uptake through the soil alone (Viskari and Karenlampi, 2000; Bryson and Barker, 2002). Many studies have indicated that needle necrosis, twig dieback, and bud kill are associated with areas of heavy road salt usage, with trees and foliage down wind and facing the roadside more heavily affected than trees further away (Sucoff *et al*., 1976; Pederson *et al*., 2000). Field tests have shown that 20% to 63% of the NaCl-based deicers applied to highways in Sweden were carried through the air with 90% of them deposited within 65 ft of the roadside (Blomqvist and Johansson, 1999). Shrubs and grasses in general can tolerate increased NaCl concentrations better than trees (Sucoff, 1975). A study performed in Massachusetts evaluated the impacts of NaCl on vegetation near roadways (Bryson and Barker, 2002). Of the species tested, pines and sumacs had the most widespread, severe damage while grasses, ferns, maples and oaks were tolerant of high salt concentrations. Na concentrations in damaged pine needles were about 75 times as high as those in healthy pine needles. The highest Na concentrations associated with pine needles and maple leaves was 3356 mg/kg and 249 mg/kg, respectively at 10 ft from the road. Similar to NaCl, $MgCl_2$ and $CaCl_2$ can cause damage to vegetation such as growth inhibition, scorched leaves, or even plant death (TRB, 1991; Public Sector Consultants, 1993; Trahan and Peterson, 2008). Field and greenhouse studies have found direct application of $MgCl_2$ to be more damaging to plant foliage than NaCl, causing decreased photosynthesis rates on exposed foliage adjacent to roadways (Trahan and Peterson, 2008). In wetlands with elevated deicer concentrations, a decrease in plant community richness, evenness, cover, and species abundances has been observed (Richburg *et al*., 2001). In wetlands specifically, reducing and/or halting deicer treatment can allow for native plant recovery after multiple water years, but this includes the re-introduction of non-native species as well (TRB, 1991; Moore *et al*., 1999).

Road salt may accumulate on the side of roadways following deicer applications and during spring as snow melts; in areas with few natural salt sources, this could attract deer and other wildlife to the road network (Bruinderink and Hazebroek, 1996). The presence of wildlife on roadways to glean deicing salts has led to increased incidents of wildlife-vehicle collisions (Forman et al., 2003). Chloride salts used for snow and ice control generally pose minor impacts on fauna, since it is rare for their concentrations in the environment to exceed the tolerance level of animals (TRB, 1991; Jones *et al.*, 1992; Lewis, 1999; Silver *et al.*, 2009). Nonetheless, ingestions of road salts have been associated with mammalian and avian behavioral and toxicological effects (Forman *et al*., 2003). Additionally, road salts may reduce wildlife habitat by reducing plant cover or by causing shifts in plant communities - in effect, decreasing food sources and/or shelter (Environment Canada, 2010). Field data and modeling of the effects of road salt on vernal-pool-breeding amphibian species found that embryonic and larval survival was reduced with increasing conductivity. The negative effects varied as a function of the larval density and the distance from the road, with the greatest impacts occurring within 150 ft of the road (Karrker *et al*., 2008).

### 8.1.2 Impacts of Acetate Based Deicers on the Environment

The high cost of acetates (KAc, CMA, and sodium acetate – NaAc) and formates (sodium formate – NaFm, and potassium formate – KFm) have hindered their wider application by highway agencies (Vitaliano, 1992; Cheng and Guthrie, 1998; Fischel, 2001; Keating, 2001). Testing of soil, vegetation, and streams on the North Island of New Zealand where CMA was used for both anti-icing and deicing had shown no negative impacts (Burkett and Gurr, 2004). CMA generally works as a deicer similar to NaCl, yet it can require 50% more by weight than NaCl to achieve the same results (Wegner and Yaggi, 2001). Relative to NaCl, CMA is "slower acting and less effective in freezing rain, drier snowstorms, and light-traffic conditions" (Ramakrishna and Viraraghavan, 2005). Other disadvantages of CMA include the air quality impacts and poor performance in thick accumulations of snow and ice and in temperatures below 23°F.

The most pronounced environmental issue associated with acetate-based deicers is the biochemical oxygen demand (BOD) increase that reduces available oxygen for organisms in the soil and aquatic environments (LaPerriere and Rea, 1989; Fischel, 2001). The acetate ion happens to be the most abundant organic acid metabolite in nature and its biodegradation could lead to anaerobic soil conditions or localized dissolved oxygen (DO) depletion in surface waters (TRB, 1991; D'Itri, 1992; Horner and Brenner, 1992; Defourny, 2000). Data pertaining to a NaAc/NaFm-based deicer suggests that during the spring thaw runoff, short periods of oxygen depletion in receiving waters may occur, with potential danger in warmer weather (Bang and Johnston, 1998). Multiple studies have found KFm to cause no undesirable changes in the groundwater chemistry, owing to biodegradation in topsoil (Hellsten *et al*., 2005a, 2005b). An aquifer scale study on the fate of KFm (Hellsten *et al*., 2005b) found KFm to be easily biodegraded at low temperatures (-2 to +6°C (28 to +43°F)) in soil microcosms, whereas chloride ions from the deicing products used in previous winters had accumulated in the aquifer.

The effect of acetate-based deicers on plants can vary depending on the type of plant and the level of deicer usage. For Kentucky bluegrass, red fescue grass, barley and cress it was found that CMA was less toxic than both NaFm and NaCl, which were of equal toxicity (Robidoux and Delisle, 2001). CMA can enhance plant growth by improving soil permeability and providing needed Ca and Mg as nutrients, which may be a valuable characteristic in areas where heavy salt use has resulted in soil compaction (Fritzsche, 1992). A NaAc/NaFm-based deicer has been demonstrated to have positive impacts on pine and sunflower growth, acting as a fertilizer at concentrations of ~0.5 g/kg of soil. At higher concentrations of 4 g/kg, detrimental effects have been observed including low germination rates, low biomass yield, lateral stem growth, suppressed apical meristem growth, browning of leaves/needles, and senescence (Bang and Johnston, 1998). KFm concentrations less than 4 $kg/m^2$ were found to have detrimental effects on vegetation (Hellsten *et al.*, 2005a).

There are also mixed effects of acetate-based deicers on animals. In general, CMA has low aquatic toxicity while KAc and NaAc have greater aquatic toxicity (Fischel, 2001). A NaAc/NaFm-based deicer was reported to cause apparent fish disorientation, concave abdomen and spinal curvature, observed gill distention, and death (Bang and Johnston, 1998). Acetates and formates have been shown to promote bacteria and algae growth (LaPerriere and Rea, 1989; Bang and Johnston, 1998). For the invertebrate *Eisenia fetida*, CMA was found to be less toxic than NaFm or NaCl, which were of equal toxicity (Robidoux and Delisle, 2001).

### 8.1.3 Impacts of Sand/Abrasives on the Environment

Abrasives (e.g., sand or grit) have been used for many decades for winter operations, as they can provide a temporary friction layer on the snowy or icy pavement. Abrasives are typically used on roads with low traffic and low level of service (LOS) (Blackburn *et al*., 2004). Abrasives, especially those not pre-wetted, had limited effectiveness on wintery roads with higher vehicle speeds; as such, the use of abrasives will not necessarily improve operations or mobility on many roads (CTC & Associates, 2008). Schlup and Ruess (2001) provided a balanced perspective on the use of abrasives and salt, based on their impact on security, economy, and the environment. The detrimental environmental impacts of abrasives are generally greater than those of deicers (Staples *et al.*, 2004). It would take a significantly higher amount of abrasives to maintain a reasonable level of service, relative to the amount of deicer that would be required.

Abrasives used for snow and ice control are relatively inexpensive but costs of damage caused by their repeated applications, along with substantial clean-up costs, can make them less cost-effective. The use of abrasives can pose negative impacts to water quality and aquatic species, air quality, vegetation, and soil and incur hidden costs. Even after cleanup, 50% to 90% of the sand may remain somewhere in the environment (Parker, 1997). Depending on their particle size, abrasives may contribute greatly to air pollution, can potentially cause serious lung disease, and is listed as a carcinogen (Fischel, 2001; Nixon, 2001). Particles smaller than 10 microns (0.01 mm) in diameter, known as PM-10, are regulated by the U.S. EPA and may become suspended in the air and contribute to respiratory problems and cause eye and throat irritation. Communities with excessive PM-10 particles in the air may surpass limits imposed by the Clean Air Act and be categorized as "non-attainment" areas (Williams, 2001). In such communities, the use of abrasives is only allowed on a limited basis (Chang *et al.*, 2002). Abrasives also pose significant risks for water quality and may threaten the survivability of aquatic species especially during spring runoff (Staples *et al.*, 2004). The risks may include: increased water turbidity from suspended solids, clogging of streams and storm water drains, and reduced oxygenation within the stream and river beds. Particles less than 2 mm in size are especially problematic as they can block the movement of oxygen into streambed gravel. Increased quantities of particles less than 6 mm in size can smother macro-invertebrates and fish eggs, affecting both food chains and fish reproduction (Staples *et al.*, 2004). Finally, abrasives used for snow and ice control can also exacerbate the environmental stress for roadside soil and vegetation.

### 8.1.4 Responding to Public Concerns/Complaints Regarding Contamination

A number of studies have established the impacts of winter maintenance materials on the roadside environment, particularly to soils, plant life and aquatics (Mills and Barker, 2002; Hagle, 2002; Akbar, et al., 2006). While proper material storage, maintenance of equipment, appropriate application rates, and preventative procedures and specialized equipment have made great strides in reducing or eliminating the environmental impacts of winter maintenance materials, it is impossible at the present time to completely prevent all roadside contamination. The occurrence of contamination has led in recent decades to greater public concerns and complaints stemming from winter maintenance practices that transportation agencies must consider and address. Different approaches have been developed and used by agencies to address such concern/complaints, which are outlined in the following paragraphs. Some of these approaches are proactive and seek to address/minimize issues before they arise, providing agencies with a means to address public concerns by showing what is already being done. In other cases, a reactive approach is employed to address public complaints that arise from potential contamination.

The Environmental Protection Agency has laid out practices to prevent pollution to waterways from the operation and maintenance of highways (EPA, 1993). These practices included several specific to winter maintenance operations, and include:

- Cover salt storage piles and deicing materials to reduce surface water contamination and locate such piles outside of the 100 year floodplain.
- Regulate the application of deicers to prevent over application.
- Use specialized equipment (e.g., zero velocity spreaders) to apply granular materials so that they remain on the roadway.
- Use alternative materials such as sand and salt substitutes in sensitive ecosystems.
- Avoid dumping snow into surface waters.

The Maryland Department of the Environment has also laid out best management practices for winter maintenance, including:

- Avoid the use of salt and deicers when more than 3 inches of snow have accumulated.
- Use treatment materials at an appropriate temperature for the specific product.
- Use salt and deicers only when a storm is imminent, and sweep and remove materials from the roadway if a storm does not occur.
- Apply materials only when and where necessary.
- Calibrate equipment and train operators in proper application procedures.
- Mix sand with granular materials for added traction and to reduce chemical use.
- Consider alternative materials that require lower application quantities.
- Store materials in a dry, covered area on an impervious surface (Maryland Department of the Environment, Undated).

The prior discussions have detailed proactive approaches to prevent and reduce environmental contamination. However, when such contamination does occur and the public contacts an agency regarding it, steps should be taken to alleviate and address concerns and complaints. The New York State Department of Transportation, in addressing public complaints stemming from site contamination from transportation facilities (e.g., maintenance yards), recommended the following steps be taken: (Venner Consulting, 2004)

- Locate the contaminated site on a map and observe what highways or maintenance facilities are located nearby to determine potential sources of contamination.
- Interview staff if a maintenance facility is located near the affected site to determine if materials were left uncovered and, if so, to recommend actions to address the issue.
- Review historical data (photos, maps, and water quality data) to determine if past maintenance facilities may have contributed to the contamination.
- Inspect the site and neighboring areas to determine whether other sources (e.g., septic systems) have contributed to the contamination and to observe whether any significant amounts of winter maintenance products are visibly present.

As these approaches indicate, both proactive and reactive measures should be taken to address public concerns and complaints regarding contamination. While it may be impossible to eliminate all contamination associated with winter maintenance, particularly treatment using deicers, it is possible to significantly prevent such issues from having an impact outside of the right of way and to address them in an effective manner when they do arise.

## 8.2 Reducing Sand Usage and Managing Traction Materials

Over the last two decades, maintenance agencies in North America have gradually made the transition from the use of abrasives to the use of more deicers (Staples *et al*., 2004). This transition has been supported by a variety of studies demonstrating the detrimental environmental impacts of abrasives generally outweigh those of chemical products, and the use of abrasives requires more material and generally provides a lower level of service (CTC & Associates, 2008; Gertler *et al*., 2006; EPA, 2005; Walker, 2005; Nixon, 2001). Despite the abundant amount of research supporting the use of chlorides and other products instead of abrasives, sand may still be a preferred choice for some agencies. Locations where dry sand and other abrasives are appropriate include low speed roads (less than about 30 to 45 mph), hills, curves, and intersections. Dry sand applied on high-speed roads is short-lasting and ultimately not cost-effective (CTC & Associates, 2008). Sand usage can be reduced by limiting the frequency of re-application; by reducing bounce and scatter and taking steps to ensure the sand stays on the ice/snow-covered road longer. Several techniques that have been tried and used successfully to reduce sand usage include (Vaa 2004; Staples *et al*., 2004; Lysbakkan and Stotterud, 2006; MTO, 2008; CTC & Associates, 2008):

- Pre-wetting sand with liquid deicers, such as salt brine.
- Pre-wetting sand with hot water (about 194°F or 90°C) at a 30 percent by weight mix.
- Heating sand to about 356°F or 180°C (this is hotter than typical hot mix asphalt mixing temperatures).
- Switching to salt or other products.

## 8.3 Strategic Planning for Reduced Salt Usage

### 8.3.1 Salt Management Plans

Salt management plans (SMP) provide maintenance agencies with a strategic tool to effectively manage salt practices while maintaining its obligation to providing safe, efficient and cost-effective road management. Salt Management Plans apply to all winter maintenance staff and personnel (including hired contractors), and protect the people and the environment (TAC, 2003). Key components of a SMP may include:

- A statement of policy and objectives
- Situational analysis – on road use, salt vulnerable areas, sand and salt storage sites, snow disposal sites, training, etc.
- Documentation
- Proposed approaches
- Training and management review.

A successful SMP may feature the following:

- It is based on policy with guiding principles from a high-level organization.
- It is activity based, with each activity assessed at the outset against clearly established standards or objectives showing minimized environmental impacts.
- Deficiencies in current operations are identified and corrective actions are established and implemented.
- Required actions are documented in policies and procedures and communicated throughout the organization.

- Activities are recorded, monitored, audited and reported periodically to assess the progress and identify areas for further improvement.
- Gaps between actions and desired outcomes are identified and corrective actions are developed and implemented, with necessary modifications made to policies and procedures and appropriate training.
- The review cycle continues on an ongoing basis.

The City of Windsor, Ontario specified responsibilities of each personnel in a SMP as follows:

- *Executive Director, Operations* – Has corporate responsibility for the SMP.
- *Maintenance Manager* – Ensure that the SMP is developed, maintained, and implemented consistently across the organization. Oversee the maintenance and upgrading of the winter maintenance facilities in compliance with the SMP.
- *Fleet Manager* –Purchase, maintain, and calibrate the winter maintenance fleet in compliance with the SMP.
- *Coordinator/Supervisor/Foreman* – Ensure that winter maintenance activities are carried out in compliance with the SMP.
- *Winter Maintenance Personnel* – Carry out winter maintenance duties in accordance with the policies and procedures set out in the SMP as directed by their manager.
- *Technical Support Manager* – Assist in the development of methods to compile performance measures in compliance with the SMP (City of Windsor, 2005)

Salt management plans can also be used during the new road design and construction stages. For a highway-175 extension in Quebec, Canada, the developmental plan considered existing maintenance operations and developmental means and established objectives to reduce the impacts of road salts during design and construction (Tremblay and Guay, 2006).

From basic SMP guidelines agencies can make modification to address their specific budgets, and climatic and road conditions. One such improvement by the City of Toronto, Canada entails innovative salt management practices, such as: implementing electronic salt dispensers to control the salt flow, mixing sand into the salt when conditions permit, and pre-wetting the road salt (Welsh, 2005).

### 8.3.2 Winter Maintenance Effects on Safety and Mobility

Highway winter maintenance activities offer such direct benefits to the public as fewer accidents, improved mobility, and reduced travel costs. For a 30-mile roadway segment in Iowa, accidents increased by 1300% and traffic volume decreased by 29% during severe winter weather events (Knapp *et al*., 2000). Another case study in 1992 found that costs related to accidents decreased by 88% after application of deicing salts (Kuemmel and Hambali, 1992). Studies in both Canada and United States show that on average, winter driving requires 33% more fuel (TAC, 2004). Indirect benefits of snow and ice control operations include: sustained economic productivity, reduction in accident claims, continued emergency services, etc. More importantly, the economy cannot afford the risk of shutting down highways in the winter. In 1996, a 4-day blizzard shutdown much of the northeastern United States and led to loss in production estimated at $10 billion, let alone accidents, injuries or other associated costs (Salt Institute, 2005).

Qiu and Nixon (2009) and Qui (2008) developed a method to measure the performance of a winter maintenance programs with respect to the provision of safety and mobility to motorists. The researchers noted that many past studies did not evaluate winter maintenance outcomes while accounting for factors including storm severity, road characteristics and maintenance efforts. To address this, a storm severity index was developed, with the effects of weather and winter maintenance on road surfaces estimated by Multinomial Logistic Regression (MLR). A Multiple Classification Analysis (MCA) was applied to estimate the contributions of winter maintenance to safety, including the use of products. Products included sodium chloride solution (brine), calcium chloride solution, or granular salt (application rates were only available for brine and calcium chloride). Results of the MCA indicated that the chemical variable was a strong indicator of property damage only (PDO) crash probabilities; the impacts of specific chemical types were not broken out (Qui, 2008). However, winter highway maintenance operations collectively (plowing and chemical use) were found to be a weak predictor of crash severity. For this analysis, the researchers found that maintenance operations indirectly impact safety through reducing snow/ice surface conditions (Qui and Nixon, 2009). Qui and Nixon (2009) also found plowing to have a more significant impact on increasing vehicle speed (improving mobility) than chemical treatment. Winter maintenance practices in general had a positive effect on traffic volume.

Fu *et al.* (2006a) examined the effects of winter weather and maintenance treatments on safety. Daily accident data, weather conditions and maintenance operations data were examined for two provincial highways in Ontario, Canada. It was found that anti-icing and pre-wetting operations improved safety on one study route (anti-icing was used on only one study route), while sanding operations had a positive effect on safety on both routes. The researchers noted that the safety effect of plowing and salting operations could not be statistically confirmed by their work, noting that there could be inter-dependencies between maintenance operations and snow conditions, with more maintenance operations dispatched during more severe weather conditions. Consequently, the variation in these operations under a given weather condition may have been small.

Fu *et al.* (2006b) performed a statistical analysis on observational data to identify the quantitative effects of weather and maintenance operations on snow melting trend. Products included rock salt with and without pre-wetting liquid, salt brine, liquid calcium chloride (corrosion inhibited), and liquid magnesium chloride (corrosion inhibited). The test site was a 50 km (31 mile) route on Highway 21 in southwest Ontario, Canada. The researchers noted that historically, quantifying the effectiveness of alternative winter maintenance treatments was a challenge due to the large variations in observational environments including weather, traffic and location. To address this, multinomial logit models were employed to capture snow melting outcomes under these conditions. The primary findings of this work were that pre-wetted salt outperformed dry salt by a reduction in snow cover from approximately 18% to 40%, $CaCl_2$ was found to be much more effective as a pre-wetting agent and outperformed $MgCl_2$ by approximately 10% to 71%, and was also more effective than salt brine (NaCl). While these findings were not directly tied to safety (or operational) performance, they do present insight into the effectiveness of different deicers in achieving snow melt, which has potential safety and operational benefits.

Kuemmel and Hanbali (1992) performed a simple before and after analysis on the effectiveness of salting on safety in New York, Minnesota and Wisconsin. The researchers found a significant reduction in crashes following salting operations, with an 87% reduction observed on two-lane undivided highways and a 78% reduction on freeways. However, the influence of weather-related factors and other maintenance activities (e.g., plowing) were not included in the research and could have resulted in an overestimate of the true contribution of salting.

## 8.4 Stewardship Practices for Reducing Salt, Sand and Chemical Usage

The true cost of winter maintenance products reflects not only the cost of the product and application of material, but also the impacts to infrastructure and the environment. In a survey conducted by Fay *et al*. (in review) survey respondents were asked to identify mitigation techniques used to reduce the impacts of chloride based deicers on the natural environment. The majority of mitigation techniques provided by survey respondents were proactive measures that can be used to reduce deicer use, and therefore put less deicer into the environment, instead of reactive mitigation technique used to clean-up or remove deicers from the environment once they have been applied. The following proactive measures identified from the survey can be used to reduce salt, sand and chemical usage in winter maintenance practices:

- **Anti-icing** consumes much less material than deicing and can be applied prior to storm events to prevent a bond between the ice and pavement from forming, leading to easier plowing.
- **Pre-wetting** solid salt and sand reduce bounce and scatter of the product, allows it to work faster, and provides a higher level of service than dry material.
- **RWIS** provides information on real-time road conditions, including pavement temperature, and can be used to properly time treatments and determine which treatments should be used.
- **Brine production** can support anti-icing and pre-wetting practices.
- **Staff training** conducted annually and post storm can aid in preservation of best practices, and allows for sharing of knowledge.
- **Monitoring and keeping records of maintenance activities** to improve operations. Consider monitoring chemical usage, application rates and conditions, etc. Monitoring in salt vulnerable areas may be supported by local conservation groups.
- **Pavement temperature** can fluctuate significantly depending upon the time of day, degree of cloud cover, subsurface conditions (e.g., frost penetration, moisture presence, thermal retention properties, etc.) and type of pavement. Therefore ongoing monitoring of pavement temperatures is important for good decision-making.
- **Equipment calibration** will keep application rates on target and prevent over application of material.
- **Deicing** at the right time, in the right place with right amount (the 3 R's) is an effective practice. This can be done utilizing forecasts, available information (e.g., RWIS), and properly calibrated equipment that utilizes technology to apply product on the road surface so that it is not lost via bounce or scatter. All of these principles apply to anti-icing as well.

- **Material storage** inside for solid products will prevent loss of product. Return unused product at the end instead heavy “end of beat” applications.

In sensitive areas consider altering application methods and or products, as well as plowing speed. Consider halting side-cast sweeping within 50ft of structures over water, and or placing barriers along water ways or utilizing drainage to move winter maintenance products away from watercourses. Alternative treatments can also be considered, such as only plowing, use of snow fencing, heated pavements, etc.

All of the proactive measures mentioned above are discussed in further detail in this report, as well as additional measures not listed above (e.g., snow fences, effective placement of material). Specific examples of how proactive measures can be used to reduce the amount of product used are provided below.

*Iowa DOT Salt Model*

The Iowa DOT developed a salt model to allocate salt to garages based on weather conditions and policy usage requirements (personal communication, A. Dunn, October 23, 2012). They needed a way for field personnel to understand how much salt they used. To accomplish this, Iowa DOT developed an algorithm that looked at the past five years of weather information at the garage level, specific parameters from the two closest RWIS stations to each garage, as well as garage lane-miles and LOS, precipitation type and start and end times, snow fall estimates, salt usage, salt ordered and salt received, and actual hours. They used this information to create a *salt budget* for each garage. Each garage is then allowed a certain amount salt for the season and if they need more they have to justify why to the central office. Any excess salt is kept for the next year.

Iowa DOT also developed an easy-to-use dash board, or user interface, that shows how much salt each garage has used versus what the algorithm predicted. This allows Iowa DOT to track how much salt they have at each garage, how much salt was purchased and how much was used. This newly developed tool is designed to assist field management staff in monitoring their salt usage. The dashboard allows for closer management of resources with outcomes and targets.

*Kentucky Department of Highways Salt Matrix and Pre-set Spreader Application Rates*

Kentucky Department of Highways developed a salt matrix to reduce application of salt while maintaining the same or better level of service (LOS) (personal communication, M. Williams, October 25, 2012). The developed salt matrices consider the pavement temperature and the heating or cooling trend, the road condition at the time of service, available maintenance strategies/actions, and provide recommended applications for liquid and solid products for both the initial treatment and subsequent treatments for four storm scenarios (light snow, moderate snow, heavy snow, and freezing rain). Reference sheets of the salt matrices are provided to county foremen.

Currently they are using a commercially available pre-wet solid product spreader system that is pre-set at four application rates (200, 400, 600, and 800 lbs/l-m). The drivers then use their judgment and the provided salt matrices to determine which application rate is needed for the given conditions.

*Kentucky Department of Highways Participation in the MDSS Pooled Fund Project*

The Kentucky Department of Highways is entering into its fourth year as a participant in the Maintenance Decisions Support System (MDSS) pooled fund study. Kentucky Department of Highways tested MDSS in the Lexington and Northern Kentucky areas and is currently expanding its use to include three sample routes within each of its 12 Highway districts. The MDSS tool provides a pavement level weather forecast for specific road segments and can help to identify the probability of bridge frost. In addition, the MDSS program will assist managers with the task of deciding when to activate personnel to respond to an approaching winter event.

To utilizing the MDSS forecasts and treatment recommendations, they will have AVL units on approximately 120 trucks that will transmit plow status, pavement and air temperature, and application rate information.

*Washington State DOT and Maine DOT Salt Spreader Slurry Technology*

Salt spreader slurry technology is essentially pre-wetting at a high ratio 70/30 percent (solid/liquid). This works out to be approximately 200 lbs/l-m of solid with 9 gal of liquid added. The slurry comes out with an oatmeal consistency. The solid salt grains are extremely saturated with this technique because the liquid is introduced at multiple locations. In the case of WSDOT the commercially available equipment adds liquid at multiple locations in the truck bed using an auger and at the spinner. WSDOT has observed the slurry going into action much quicker on the road, acting immediately and lasting longer on the road (up to 5 days under the right conditions) (personal communication, M. Mills, October 10, 2012).

Maine DOT utilized existing equipment and retrofitted their trucks with a similar system they made in-house (personal communication, B. Burn, October 10, 2012). With the in-house developed product Maine DOT has not been able to achieve the full extent of the commercially available products. Maine DOT published an evaluation of six retrofit designs and determined the approximate cost to be $7500 (2006 US dollars) per unit (Maine DOT, 2007). Maine DOT found an average savings of 7.8% per mile in product[i], with estimated cost savings of $1329 per unit when comparing the slurry system to control vehicles. Interviewed employees stated that they found the 70/30 slurry mix to out-perform typical pre-wetting methods (liquid application of 6, 8, or 10 gal per ton) while also minimizing bounce and scatter of product. Crews also stated that using a "heavier application on the first application followed by smaller applications", worked best and allowed for the product savings. Crews also stated the importance of getting out early in the storm.

### 8.4.1 Shifting to Anti-icing

Over the last two decades, maintenance departments in North America have gradually made two transitions in their snow and ice control strategies. First is the transition from the use of abrasives to the use of more deicers (Staples *et al.*, 2004). Currently, the United States applies approximately 20 million tons of salts each year for winter road maintenance. This is partially owing to the negative impact of abrasives to water quality and aquatic species, air quality, vegetation, and soil and the hidden cost of sanding (e.g., clean-up costs). In addition, the use of abrasives for winter maintenance has financial and environmental implications as it depletes valuable aggregate sources.

In more recent years, there is increased adoption of anti-icing strategy by many highway agencies in the U.S. in place of deicing (O'Keefe and Shi, 2005). According to a survey conducted by Fay *et al*. (in review), the majority of survey respondents (78%) indicated they have implemented anti-icing as a tool for reducing product application while maintaining or improving LOS. Anti-icing was also identified by the respondents as one of the ten most common practices that have been implemented or modified by their agencies. Anti-icing is defined as "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" (Ketcham, 1996). Generally, applications of liquid products mitigate frost and light black-ice events either before or after the weather incident, but are not considered practical for burning through thick snow and ice (Blackburn *et al.*, 2004). The U.S. Federal Highway Administration (FHWA) provides guidance on the application rate of anti-icing materials, including liquids, solids and pre-wetted solids in its "*Manual of Practice for an Effective Anti-icing Program*" (Ketcham, 1996). This guidance covers four types of storm events: light snow, light snow with periods of moderate or heavy snow, moderate or heavy snow, and frost or black ice (note that guidance for the first three events only applies to solids and pre-wetted solids). For light snow, anti-icers should be applied at rates of 100 to 200 lbs/l-m, whereas light snow with periods of moderate to heavy snow application rates ranged from 100 to 225 lbs/l-m, depending on pavement surface and temperature conditions. Moderate to heavy snow application rates ranged from 100 to 250 lbs/l-m, whereas frost and black ice application rates ranged from 25 to 200 lbs/l-m, depending on pavement surface and temperature conditions. Depending on the pavement temperature, an anti-icer application rate of 65 to 400 lbs/l-m was suggested by Levelton Consultants (2007). Mitchell *et al*. (2006) conducted a survey of state DOTs regarding their application rates of anti-icers and found the typical application rates ranged between 20 and 65 g/l-m. Within Ohio, the anti-icer application rate ranged between 30 to 49 g/l-m.

A recent study sponsored by Clear Roads (Peterson *et al*., 2010) synthesized the current practices of during-storm direct liquid applications (DLA) and found DLA to be "a valuable asset for the winter maintenance toolbox". The DLA benefits listed by the synthesis include: reduced application rates, reduced loss of materials, faster post-storm cleanup, quick effect, further prevention of bonding, expanded toolbox, accurate low application rates, reduced corrosion effects, and leveraging proven benefits of liquids.

In practice, most agencies currently take a toolbox approach customized to their local snow and ice control needs as well as funding, staffing, and equipment constraints. Depending on the road weather scenarios, resources available and local rules of practice, departments of transportation (DOTs) use a combination of tools for winter road maintenance and engage in activities ranging from anti-icing, deicing, sanding (including pre-wetting), to mechanical removal (e.g., snowplowing), and snow fencing.

#### 8.4.1.1 Benefits of Shifting to Anti-icing

Anti-icing has proven to be a successful method of maintaining roadways during the winter season. Relative to deicing and sanding, anti-icing leads improved LOS, reduced need for products, and associated cost savings and safety and mobility benefits (Dye *et al*., 1996; Gilfillan, 2000; Kahl, 2002; Blackburn *et al*., 2004; Conger, 2005). A study performed in Kamloops, B.C. predicted that the majority of collisions caused by slush, snow, or ice could have been prevented by using a liquid anti-icer (Gilfillan, 1999). Russ *et al*. (2008) concluded that "if there is forecast winter weather likely to affect driving conditions, it is desired to have some form of salt on the road, preferably in the form of dried brine. If there is no or very little salt residue on the road, pretreatment is recommended, except under the following conditions: pretreatment would be rendered ineffective by weather conditions or (b) blowing snow may make pretreated roads dangerous". Rochelle (2010) evaluated various anti-icers in the laboratory and found that "the presence of chemical, regardless of chemical type, increased the friction of the pavement surface and reduced the shearing temperature as compared to non-chemically treated substrates for all pavement types, all application rates and all storm scenarios". Along with the effective use of deicers for snow and ice control, a successful anti-icing program can lead to substantial environmental benefits.

#### 8.4.1.2 Stewardship Practices to Minimize Anti-icing Materials Application

Anti-icing has emerged as the most commonly used proactive winter maintenance practice. Anti-icing has been shown to improve level of service (LOS); reduce the need for products, abrasives or plowing; and associated cost savings and safety and mobility benefits (Dye *et al*., 1996; Gilfillan, 2000; Kahl, 2002; Blackburn *et al*., 2004; Conger, 2005). The side benefit of anti-icing is that it reduces winter maintenance products impacts on the environment, infrastructure and vehicles. Generally speaking anti-icing is an effective practice at reducing application of winter maintenance products relative to other practices, such as deicing, because lower application rates can be used.

For anti-icing, decision processes can be unique to each maintenance division or department. Russ *et al.* (2007) developed a decision tree for liquid anti-icing for the Ohio DOT, which aimed to help maintenance supervisors consider a number of factors, including: current road and weather conditions, the availability of maintenance personnel and the best treatment strategy. Russ *et al*. (2008) concluded that "if there is forecast winter weather likely to affect driving conditions… (and) there is no or very little salt residue on the road, pretreatment is recommended, except under the following conditions: (a) pretreatment would be rendered ineffective by weather conditions or (b) blowing snow may make pretreated roads dangerous". In contrast, the Montana DOT uses *just-in-time anti-icing*. Under this strategy, rather than relying on a forecast, treatment of roadways does not begin until the maintenance agency identifies visual signs that a weather event is approaching such as moisture and temperatures drop, at which time crews will begin deploying anti-icing trucks. When used appropriately, this may avoid extra cost, reduce exposure of equipment and infrastructure to corrosion, reduce wastes, and maintain good public relations (Conger, 2005). This strategy, however, may pose a challenge for maintenance sheds in rural areas where the maintenance personnel are in charge of extended roadway segments.

Anti-icing applications do not perform satisfactorily below 20° F, as the liquid chemical can freeze if the pavement temperature is too low. In addition, anti-icing before a rain to sleet event can wash the chemical off the road (Blackburn *et al*., 2004). To avoid slippery pavement, agencies should not use anti-icing as a strategy and should particularly avoid the use of $MgCl_2$, if there is blowing snow or the air temperature is above freezing and rising and the relative humidity is high (O'Keefe and Shi, 2005) due to the hygroscopic nature of $MgCl_2$. Also, caution must be used if anti-icing applications are made after extended dry spells, as they may lead to "a slippery emulsion to be formed by chemical and the contaminants that have built up on the roadway" (Leggett and Scouts, 2001).

The application rate of anti-icing products may significantly affect the skid resistance on asphalt pavement. In some cases, too high an application rate can lead to a reduction in the coefficient of friction of pavement. For instance, field tests were conducted in Michigan, which revealed that doubling the application rate of a commercially available liquid calcium chloride product from 30 gal/lane-mi (70 L/lane-km) to 60 gal/lane-mi led to a drop of average friction coefficient from 0.52 to 0.43. Note that the friction coefficient for dry and wet pavements averaged at 0.72 and 0.62 respectively (Leggett, 2001). The chemical residue remaining on the pavement can lead to slipperiness by drawing water to the road surface. There have been a few reported instances of this occurring across the Snowbelt region; however, not all cases are traced back to winter maintenance products. In some cases, slipperiness is the perception of the driver and sometimes it is caused by other contaminants on the roadway. In a few instances, it is a result of chemical application, but this only happens when dilution has occurred and refreeze is possible (Leggett, 1999). Applying liquids in streams spaced at least 8 inches apart will help minimize slipperiness in rare cases by not wetting the entire pavement surface at once (Blackburn *et al*., 2008).

*Reductions in application of anti-icing materials can be observed from the these practices if the winter maintenance product can remain on the road longer and if less product is lost from plowing, vehicle splash off the road, or due to bounce and scatter*.

### 8.4.2 Road Weather Information System (RWIS)

Weather information is central to the success of winter maintenance operations. Knowing when to apply treatment materials, what materials to apply, the correct amount that should be used and the locations where materials are needed all rely on timely and accurate weather information to guide decisions. Having access to such information can greatly assist in effective winter maintenance operations, but having the right data can be a challenge. For example, National Weather Service data, while widely available via the internet, is not typically highway-specific and does not lend itself to making real-time predictions. Other internet-based weather data sources present similar limitations and lack the capability of providing highway-specific information such as pavement temperature and condition status. However, Road Weather Information Systems (RWIS) are a tool that addresses these shortcomings and provides decision makers with real-time information specific to the roadway itself.

RWIS uses pavement and atmospheric sensors, Closed Circuit Television (CCTV) and communications to collect real-time roadway and weather data and provide it to agency personnel at garages, offices and in the field. RWIS stations are distributed throughout the roadway network, particularly at sites where weather and roadway conditions are of concern (e.g., mountain passes), to provide weather and roadway conditions data continuously through weather events.

To date, a good deal of research has been completed that has shown RWIS to be an effective and beneficial tool, providing material savings, improved level of service and reduced labor costs  The following sections provide an overview of RWIS, the benefits it provides, and its location in the field, among other aspects.

*What Are Road Weather Information Systems (RWIS)?*

Road Weather Information Systems (RWIS) are networks of stations that collect various atmospheric (Environmental Sensing Stations, or ESS), pavement surface, sub-surface and video data (optional) to provide weather information for a specific site along a roadway.  Aside from these sensors, RWIS is also comprised of communications, processing and display components.  Collectively, RWIS stations provide information to managers that support decision-making with respect to deicing chemical applications, anti-icing strategies, materials and staff, and equipment scheduling and optimization.

A single RWIS site, which can consist of a number of different sensors both above and below ground, is a remote processing unit (RPU) station. Such a site typically consists of atmospheric condition sensors and CCTV cameras mounted to a tower, with pavement and subsurface sensors embedded in the pavement and below ground.  A data processing unit and communications hardware are also present at the site, located in a weather-hardened enclosure (cabinet).  Sensor data are processed on site and sent to a central processing unit (CPU) for storage, transmission to other workstations, or accessed directly when a need for records arises.

A key aspect of RWIS is its data processing and display capabilities, which provide maintenance staff with tools and information necessary to support improved decision making.  As the technology has evolved, RWIS data has reached a point where it can be accessed from nearly any desktop workstation in an organization, we well as from remote terminals (including home computers) via the internet (provided the user has authorized access to the website or software).  This provides the opportunity for decision making to be either centralized or decentralized, depending on the particular needs of an agency.  Regardless, access to real time weather and condition information allows for better treatment decisions to be made, resulting in timelier winter maintenance activities to occur.

*Benefits of RWIS*

RWIS has been well documented through studies such as the *NCHRP Synthesis 344: Winter Highway Operations* and the *FHWA Test and Evaluation Project 28: Anti-icing Technology, Field Evaluation Report* (NCHRP, 2005; Ketcham *et al*., 1998).  Consequently, the benefits it provides have been thoroughly identified and documented by a number of different studies and sources.

The Strategic Highway Research Program (SHRP) sponsored research in the early 1990s examined the potential benefits of improved weather information (Boselly *et al.*, 1993a, 1993b). The study analyzed the potential cost-effectiveness of adopting improved weather information (including RWIS and tailored forecasting services), which used a simulation model based on data from three U.S. cities. It indicated that the use of RWIS technologies can improve the efficiency and effectiveness as well as reduce the costs of highway winter maintenance practices.

An NCHRP study documented the cost savings and benefits of RWIS technology, finding that the primary benefit offered was safer travel for motorists (Boselly, 2001). Other benefits included:

- Improved Level of Service
  - Safer travel; improved driver information; help for local agencies, public service functions (through sharing data).
- Cost Savings
  - Save agency money; reduce staff/equipment requirements; reduce use of salt (also environmental benefits); reduced patrolling.
- Maintenance Response to Information.
  - Get the right equipment and materials at the right place at the right time; assist with crew scheduling; increased efficiency; implement better response strategies; helps make maintenance more effective; helps with decisions to "do nothing" when appropriate.
- Indirect Benefits
  - Shorter travel times; reduced accident rates; reduced workplace absenteeism; less disruption of emergency services.
- Other Benefits
  - Reduced wear on equipment and bridges; help in paving operation planning (other than winter maintenance); assistance in avalanche risk assessment.

In addition, the report states that based on the literature/agencies reviewed, a benefit-cost ratio of between 1.1 and 5.0 may be expected from RWIS systems, depending on the application (Boselly, 2001).

A study performed for Caltrans noted that past research on RWIS data indicated that when integrated with other data sources, such data resulted in cost savings through reduced crashes, lower insurance premiums, improved snow removal efforts, and reduced congestion (Laskey *et al*., 2006). Earlier work for Caltrans in 2002 showed that agency personnel perceived RWIS as useful, especially for snow/ice control and traveler information (Ballard *et al*., 2002; Ballard, 2004).

Strong and Shi performed a cost-benefit analysis of the use of customized weather service for winter maintenance activities. The research applied an artificial neural network model that included winter maintenance data from dozens of Utah DOT (UDOT) maintenance sheds for 2004-2005 to estimate the effectiveness of UDOT's weather information program (Strong and Shi, 2008). This program employed weather data from UDOT's 48 RWIS stations, as well as forecasts from four staff meteorologists. The benefit-cost ratio of the UDOT weather operations program was determined to be 11.0, based on material cost savings alone.

Ye *et al*. (2009) evaluated the effects of weather information on winter maintenance costs by using the methodologies of sensitivity analysis and artificial neural network. As part of this work, the researchers performed a cost-benefit analysis for the states of Iowa, Nevada, and Michigan to determine whether the use of accurate weather information provided by RWIS was effective in reducing winter maintenance costs (Ye *et al*., 2009). The direct benefits were found to outweigh the costs of using weather information (costs of the entire system), producing benefit-cost ratios of 1.8 (Iowa) and 3.2 (Nevada) [1].

Boon and Cluett discussed the use of RWIS in enabling proactive maintenance practices in Washington State (Boon and Cluett, 2002). The work identified a number of benefits associated with various winter maintenance practices, including:

- Anti-icing – Lower labor and material costs; higher level of service; travel time savings, and improved mobility; improved safety; reduced equipment use hours and cost; reduced sand cleanup; less environmental impact; road surfaces returned to bare and wet more quickly.
- Routine Patrolling – Reduced equipment use hours and cost; improved labor productivity.
- Allocation of Resources - Increased labor productivity; reduced weekend and night shift work; improved employee satisfaction; reduced maintenance backlog; more timely road maintenance; reduced labor pay hours; overall higher level of service; more effective labor assignments.
- Traveler information – Better prepared drivers; safer travel behavior; reduced travel during poor conditions; fewer crashes, injuries, fatalities and property damage;
- Increased customer satisfaction and political support; improved mobility; safer, more reliable access.

Furthermore, the authors briefly discuss the results of previous studies on RWIS that had developed benefit-cost ratios. These ratios ranged from 1.4 to 5.0.

McKeever *et al*. (1998) developed a life cycle cost-benefit model for RWIS using a site in Abilene, Texas. Direct costs of RWIS used as inputs included initial capital purchase. Direct savings (benefits) included reduced winter maintenance costs (patrol, labor, equipment and materials), while indirect savings included reduced liability risk, accidents, pollution, and travel costs. It was found through the model that a savings of approximately $923,000 could be accrued over a 50 year period.

Strong and Fay (2007) found that Alaska's benefits from RWIS usage included: reduced staff overtime, less misdirected staff time, fewer wasted materials and equipment, and improved roadway level of service (LOS) (Strong and Fay, 2007). However, the RWIS network appeared to be achieving only some, but not all, of these benefits statewide. The researchers concluded that the full benefits of RWIS would be achievable only if there was a concerted effort toward proactive winter maintenance, namely anti-icing.

[1] The benefit-cost ratio of the Michigan case study was not recommended as the calculation of costs were not based on statewide numbers.

Ye and Strong discussed the potential benefits of weather information in winter maintenance. Specifically, the researchers identified secondary applications of RWIS information (enhanced signal timing, weather-responsive operations, etc.), including the costs and benefits associated with them (Ye and Strong, 2009). These included:

- Enhanced traffic signal timing
  - Reduced vehicle delay; less fuel consumption.
- Weather-responsive operations
  - Improved accessibility of information; ability to coordinate and pool resources; improved cost effectiveness; improved public safety; more efficient evaluation activities; more timely and accurate information provided to the traveling public; better prepared TMC operators to address adverse weather.
- Dynamic warning systems
  - Reduced vehicle crashes; reduced crash severity; more comfortable driving.
- Anti-icing spraying system
  - Reduced vehicle crashes; reduced crash severity.
- Traveler information
  - Safer and more comfortable driving; better trip planning for travelers.
- Intelligent Transportation System (ITS) Nodes
  - Provide power and communications system to other technologies.
- Network expansion
  - Provide road weather information to interested agencies/entities; share data with other states; help calibrate weather models.

Experience with RWIS in Iowa indicated that three primary benefits could be achieved. These included improved maintenance of ice free roadways, reduced labor costs, and reduced chemical usage (FHWA, 2009a). By providing accurate information on current conditions, faster and more efficient responses to storm events could be made.

The Transportation Association of Canada highlighted a number of the benefits of RWIS, including the following:

- Provides an understanding of pavement temperatures and trends that can improve the accuracy of decision making.
- Pavement and subsurface sensors can provide data for developing trends and aid in forecasting.
- Provides temperature monitors to aid in determining treatments based on pavement status (wet/dry), freeze point of the solution on the road, presence of and concentration (for some deicers), as well as subsurface temperature.
- Data can aid in helping staff make better decisions regarding snow and ice control.

- Salt use optimization is achieved by more accurate deployment of equipment and application (TAC, 2003).

In addition to the literature discussed in this section, the current (2012) update of this chapter has conducted a survey of winter maintenance professionals. The following are the survey responses from this survey synthesis that pertain to weather forecasting and RWIS:

- Currently have 18 RWIS sites with sensors that give the chemical factor and thus help us to avoid the over application of salt when we do have a winter storm event (South Carolina DOT).
- Currently have 49 fixed road weather stations and more than 140 mobile road weather stations are made available to decision makers. Training sessions were held and others will be held again over the coming years so that users can use the devices to their full potential (Quebec, Canada).
- Have reduced chloride use by storm intensity/duration forecasting (Utah DOT).
- Road weather stations were implemented first as tools to help decision makers to better plan operations. If the operations are better planned, it is possible to reduce the amount of road salts spread by using other technologies, other materials or simply to spread the right amount at the proper time (Quebec, Canada).

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

The location of RWIS stations is crucial in ensuring their successful use in winter maintenance operations (FHWA, 2013). Strategically placed RWIS stations provide forecasts that are 90% to 95% accurate, a rate which improves with the addition of more stations and better technology (FHWA, 2009b). Specific information regarding RWIS, its 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* (Boselly *et al.*, 1993a, 1993b). These documents provide background information on RWIS sensors and equipment, sensor siting, communications needs, equipment siting, and steps to implementing each station. The reader should be aware however, that many sensor technologies and communications mechanism have evolved in the years since these reports were written (1993), although much of the information provided, particularly with respect to locating RWIS sites, remains practical and valid.

Fleege *et al*. (2006) provide best practices and practical guidelines to ensure the reliable operation of RWIS sensors in the field in NCHRP Web-only Document 87, *Test Methods for Evaluating Field Performance of RWIS Sensors*. This information will assist maintenance staff in maintaining RWIS equipment to ensure accurate data is measured and reported by the system.

Once RWIS sites have been deployed, the information they provide must be put to use. The National Cooperative Highway Research Program (NCHRP) Report 526, *Guidelines for Snow and Ice Control Materials and Methods*, provides guidance related to the selection of appropriate treatment strategies and tactics for specific winter storm conditions (Blackburn *et al*., 2004). RWIS data directly compliments this effort by providing the timelier storm and pavement condition data needed to drive the different strategies and tactics outlined in the report. When combined with the information outlined in NCHRP Report 577, *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental*

*Impacts*, RWIS data can help agencies develop treatment strategies that minimize material usage, maximize efficiency, produce better pavement conditions and minimize impacts on the environment (Levelton Consultants, 2007).

Improved friction is a central aspect of winter maintenance, and RWIS data can assist in improving pavement friction conditions by guiding treatment strategies. NCHRP Web Document 53, *Feasibility of Using Friction Indicators to Improve Winter Maintenance Operations and Mobility*, provides insights on the use of friction data with RWIS data to aid in decision making during storms (Al-Qadi, 2002).

Training in the use of RWIS and its applications to maintenance is also a critical aspect that must be considered. Mitchell *et al*. (2006) as part of a larger effort examining snow and ice removal operations in Ohio, found that regular training and refresher courses for maintenance staff, particularly at the county level, were essential in the use of RWIS. Training was viewed as a way to obtain more and effective utilization of RWIS information and for counties to share best practices.

### 8.4.3 Pavement Sensors and Thermal Mapping

Pavement sensors monitor surface conditions and can serve as a data input for warning systems (e.g., ice warning). They can provide information for use in producing forecasts of pavement conditions based on temperature measurements. Pavement sensors can also measure chemical concentrations, providing information that can help determine when additional treatments should be made. Many available sensors also can measure the freezing point of the solution present on the sensor, providing insight into when diluted products may be likely to refreeze. Collectively, the information generated by pavement sensors can be used in monitoring conditions and planning and carrying out treatment strategies.

Sensors intended to measure roadway weather conditions can be of two general types, invasive and noninvasive. The invasive sensors, more commonly known as in-pavement sensors, are installed in the pavement level with the road surface and can use many different sensing technologies in determining roadway conditions. Noninvasive sensors are typically installed on the roadside or somewhere over the road surface and use non-contact means of monitoring weather surface conditions.

In-pavement sensors use the dielectric characteristics of the condition present on the surface of the sensors to determine if the road is dry, damp, wet, or icy and to detect the presence of deicers (Schedler, 2009). The conductivity of the liquid present on a sensor can be used to determine the freezing point temperature of that liquid; this type of sensor is known as a passive sensor. An active sensor is one that actively heats or cools itself to directly measure the freezing point of a liquid present on the sensor (Jonsson, 2010). Some in-pavement sensors also utilize microwave radar to measure the depth of water present on the sensor (Schedler, 2009).

Non-invasive sensors can be mounted apart from the road surface, either above the roadway or at the roadside, or handheld, and use spectroscopic methods, thermal radiation, and infrared radar methods to determine surface weather conditions from a distance. Infrared radiation and thermal radiation are measured to determine the temperature of the road surface. Spectroscopic measures are used to determine roadway surface conditions (dry, damp, wet, ice, etc.) remotely. Friction metrics can be calculated from the temperature and surface conditions (Jonsson, 2010). Inexpensive handheld salinity measuring devices are also available.

In addition to pavement sensors, thermal mapping, or thermography, can also be used to determine thermal profiles of road surfaces. This approach can be used to infer pavement temperatures between sensor locations, as well as for forecasting temperatures at given points. Thermal mapping can be accomplished by using inexpensive hand-held radiometers or vehicle-mounted sensors specifically designed to measure pavement temperature. Thermal measurements are typically made in the early morning to ensure that there is minimal change of temperature during the measurement process. Data from thermal mapping has been used to forecast pavement temperatures in locations without RWIS stations, to site RPU stations, and to aid in the development of treatment strategies.

### 8.4.4 Infrared Thermometers (IRTs)

Pavement temperature has a greater influence on deicer performance than air temperature. Thus, pavement temperature should be considered when deciding salt application rates. Air temperature is readily available, and has some influence on pavement temperature. Pavement temperature models exist, but are difficult to develop and calibrate and are often only regionally applicable (Sato *et al*., 2004; Adams *et al*., 2004; Fu *et al.,* 2008). Infrared thermometers are an easy, quick and generally accurate tool for measuring pavement temperature. Handheld and mobile (vehicle mounted) versions are available. Controlled laboratory and field tests of mobile pavement temperature sensors found the average error was 1.4°F, they were more accurate on concrete pavements and the presence of salt did not affect the temperature readings (SRF Consulting, 2005).

### 8.4.5 Road Surface Traction/Friction Measurements

Information about the real-time friction level of the road surface can be used in decisions to plow and/or apply materials and, if used properly, can prevent over application. However, friction measurements are not often routinely collected on streets and highways during winter storms because equipment is either expensive (such as friction trailers) and/or may have limitations for operation in traffic (some equipment requires heavy braking or reduced speeds). Friction trailers provide physical friction measurements by an instrumented "fifth wheel." Recent research has indicated some potentially promising strategies for determining friction with standard passenger vehicles equipped with 1) traction control systems, or 2) GPS and motion sensors, to back-calculate friction based on vehicular motion (Al-Qadi *et al*., 2002; Takahashi *et al*., 2004; Nakatsuji *et al*., 2007). However, these remain a topic of research and widespread implementation is still a ways off. There are several non-contact optical sensors that measure the amount of ice, snow and water on the pavement using spectroscopy and provide an estimate of the friction. There are a variety of sensors available, some of which can be mounted on vehicles to collect friction during patrols or mounted at RWIS sites. See section 8.6.1.2 for a case study on the use of non-contact optical friction measurements to assess winter maintenance product performance.

Friction measurements have been used extensively at airports and a summary of these techniques can be found in (Fay et al., 2010).

## 8.4.6 Residual Chemical Measurement

Salinity sensors can be used to monitor the residual salt concentrations on the road surface, helping maintenance managers make educated decisions related to chemical reapplication (Ye *et al*., 2012). Potential advantages of using on-vehicle salinity sensors include monitoring the concentration of the solution on a road surface along entire stretches of roadways, which allows for more accurate application rates, and integrating measurements from salinity sensors to automatic spreader controls to apply the right amount of product in the right place. There are two general methods for on-vehicle salinity sensors, measuring the conductivity of collected tire splash (Garrick *et al*., 2002a, 2002b) and the refractive index of an aqueous solution atop of the road surface (Iwata *et al*., 2004; Mexico Company, 2010), respectively.

In addition, Atkins highways and transportation (2007) identified two non-contact methods of measuring salinity on pavement: laser-induced fluorescence (LIF) (Hammond *et al*., 2007) and laser-induced breakdown spectroscopy (LIBS) (Nail and Kumar, 2004). Both LIF and LIBS have been successfully used in architectural, defense and medical applications. They could offer the potential for development into viable traffic-speed residual salt measurement techniques. However, some important issues need to be addressed before these techniques are used in monitoring residual salt concentrations on pavement. These include operator and road user safety related to exposure of the laser discharge (in particular with LIBS), and the need for the device to measure salinity on both wet and dry surfaces.

According to Mitchell *et al*. (2004), "an effective anti-icing program requires prediction and estimation of the amount, type, and timing of chemicals needed for the expected precipitation event while compensating for time and traffic decay of the chemical on the highway surface". As such, they investigated the decay of deicer residuals on several pavement types in Ohio and used field and laboratory data to predict the amount of residual chemical on three types of pavement as a function of time and traffic and to predict the required application rate for the given precipitation conditions. Lysbakken and Norem (2011) and Blomqvist *et al*. (2011) developed models to account for processes and factors that define the change of salt quantity on road surfaces after salt application.

A recent case study investigated the longevity of inhibitors and the performance of corrosion-inhibited anti-icing products after pavement application during winter storms (Shi *et al*., 2012b). The field operational tests included the daily sampling of anti-icer residuals on the pavement for seven days after anti-icer application for a black ice event, a man-made snow event, and a natural snow event, respectively. Subsequently, multiple analytical methods were used to examine the properties of pavement-collected samples in the laboratory. It was found that more than 62% of the inhibitor in the $CaCl_2$-based anti-icer and more than 20% of the chlorides (especially for the $MgCl_2$- and NaCl-based anti-icers) remain on the pavement four days after the application of liquid anti-icers to treat black ice. The longevity of chlorides and inhibitors on the pavement after anti-icer application can vary greatly depending on the pavement temperature, the amount of precipitation, etc.

## 8.4.7 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 a tool that can be used for decision making, such as when to call in personnel, mobilization, and timing. Needs 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. (Ketcham *et al*., 1996)

## 8.4.8 Road Weather Management Decision Support

### 8.4.8.1 Clarus Initiative

The Clarus Initiative is a joint effort of the US DOT ITS Joint Program Office and the FHWA Road Weather Management Program. The goal of the Clarus Initiative is to develop and demonstrate an integrated surface transportation weather observation data management system, and to create a Nationwide Surface Transportation Weather Observing and Forecasting System (FHWA, 2011). The system is designed to enable public agencies to more accurately assess weather and pavement conditions, and their impacts on operations. As of 2009, 46 state and local US, and Canadian provincial agencies are participating the program and contributing data.

Through the Road Weather Management Program, FHWA has sponsored research investigating the use of vehicles as meteorological sensor platforms (FHWA, 2011). Work by the National Center for Atmospheric Research (NCAR) assessed the feasibility of using this data to improve surface transportation weather observations, predictions and road condition hazard analysis and predictions. Research in this area is ongoing. Another example of using vehicle data to support road weather management is the Connected Vehicle (CV) program funded through the Research and Innovative Technology Administration (RITA). Testing conducted in 2009 found that vehicles accurately measure temperature, but are not as accurate at measuring barometric pressure (Chapman *et al*., 2010). At this time the future direction of this program in unknown.

### 8.4.8.2 MDSS

Maintenance Decision Support System (MDSS) is a decision support tool that integrates relevant road weather forecasts, coded maintenance rules of practice, and maintenance resource data to provide winter maintenance managers with recommended road treatment strategies (FHWA, 2011). MDSS is an integrated software application that provides users with real-time road treatment guidance for each maintenance route. Additional information on the development of MDSS and its evolution can be found in *Deployment of Maintenance Decision Support Systems for Winter Operations* (Pisano *et al*., 2006). MDSS has developed into an automated decision support tool for winter road maintenance managers, but also serves to provide forecasts, weather predictions, reports on observed weather and road conditions, serves as a training tool, and is a management support system that can be used year round (McClellan et al., 2009).

Over 20 states have implemented MDSS to some extent. Indiana DOT documented the progression of limited use of MDSS to statewide implementation in the 2008 – 2009 winter season (McClellan et al., 2009). With the statewide implementation INDOT paid careful attention to understanding the changes needed in the management strategy of MDSS and their winter operations, as well as how this change would impact INDOT. They found demonstration of MDSS to all levels of INDOT personnel, allowed for easier understanding of the value of MDSS as a business practice and to the financial bottom line. Training for employee's occurred prior the winter season and a detailed management plan was developed for all aspects of implementation. Throughout the season INDOT proactively resolved issues within INDOT and with the forecast provider. With the well-orchestrated implementation in the first year of statewide implementation, INDOT was able to use 228,470 less tons of salt, for a savings of $12,108,910 and 58,274 less overtime compensation hours, for a savings of $1,359,591. When normalized for varying winter conditions the total combined saving for salt use and overtime compensation hours was $10,957,672.

Additional observations were, MDSS proved to be a powerful management tool, considerable time was spent refining the forecasts with the vendor, and it took time for the management to become comfortable using MDSS but eventually many used it as a planning tool instead of reacting to winter conditions (McClellan et al., 2009). Continued training and exposure to MDSS was needed to ensure the success of the program.

A cost-benefit analysis of MDSS use over two winter seasons 2007 – 2009 in the City and County of Denver, Colorado found savings that exceeded the costs of the system while maintaining the LOS (Cluett and Gopalakrishna, 2009). The saving from the use of MDSS were realized from more effective tactical crew deployment decisions, rather than using the recommended treatments mode of MDSS.

A cost-benefit analysis of MDSS implemented in New Hampshire, Minnesota, and Colorado identified benefits as reduced material use, and improved safety and mobility and identified significant cost savings (Ye *et al*., 2009c). The benefits were found to outweigh the costs associated with the technology in all three states, with benefit-cost ratios ranging from 1.33 to 8.67 due to varying conditions and uses of resources. Identified intangible benefits and needs were:

- MDSS provides a quantitative evaluation of performance measures.
- MDSS can be used as training tool.
- Outcomes associated with changes in rules of practice can be evaluated through MDSS.
- Use of MDSS requires a quality weather forecast.
- The quality of the recommendations from MDSS is dependent on properly sited, maintained and reliable ESS.
- Less use of maintenance vehicles.
- Consistent/seamless treatment of roads among maintenance sheds.

### 8.4.9 Weather Forecasts and Information Services

In order to facilitate best practices in winter maintenance operations, it is crucial to obtain and utilize accurate weather information. Otherwise, the consequences could be: excessive use of deicers and materials, failure to respond in a timely manner to a storm event (resulting in greater crash risk and user delay), unplanned use of overtime staffing, etc. Improvements in weather information can help in all stages of winter storm response, including pre-, during and post-storm. When considering the choice between spatially or temporally improved forecasts, Fu *et al*. (2009) found that improved spatial resolution of forecast data will provide greater expected benefit to service levels.

Boselly *et al*. (1993) analyzed the potential cost-effectiveness of adopting improved weather information, including road weather information systems (RWIS) and tailored forecasting services. The simulation results indicated that the use of RWIS technologies can improve the efficiency and effectiveness as well as reduce the costs of highway winter maintenance practices. A 2007 survey of winter maintenance personnel (Ye *et al*., 2009a) found that free weather information sources, private-sector weather providers, and RWIS were the most widely used weather information sources. Air temperature, wind, and the type and amount of precipitation were primary parameters of current and forecast weather conditions, whereas road weather elements (e.g., pavement temperature, bridge temperature, and pavement conditions) were also widely used in winter maintenance. Three case studies at the State level collectively showed that winter maintenance costs decreased as the use of weather information increased or its accuracy improved (Ye *et al*., 2009a). A survey conducted for this project found the majority of the respondents (75%, n=24) identified "utilizing additional information sources (road weather forecasts, RWIS, maintenance decision support systems - MDSS, pavement and/or vehicle sensors, etc.)" as an effort their agency made in the last 10 years to reduce the amount of winter maintenance products applied during winter maintenance operations while maintaining the same or better LOS.

Anti-icing is more sensitive to weather conditions than other winter maintenance practices, since it is a proactive practice that is sensitive to pavement temperature, dilution, and other factors (Blackburn *et al*., 2004). Near-real-time weather and road condition information and accurate weather forecasts are critical to the success of an anti-icing program; as such information will guide the timing and amount of product needed for pro-active operations (Shi *et al*., 2007; Ye *et al*., 2009a, 2009b). To this end, reliable, micro-scale models for the forecasting of localized weather (or road surface temperature) should be established and a network of weather stations should be in place to enable, validate and refine the models. For instance, the Utah DOT features a Weather Operations program that provides reliable, site-specific local weather forecasts for the highway maintenance staff, which promotes the adoption of anti-icing practices by winter maintenance managers and crews (Shi *et al*., 2007).

Russ *et al*. (2008) identified real-time Doppler as a helpful tool for providing weather information in a timely manner. Mesons, also referred to as mesonets, regional networks of weather information that integrate observational data from a variety of sources, have also been identified as a useful tool (Strong *et al*., 2010). Mesons aim to provide a more comprehensive and accurate picture of current weather conditions. These data management systems are expected to maximize availability and utility of road weather observations and facilitate more accurate, route-specific forecasting of road weather conditions. Weather service customized for winter maintenance operations can be extremely valuable. Shi *et al*. (2007) examined the labor and materials cost for winter maintenance in the 2004-05 season for 77 Utah DOT sheds and established an artificial neural network model to treat the shed winter maintenance cost as a function of UDOT weather service usage, evaluation of UDOT weather service, level-of-maintenance, seasonal vehicle-miles traveled, anti-icing level, and winter severity index. The model estimated the value and additional saving potential of the UDOT customized weather service to be 11 to 25% and 4 to 10% of the UDOT labor and materials cost for winter maintenance, respectively. It was also estimated that the risk of using the worst weather service providers to be 58 to 131% of the UDOT labor and materials cost for winter maintenance.

### 8.4.10 Traffic Information

Traffic is a critical consideration in winter maintenance, as vehicles have a direct impact on the condition of the roadway during and after a storm event. From a winter maintenance perspective, roadway surfaces are affected by vehicles in a number of ways, both negatively and positively. Vehicle tires can compact or abrade snow, slush and ice. Vehicles can also displace/disperse snow, ice, slush and treatment materials, all of which impact the effectiveness of winter maintenance operations. All of these can be considered negative impacts on winter maintenance. The positive impacts of vehicles include engine heat and exhaust providing warmth to melt snow, slush or ice, aiding in restoring bare pavement.

All of these impacts must be considered when planning and conducting all winter maintenance operations, but particularly anti-icing. Consequently, traffic information should be taken into consideration during the planning of upcoming winter maintenance operations. Specifically, traffic rates and associated variations over a 24 hour period (particularly for a day of week similar to a storm event that is being planned for) should be consulted to understand when and where traffic may be at different times and what treatments might be most beneficial to address those traffic volumes. Traffic information is typically electronically available in the form of continuous counts collected by Automatic Traffic Recorders (ATRs) that are strategically located along different highways by state (and occasionally local) highway agencies.

### 8.4.11 Patrols

There is no substitute for visual observation of weather conditions and conditions on and near the pavement surface by trained maintenance personnel through the use of patrols. The use of real-time cameras and sharing of real-time information with AVL technology and RWIS can aid maintenance staff in the task of performing patrols by providing information before going out on the road, automatically documenting conditions and information, with the potential to reduce the need for some patrols which can lead to – saving time, money, wear and tear on vehicles, and keeping maintenance personnel safe by keeping them off the roads in inclement weather.

### 8.4.12 Drift Control/Snow fences

A properly designed and placed snow fence can be a cost-effective tool for snow and ice control for highway segments where the abundance of wind leads to blowing and drifting snow on the winter roadways. For such locations, there is a considerable risk of closing the roadways or requiring excessive plowing and chemical usage. The use of primary drift control technique (snow fence) to minimize the amount of snow blowing onto the roadway will provide a number of benefits to the public and landowners. Some of the benefits include:

- reducing blowing/drifting snow on roadways

- storing snow at low cost
- creating safer travel condition
- reducing the need for snow and ice control products (TAC, 2003).

There are two types of snow fence to manage drifting snow, permanent and temporary. Tabler (1991) found a single row of taller snow fence (at least 8 ft tall) traps more snow, more effectively improves driver visibility, costs less and requires less land than multiple shorter fences.

Snow fence has been proven to be a low-cost mitigation method to prevent blowing snow related accidents. It also helps by reducing maintenance costs and wear-and-tear on the winter maintenance equipment (Wyoming DOT, 2009)

Costs for snow fence can be as little as $1.39 per $ft^2$ of fence (Tabler, 2005). Data from a Wyoming study shows that ”storing snow with snow fences costs three cents a ton over the 25-year life of the fence, (relative) to three dollars a ton for moving it" (Tabler, 1991). In the 1970s, the Wyoming DOT reduced snow and ice removal costs by more than one-third on a 45-mile stretch of I-80 where fences were installed. The fences had been remarkably effective in preventing drift formation over the 20 years since installation (Tabler, 1991).

#### 8.4.12.1 Living Snow Fences

Living snow fences are barriers made of trees, shrubs and native grasses along roadsides. When properly designed and placed, living snow fences trap snow as it blows across the ground, piling it up before it reaches roads. Living snow fences prevent big snowdrifts, maintain mobility and visibility, allow for less product and fuel used to keep roads clear, provide habitat for wildlife, control soil erosion, improve water quality, reduce spring-time flooding, and sequester carbon (Leaner and Greener, 2012). “A living snow fence offers benefits worth $17 for every $1 spent” or a cost:benefit ratio of 17:1 (Leaner and Greener, 2012). Living snow fences can also be constructed of corn stalks, or other agricultural products. Agreements have been made with farmers to not remove corn stalks near roads so they may act as annual snow fences (Wyatt *et al*., 2012).

## 8.5 Precision Application to Manage and Reduce Chemical Applications

Precision application equipment can represent a large cost in ever shrinking winter maintenance budgets, and purchase of this equipment often requires justification or benefit-cost analysis prior to purchase. Identified benefits of precision application equipment for deicing and anti-icing include (Kroeger and Sinhaa, 2004):

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

Cost, benefit or effectiveness information related to material distribution systems have been conducted but were unable to produce a benefit-cost ratio (Colson, 1997; Nantung, 2001; Sharrock, 2002; Iowa DOT, 2000). Identified costs of material distribution systems included equipment costs, as well as the costs of maintenance and calibration. Identified benefits were cost savings, material savings, and improved material placement. The effectiveness of such systems was only identified by one document, which found such systems to be effective in producing bare pavement in a timelier manner. Veneziano *et al*. (2010) developed a web-based tool to assist winter maintenance manager is computing benefit-cost ratios and can be used for material distribution systems.

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.)

Pre-wetting material, whether it be sand/grit or solid deicing product, with liquid (e.g., brine) before application allows the product to stick to road surface producing less bounce and scatter and allows the product to begin to worker sooner. MDOT conducted a bounce and scatter field test and found to optimize application of solid material it should be pre-wet and applied at vehicle speeds between 25 and 35 mph (Michigan DOT, 2012).

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. (Perchanok *et al*., 1993; TAC, 2003) Additionally, Clear Roads has funded the following projects - *Comparison of Material Distribution Systems for Winter Maintenance Phase I* and *Development of a Totally Automated Spreading System* currently underway, and reports are expected to be available to the public in early to mid-2013.

### 8.5.1 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. Or the spreader has crushing system so that all applied material is the same size.

- 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.

#### 8.5.1.1 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, or augers used to create a slurry are gaining popularity, particularly for pre-wetted applications.

Work conducted by Bolet and Fonnesbech (2010) testing spreader material application versus the amount of winter maintenance product on the road recommend focusing on spreading quality, the stability of spreaders adjustments, and the development of simple verification tests for adjustments made through out a season.

## 8.5.2 Material distribution systems (MDS)

Material distribution systems are the front line in the application of anti-icers and deicers to the roadway. It is of great interest to agencies to apply the right amount of materials in the right location at the right time, and advanced material placement systems can assist in meeting these goals (Veneziano *et al.*, 2010). Ideal systems should lead to uniform distribution of applied materials on the pavement and minimal material loss due to bounce and scatter; as such, they would enable the maintenance agency to adopt reasonably lower application rates without reducing the level of service. This could translate to significant cost savings and environmental benefits.

Material Distribution Systems have been documented to various degrees. In a nationwide survey, CTC & Associates (2010) collected information from snowy states to learn more about the best field practices pertaining to using and adapting material spreaders and related equipment. Results have shown that more than half of the agencies use more than one type of material spreader, while two-thirds of the agencies use more than one type of delivery mechanism to get material from the spreader to the pavement. The listed delivery mechanisms include: zero velocity spreaders, dual spinners, spinners, modified spinners, homemade chutes and other types of mechanism. Challenges in working with the material spreaders include bearing failure and hydraulic motor/gearbox failure; clogging, clumping or refreezing of material in the chute; corrosion; difficulty making the transition from spinner to chute in installations lacking a remote-controlled gate; frozen spinners and augers; repeated adjustments or breakage of conveyor chains; and snow accumulating on the back of the truck, plugging the opening to the delivery system.

### 8.5.2.1 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.

#### 8.5.2.2 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.

#### 8.5.2.3 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 pre-wetted 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” or “slurry” 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, or in the hopper using an auger, or both. 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. To solve this problem installing a crusher on the hopper to reduce the particle size may help.

#### 8.5.2.4 Electronic Spreader Controls

Currently, the vast majority of road agencies use spreader systems that are adjustable as to amount of material applied per lane mile. Spread rates can be manually reset by in-cab controls. The Minnesota DOT developed a spreader control that used on-vehicle friction sensors and vehicle location to automatically adjust a zero-velocity spreader (Erdogan, 2010). The controller that was developed was found to adequately apply granular materials up to speeds of 25 mph.

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 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 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.

Hoppers configured to allow the snowplow to carry and spread both liquid and granular materials in different amounts are becoming popular, especially in areas sensitive to certain chemicals and materials. A more advanced version of such systems has been patented, which claims to enable "coordinated application of a plurality of materials to a surface simultaneously and in desired proportions and/or widths automatically and/or selectively" (Doherty, 2005).

#### 8.5.2.5 Rearward Casting Spreaders (including Ground-Speed and Zero-Velocity Spreaders)

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.

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 scatter allowing more of the material to remain on the pavement, saving up to 40% 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 products 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. Minnesota DOT tested eight zero-velocity spreaders that same season and discovered savings of 30% 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 (original reference no longer valid). Zero-velocity spreaders allowed roads to be treated at speeds of 40 to 50 miles per hour while keeping up to 90 percent of the granular salt material on the road surface in the wheel tracks where it is most effective

(Sharrock, 2002). Cost savings over two years were over $70,000 (1998 dollars). Nantung evaluated the use of a zero-velocity deicer spreader and salt spreader to determine their effectiveness for the Indiana DOT. The primary benefit of the system was viewed to be the more accurate placement of material, producing significant potential for cost savings (Nantung, 2001). Maintenance downtime was identified as a potential cost of zero-velocity systems, as the hydraulic nature of the system would require lengthier maintenance time compared to traditional spreader systems. Work conducted by Nixon (2009) found that three tested zero-velocity systems provided superior performance in terms of material retention on the road than the tailgate spreader or a chute system.

### 8.5.3 Pre-Wetting Solid Materials to Minimize Bounce and Improve Performance

Pre-wetting is defined as the approach of adding liquid products to abrasives or solid salts to make them easier to manage, distribute, and stay on roadways. The pre-wetting of solids is performed either at the stockpile (pre-treatment) or at the spreader. The liquid chemical helps accelerate the break-up of the snow/ice pack, and keeps the material on the roadway longer by preventing loss due to rebound and traffic. A survey conducted for this report found that the majority of survey respondents (88%, n=28) indicated they have implemented pre-wetting as a tool for reducing product application while maintaining or improving LOS. Pre-wetting was also identified by the respondents as one of the ten most common practices that have been implemented or modified by their agencies.

Pre-wetting has shown to increase the performance of solid products or abrasives and their longevity on the roadway surface, thereby reducing the amount of materials required (O'Keefe and Shi, 2005). Pre-wetting accelerates the dissolution of solids and enhances its melting action (TAC, 2003). An evaluation of pre-wetting salt in Canada showed that fewer chemical applications were needed, resulting in up to 53% less material used (Warrington, 1998). In Nebraska, pre-wetting salt reduced salt usage by 35%-40% (Keating, 2001). Relative to dry salt, pre-wetted salt (with 10-mm or smaller particles) has been proven to be better retained on dry roads and its spreading leads to less wasted salt and quicker deicing effect (Burtwell, 2004). It was found that pre-wetted rock salt applied along the centerline in a windrow had 96% material retention compared with 70% of the dry rock salt (TAC, 2004). In a case study, the use of brine to pre-wet salt allowed for a 15% reduction in product usage, as the pre-wetted salt exhibited equivalent ice melting performance, better adherence to the road surface, and less loss and scatter (personal communication, P. Noehammer, City of Toronto, March 28, 2012). Looker *et al*. (2004) compared the performance of dry rock salt and six pre-wetted salt mixtures in the laboratory. The rate of pre-wetting was explored at 4, 8, and 12 gallons of liquid chemical per ton of rock salt respectively, and the melting of compacted snow improved with the rate of pre-wetting. Pre-wetting salt slightly decreased its performance at relatively warm temperatures (–1°C and –5°C, 30°F and 23°F, respectively) in some cases but "all of the rewetted mixtures were effective at –10°C (14°F), unlike the dry rock salt".

Pre-wetting with deicing agents helps abrasives stick to the roadway, as does pre-wetting with hot water (Perchanok, 2008; Perchanok *et al*., 2010). Pre-wetted abrasives tend to refreeze quickly to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50% in cold temperatures (Williams, 2003). Nixon (2001) examined the use of pre-wetted abrasives on five different road types, including: high-volume paved roads, low-volume paved roads, low-speed paved roads, unpaved roads, and urban intersections. The only instance where using chemical products to pre-wet abrasives was discouraged was for unpaved roads because it could cause the road to thaw and become unstable. For all other conditions, pre-wetting increased performance and longevity of the abrasive. Dahlen and Vaa (2001) found that "by using heated materials or adding warm water to the sand it is possible to maintain a friction level above the standard, even after the passage of 2,000 vehicles". A new sanding method based on a mixture of sand and hot water has been adopted at some airports in Norway. This method showed promising results as a long-lasting effect was observed along with the prevention of sand from being blown to the side by operating aircraft. However, an event occurred where the treated surface lost its frictional properties (Klein-Paste and Sinha, 2006a). The authors (2006b) also reported that the wetting the sand with hot water before applying it onto the runway surface resulted in a sandpaper-like appearance, of which the performance in practice, optimization, negative effects, and limitations are also discussed. During the winter of 2003-2004, field tests comparing salt pre-wet with hot water versus pre-wet with brine showed similar performance on thick ice and that pre-wetting with hot water provided higher friction levels on thin ice and was more rapid at deicing (Lysbakken and Stotterud, 2006). Vaa and Sivertsen (2008) observed Norway's winter maintenance operations and found that mixing hot water and sand was an effective alternative to salting when temperatures were low. While a specific temperature associated with this operation was not specified, subsequent text indicated salting was performed down to 12ºF.

### 8.5.4 Fixed Automated Spray Technology (FAST)

Fixed Automated Spray Technology, FAST, systems aim to deliver anti-icers to key locations in a controlled manner, using pumps, piping, valves and nozzles or discs (Zhang *et al.*, 2009). As an anti-icing strategy, it reduces the chemical usage by applying the chemical "just in time" (Pinet *et al*., 2001). Ideally, the application should be fully automated, using pre-programmed logic and real-time input from a number of atmospheric and pavement sensors on-site. There are sensitive structures and critical segments of roadway network that need to be free of snow and ice in a timely manner, before maintenance vehicles can even travel to the site and treat them. There are also high-risk areas far from maintenance sheds or areas that experience a high traffic volume, where it is desirable to apply the anti-icing chemical just prior to the frosting or icing event. FAST systems are able to deploy alternative anti-icers to treat specific areas (e.g., bridge decks), which would be impractical for mobile operations to accomplish. The anticipated benefits from FAST systems are site-specific, as a function of winter weather severity, traffic density, accident history, distance from maintenance yard, among other factors (Ye *et al.*, 2012b). In principle, FAST systems should be deployed at locations that are remote, feature high traffic density and significant congestion, or feature considerable safety risk during wintery weather.

Experience with FAST systems in North America and Europe has revealed a mixed picture. Since the mid-1980s, hundreds of automated anti-icing systems have been used throughout Europe as an established tool to battle snow and ice conditions on highways, bridges, and airports (Gladbach, 1993; Friar and Decker, 1999). In North America, FAST is a relatively new technology that has gained popularity since the late 1990s (SICOP, 2004). Several studies have indicated reductions in mobile operations costs and significant reductions in crash frequency, resulting in favorable benefit-cost ratios (Keranen, 2000; Johnson, 2001; Lipnick, 2001; Birst and Smadi, 2009). Yet, there have been a variety of problems related to activation frequency, system maintenance and training. On balance, North American transportation agencies consider FAST to be an evolving technology and future improvements in system design, hardware, software, and installation techniques may help improve the reliability and user acceptance of FAST systems (Ye *et al.*, 2012b). A survey conducted in 2007 revealed that the transportation agencies in North America were not planning to expand their number of FAST installations.

FAST is not an "off-the-shelf" system that can be purchased and installed right away at any given site. Customized design of the installation (e.g., spray logic) at each site after studying the site specifics and conditions is suggested (CERF, 2005). The FAST systems have been found to not spray when wind speed is greater than 15 mph and when pavement temperature drops below 12°F (Birst and Smadi, 2009). Note that there are two distinct hydraulic system design philosophies of FAST systems (Barrett and Pigman, 2001; Ye *et al*., 2012b). The first (referred to as Type I), more common in North America, utilizes a pump located in a pump house to deliver the fluid to the nozzles some distance away. The delivery pressure needs to be rather high to overcome the hydraulic head loss in the delivery lines. In these systems the flow is metered by the size of the nozzle orifice. The reliability of these systems becomes more problematic as the nozzles get farther away from the pump. In the second design philosophy (referred to as Type II), common in European systems, the pump at the pump house is used to fill a small pressurized vessel (tank) located in close proximity to each individual nozzle. When the signal to activate is given, a valve on the small pressure vessel is opened and the liquid is discharged through the spray head. This reduces the effect of the head loss, delivering a fixed amount for each activation.

### 8.5.5 Calibration

Whether materials are distributed by spreaders or FAST systems, the application rates that these pieces of equipment are set at must be accurate. In order to ensure an accurate amount of material is being distributed, equipment must be calibrated. Calibration ensures that materials are being applied at the appropriate rate/setting for a given material and storm scenario. Conversely, equipment that has not been calibrated may be over applying materials, resulting in wasted product, added financial cost, and environmental impacts.

Regardless of the equipment that must be calibrated, a calibration policy should be in place at an agency to ensure that the application rate settings for different materials are correct. When a material is applied by weight (e.g., pounds per lane mile) or fluid measure (e.g. gallons per lane mile), calibration should be by weigh or fluid quantity, respectively. Calibrations should be made when a piece of equipment is acquired or installed; calibration should also occur prior to and at points during the winter season, as well as whenever a new material is to be used. Calibration should also occur after repairs have been made to equipment or when material usage calculations indicate a significant discrepancy. Of course, the identification of material use discrepancies relies on accurate tracking of material use by operators through appropriate data records.

As stated, a thorough approach to calibration is necessary to account for the different anti-icing, deicing and sanding materials that may be distributed by equipment. Consequently, calibrations for both liquids and solids should be carried out on each piece of equipment for all materials that will be dispensed by that piece of equipment. Records of calibration should be kept digitally and as a paper file for redundancy. When a controller is replaced, recalibration for the vehicle must be performed. Concurrent with calibration, the spread pattern for a particular piece of equipment should also be checked. This will further ensure that materials are being placed properly, reducing waste and environmental impacts. Similarly, the different components of the equipment being calibrated should be checked to ensure they are operating as intended. Such components include ground speed controls, belts and chains, chutes, nozzles, gates, spinners and deflectors.

Frequent calibrations should be conducted by maintenance staff that has been trained at least yearly so that they understand the importance of proper calibration and conduct it diligently. Training should provide an overview of calibration, its steps, and other pertinent information. This training may be conducted at any organizational level, but is being used most commonly at the districts. Calibration training can be integrated with other training to maximize the use of operator's time while also providing information related to other aspects of winter maintenance, such as discussions of application rates and material quantities. Note that for agencies that employ contracted maintenance, the equipment of contractors must also be calibrated frequently (by their own personnel), with agency staff carrying out calibration checks when necessary (e.g., prior to start of winter season, at points during the winter, etc.) as specified by the maintenance contract.

In conjunction with calibration, spreader and sprayer equipment should be set up so that they are mechanically restricted from applying more than a maximum amount of material approved for a given set of routes. This will further ensure that excessive materials are not used during anti-icing and deicing operations. Application equipment should also be set up so that materials are only applied in the travel lane, avoiding scatter or bounce that can lead to material leaving the roadway and impacting the roadside environment.

Spreader calibration is a straightforward process that can be completed with a minimum of tools and equipment. It consists of calculating the pounds or gallons per mile of material that should be discharged at different controller settings and vehicle speeds (Salt Institute, 2007). Spreaders must be calibrated individually, as the same models used on two different vehicles can have varying application rates. Different calibrations must also be made for different types of materials for different spreader units. The goal of spreader calibration is to ensure that materials are being discharged at appropriate rates, minimizing wasted materials (and producing cost savings) and reducing environmental impacts. The equipment used for calibration can be quite basic and includes a scale for weighing, a canvas or bucket/collection device, chalk, crayon or other markers, and a watch with second hand (Salt Institute, 2007).

The Salt Institute's "Snowfighters Handbook" presents an overview of the steps and calculations employed in granular spreader calibration. The steps in the process include:

1. Warm truck's hydraulic oil to normal operating temperature with spreader system running.
2. Put partial load of salt on truck.
3. Mark shaft end of auger or conveyor.

4. Dump salt on auger or conveyor.
5. Rev the truck engine to operating RPM (at least 2000 RPM).
6. Count number of shaft revolutions per minute at each spreader control setting, and record.
7. Collect salt for one revolution and weigh, deducting weight of container. (For greater accuracy, collect salt for several revolutions and divide by this number of turns to get the weight for one revolution.) (Salt Institute, 2007)

Similar procedures should also be used when calibrating equipment that applies liquid materials.

The Clear Roads pooled fund developed a calibration guide as part of a larger effort examining ground speed controller units (Blackburn, *et al*., 2009). This spreader calibration guide was developed for both ground speed controlled and manually controlled spreaders used to apply granular and liquid materials. The guidelines discuss various aspects of calibration and outline different procedures to use in performing such activities. Guidance is also provided regarding when calibration/recalibration should be performed, including:

- When the spreader/controller unit is first put into service.
- Annually, before snow and ice control operations begin.
- After major maintenance of the spreader truck is performed and after truck hydraulic fluid and filters are replaced.
- After the controller unit is repaired or when the speed (truck or belt/auger) sensors are replaced.
- After new snow and ice control material is delivered to the maintenance garage location (Blackburn *et al*., 2009).

In general, the spreader calibration process can take between 10 minutes and 1 hour, depending on the number of staff involved, the type of controller (open or closed loop), the number of materials calibration is being done for, and even the age of the vehicle (new equipment requires added time to calibrate from scratch). Past experience from agencies has indicated that 1 to 3 staff is used to complete calibrations, with 2 staff members generally being most widely used.

### 8.5.6 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:

#### 8.5.6.1 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 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.

#### 8.5.6.2 Material Loading and Handling

Sand, deicers, and anti-icers 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 tanks or treated stockpiles. Covered storage for dry products is preferred.

*Avoiding Contaminants to Materials*

- Liquid and solid products, 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. This method is highly inefficient and 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.

## 8.6 Monitoring and Recordkeeping

To facilitate deicer environmental management, it is important to monitor environmental parameters and have sound record keeping practices. Such data will greatly assist in the understanding of deicer migration from work sites and roadways to the adjacent environment. Good practices of equipment calibration, deicer monitoring and record keeping will also aid in assessing cost saving, productivity, etc. Consider documenting the following data on a regular basis:

- Salt stored under cover
- Storage sites with collection and treatment of wash water and drainage
- Inspection and repair records
- Stockpiling records
- Brine production quality control (e.g., concentrations)
- Pavement temperature trends in daily logs, along with pavement conditions, weather conditions and winter treatment strategy (TAC, 2003)

To enable benchmarking, the maintenance agency may also consider obtaining a baseline condition of the working sites and surrounding areas before the deicer application. This will provide a reference for future monitoring and comparisons. The amount of material used during the year should be monitored. Advanced sensing devices (e.g., weight-in-motion - WIM sensors or scale sensors) for truckload tracking can be combined with the routine monitoring to provide more accurate information for operators and managers (TAC, 2003). The maintenance agency may report the following activities or conditions:

- Total length of road on which salt is applied
- Winter severity rating
- Total number of events requiring road salt application during the winter season
- Materials usage (e.g., total quantity of road salts used)
- Description of non-chloride materials used for winter road maintenance
- State of calibration equipment

- Average chloride concentration and frequency of sampling at each sampling location, if available (Highway Deicing Task Force Report, 2007)

A major component of deicer monitoring is the monitoring of chloride levels in roadways and in water bodies. While it is not practical for most road authorities to monitor the chloride level in all the stormwater runoff from roadways, consider monitoring of salt-vulnerable areas. A good example comes from a municipality in Canada, who worked with their local conservation authority to add chloride sensors to their stream monitoring network.

Data obtained from the deicer monitoring and record keeping can be used to determine whether and how a particular measure (e.g., new winter maintenance technique) or event affects the natural environment (e.g., chloride levels in the aquatic environment). According to the TAC (2003), "specific staff should be tasked with monitoring what is brought onto each site, what is being discharged from the site, any onsite or downstream contamination and environmental impacts".

### 8.6.1 Evaluating Treatment Effectiveness

It is beneficial to conduct post-storm evaluations of the treatment effectiveness. This can be done at the shop level as an informal talk with operators and/or as a formal review. Post-storm reviews allow for discussions of what worked and what did not work, and provides an open dialog between operators and supervisors on their expectation, needs, and performance. Things that can be discussed:

- Was the forecast accurate? Were you prepared heading out?
- Was our prescribed treatment sufficient?
- Was the prescribed treatment modified? If so how?
- What worked? What did not work?
- Compare LOS guidelines with what was actually achieved

#### 8.6.1.1 Environmental Performance Measures for Winter Operations

A performance measure is a tool used to assess progress toward achieving defined goals (FHWA, 2012). The following environmental factors and performance measures that apply to winter maintenance operations have been identified (Environmental Plan, 2008; SHRP, 2009):

- Ecosystems, habitat and biodiversity – Maintain or improve ecological functions of affected ecosystems or habitat.
- Water quality – maintain or improve water quality and minimize indirect impacts on water quality at the watershed scale.
- Wetlands – minimize taking of wetlands and impacts to "high-quality" wetlands.
- Air quality – meet National Ambient Air Quality Standards and reduce particulate matter hotspot violations.

Information needed to assess the environmental performance measures listed above includes hydrologic, biological, and or atmospheric data. Remote sensing equipment, GIS and AVL facilitate data collection, analysis and reporting (SHRP, 2009), but additional monitoring equipment may be needed for data collection in aquatic bodies, the atmosphere, and or environments adjacent to the road.

Examples of environmental performance measures put into action are provided below.

- Washington State DOT developed the *Environmental Procedures Manual* which states, "various general practices and specific practices (such as BMPs) that WSDOT will use to avoid and minimize adverse impacts to fish and aquatic habitat" (WSDOT, 2012). Also discussed are the *Roadside Vegetation Management Plans* which covers soils, plants and wetland mitigation and the *Wetlands Protection and Preservation Policy P2038* pertaining to wetland stewardship.
- State DOT Environmental Programs: Evaluation and Performance Measures provided the following information on environmental operations and performance measures from state DOTs (CTC & Associates, 2007):
  - *Arizona*- Environmental Planning Group (EPG) Annual Report for FY 2006. EPG uses a variety of methods to continuously monitor its performance and improve its value to the ADOT organization, including the number of environmental clearances actually issued within a fiscal year. Process improvements include the rollout of Version 1.2 of a centralized project tracking system database.
  - *California*- Standard Environmental Reference. The Caltrans Division of Environmental Analysis manages the Standard Environmental Reference, an online resource to help state and local agency staff plan, prepare, submit and evaluate environmental documents for transportation projects.
  - *Florida*- Efficient Transportation Decision Making (ETDM) Performance Management Plan. FDOT, through its Central Environmental Management Office, is implementing the Efficient Transportation Decision Making process. The ETDM Performance Management Plan illustrates the benefits of collecting, monitoring and reporting on performance measures such as the ability to continuously monitor program area performance, identify problems early and develop efficient and effective solutions and to recognize and promote successes.
  - *New York*-
    1. Environmental Audit – NYSDOT conducts an annual State Agency Environmental Audit which assesses compliance and reports non-compliance with all State Environmental Laws and Regulations, including storage and management of deicing materials. This is a self-reporting audit with the goal of correcting any violations, improving performance and establishing statewide consistency.
    2. Environmental Handbook for Transportation Operations – Published in 1995, this Handbook contains guidance for Operations staff regarding environmental compliance and recommended best management practices for many day-to-day issues including storage and handling of deicing materials. This Handbook is updated bi-annually and is available in electronic format. The goal of this manual is to improve NYSDOT performance and consistency by boiling-down the often complex and voluminous regulatory language to a more brief, understandable and applicable format.
    3. Maintenance Environmental Coordinators – In 2001, NYSDOT established the new position of Maintenance Environmental Coordinator (MEC) in each Regional Maintenance Office. These Senior-level staff work directly with the Regional maintenance staff with the goal of improving overall environmental performance through providing training, promoting stewardship, providing assistance with

regulatory compliance and developing new and innovative approaches to balancing operations needs with sustainability.

- *Oregon*- ODOT Annual Performance Progress Report for FY 2005-06. This report covers the 28 Key Performance Measures (KPM) used during the year which directly support department goals and the report highlights these connections. Measures that affect Oregonians' livability and the state's environment are highlighted, and discussion includes performance-tracking targets for KPM 17 -- the improvement of fish passage.
- *Vermont*- Environmental Operations Manual. This manual serves as a guide to the environmental procedures typically required on Vermont Agency of Transportation projects. The manual also serves as a sourcebook that identifies the various environmental laws and regulations that come into play on transportation projects, describes the framework for environmental resource assessment, and explains how resource assessment is integrated into the overall project development process.
- *Washington*- Gray Notebook. WSDOT's Measures, Markers and Mileposts, also called the Gray Notebook because of its gray cover, provides quarterly, in-depth reports on agency and transportation system performance and is an important internal management and integration tool. The electronic subject index provides access to current and archived performance information, and links to every performance topic published to date, including Environmental Stewardship. WSDOT's Environmental Procedures Manual, and the Performance Measure Library of best state performance measurement practices, are also helpful online resources.

Additional resources on environmental performance measures include:

- FHWA maintains the Environmental Guidebook (http://environment.fhwa.dot.gov/guidebook/index.asp). A web-based information resource.
- FHWA maintains the Environmental Review Toolkit (http://www.environment.fhwa.dot.gov/index.asp). A web-based resource for information and updates on transportation and the environment.
- AASHTO operates the Center for Environmental Excellence (http://environment.transportation.org/). A website offering products and services to assist transportation agencies in achieving environmental excellence in transportation programs.
- Eco-Logical: An Ecosystem Approach to Developing Infrastructure Projects (http://www.environment.fhwa.dot.gov/ecological/eco_index.asp). A resource on developing environmentally sustainable infrastructure development.
- FHWA INVEST Sustainable Highways Self Evaluation Tool (https://www.sustainablehighways.org/). A web-based self-evaluation tool for assessing sustainability over the life cycle of a transportation project or program – from system and project planning through design and construction, to operations and maintenance (Sandhu, 2012).

- FHWA INVEST, OM-12 Road Weather Management Program (https://www.sustainablehighways.org/764/108/road-weather-management-program.html)

#### 8.6.1.2 Winter Operations Performance Measures

Non-environmental performance measures utilized in winter maintenance operations generally pertain to – mobility, reliability, accessibility, and safety (SHRP, 2009). The most commonly used performance measures for winter operations are various measures of road surface condition (e.g., time to bare pavement, bare wheel path, clear condition of the road, or roadway cleared to shoulder-to-shoulder and friction) most likely because this information is easy to collect and use (Maze *et al*., 2007; CTC & Assoc. 2009; Qiu and Nixon, 2009). The ability to maintain vehicle speed is a performance measure recommended by Qiu and Nixon (2009) because it accounts for both safety and mobility. Other identified performance measures include – time to return to a reasonable near-normal condition, length of road closures, crash reduction, and customer satisfaction (Maze *et al*., 2007).

Adams *et al*. (2003) described principles to guide the selection of performance measures including;

- Meaningful and appropriate to the needs and concerns of decision makers.
- Reflect specific goals or guidelines
- Reflect current issues
- Allow for comparison of products, equipment, etc.
- Allow for prediction of future trends in planning and budgets.
- Allow for comparison of performance across states.

The pavement ice condition index (PSIC) is a visual method used to characterize roadway conditions (Blackburn, 2004). PSIC can be used to assess during-storm and post-storm performance. PSIC is easy to use and low cost, but is deficient in that it is a subjective because it is based on the perspective of who is collecting the information.

Friction measurements have been identified as an indicator of road condition that can be used to measure performance (Maze *et al*., 2007; Fay *et al*., 2010). Colorado DOT is currently testing the use of non-contact friction measuring devices to assess winter maintenance product performance. Since installation on traffic poles CDOT personnel have noticed an initial performance difference between winter maintenance products, as well as a difference in bare pavement regain time. Bare pavement regain time is the performance measure used by Colorado DOT to assess product performance and is an assessment of longer term product performance. This suggests that the non-contact friction measurements provide a good estimate of both short and long term product performance. Based on these results, CDOT has been able to reduce winter maintenance product application rates for one of the products and still satisfy the bare pavement regain time performance measure that is targeted for CDOT's current funding level. Similar research is being conducted at four other sites in the US and Canada (personal communication, P. Anderle, March 22, 2012 and J. Trujillo, December 13, 2012).

The Idaho DOT utilizes RWIS data elements (pavement surface and air temperatures, dew temperature, presence of ice, snow or water layer on pavement, relative humidity, wind speed including maximum winter speed), and grip level using a non-contact pavement friction measuring device, and storm severity to determine the Performance Measure Index of a storm and the associated treatment (Cole, 2012). Idaho DOT began statewide implementation of the Performance Measure Index in the winter of 2011-2012, with the intention of learning, not grading the achieved level of service. The Performance Measure Index was identified as a useful tool to improve performance, allow for identification of benchmarks, and identify areas for improvement.

## 8.7 Winter Operations Facilities Management

### 8.7.1 Materials Storage

Sand, liquid and solid products 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 tanks or treated stockpiles.
- Stockpiles of winter materials should be maintained according to best management practices.
- Covered storage for dry/solid products is preferred.
- Low permeability pavements that are sealed, impermeable pavements and plastic liners that provide containment under and around the sides of the solid stockpiles can reduce the long term-loss of product.
- All usage of sand, liquid and solid products should be continuously and accurately recorded.
- Vehicle wash water should be managed, either treated or re-used.
- Knowledge of local environmental regulations specific to material storage is recommended.

Practical considerations include: noting the prevailing winter wind direction and positioning building and doors with regard to sheltering loading operations, minimizing snow drifting around doorways, keeping precipitation out of the storage areas; avoid spillage during stockpiling and truck loading; etc. (TAC, 2003). Specific information on pile size and storage capacity, loading and storage styles and techniques can be found in The Salt Storage Handbook (Salt Institute, 2006).

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

### 8.7.2 Management of Snow Disposal Sites

The most efficient way to dispose of snow is to let it melt where it accumulates, but where space is limited snow can be transported to a designated disposal site where it can melt on its own or with a snow melter (TAC, 2003). When choosing a location to operate a snow disposal site some things to consider include:

- Minimizing the impacts on the natural environment and control nuisance effects, including noise, dust, litter and visual intrusion on adjacent landowners.
- Manage the discharge of meltwater to comply with local water quality regulations and protect surface and groundwater resources.

- Collect and dispose of onsite litter, debris and sediment from the meltwater in accordance with local waste management legislation.
- Snow handling, storage and disposal design should be practical (TAC, 2003).

Routine monitoring of the site including meltwater capacity, collection, and retention and discharge systems may be considered, including periodic collection of water and soil samples. This can be done using onsite monitoring equipment or samples can be sent to an accredited laboratory. If retention ponds are being used to hold meltwater, consider annual cleaning of the ponds to maintain capacity to handle the worst case year snow load (TAC, 2003).

The *Municipality of Anchorage (MOA)* conducted a four-year study (1998-2001) of snow disposal sites and found three factors that related to how pollutants are released during snow melting:

- The initial source of hauled snow,
- The melt processes of stored snowfall, and
- The shape of the snow storage areas and the snowfills (Wheaton and Rice, 2003).

The study concluded that:

- Chlorides can be controlled passively through detention and dilution.
- Mobilization of metals and polynuclear aromatic hydrocarbons relates to chloride concentration, but a large fraction can be controlled with particulate capture.
- Particulate loading in melt water relates to the shape of the snow fill and the pad on which it is situated and can be controlled by manipulation of these elements.

The City of Toronto uses stationary and mobile snow melters when they run out of the capacity to store the snow until it melts on its own (not necessarily every year) (personal communication, P. Noehammer, March 28, 2012). They have dealt with several important issues:

- Treating all snow melt as stormwater runoff and handling it appropriately.
- Consider site grading for appropriate drainage.
- In the snow melt filtering processes, removing all the grit and oils and picking up all the debris.
- The snow melters are burning hydrocarbons and so there are associated emission and noise issues that need to be dealt with (e.g., location should be considered).

#### 8.7.2.1 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.
- Use of low permeable surfaces at the site.

- Avoiding spillage during stockpiling and truck loading, and encourage prompt clean-up when spills occur.

#### 8.7.2.2 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 each spring by the conclusion of the winter season.
- 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.

#### 8.7.2.3 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.

#### 8.7.2.4 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 of snow disposal sites aids in the determination of the extent of the impacts, the effectiveness of the mitigation measures taken, and allows for 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 affect 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 melt water.
    - 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 contaminants that can be monitored. Important contaminants from a salt management perspective include chlorides, sodium, pH, - metals, Total Petroleum Hydrocarbons (TPH), and suspended solids (TAC, 2003). Additionally if agriculturally derived products are being used consider testing the melt water for biological oxygen demand (BOD) and potentially their co-products.

#### 8.7.2.5 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.

#### 8.7.2.6 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.
  - Snow disposal site run-off collection and/or treatment system(s).
  - 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.

## 8.8 Training for Salt Management and Winter Maintenance Operations

Training of winter maintenance staff and personnel is of particular importance for the effective and efficient use of chloride roadway deicers. The success of winter maintenance operations often hinges on changing the daily practices and perceptions about chloride deicer usage and updating the related value system and workplace culture. Such changes often require the personnel at different levels including managers, supervisors, operators and hired contractors to learn new ideas, technology and skills and to accept and implement new approaches. It is interesting to note that research has suggested that only 20 percent of the critical skills are obtained through training whereas the remaining 80 percent is learned on the job (TAC, 2003). Proper training and good management help agencies select the best tools available for the specific combination of site, traffic and climatic conditions, which may include conventional and emerging methods for snow and ice control (Smithson, 2004). Staff training was identified by the survey respondents as one of the ten most common practices that have been implemented or modified by their agencies (Fay *et al.*, in review). A Utah DOT study found that during a 6-month period following simulator training, a plow driver's odds of being in an accident were lower compared with an untrained group. Additionally, data indicated that fuel efficiency was greater for the simulator-trained drivers (Strayed *et al.*, 2005).

A comprehensive training program is recommended to demonstrate the purpose and value of new procedures, to address resistance to change, and to ensure competency of personnel carrying out their duties. The training can also focus on using less deicer without compromising public safety or mobility of the traveling public. According to the TAC (2003), components of training include:

- A needs assessment of the staff.

- Considering who is to be trained and how best to convey the information to an audience and maximize the learning (verbal and visual aids, group discussion, practical application, etc.).
- Designing the training program to identify the learning goals, components and a logical progression, and developing a lesson plan.
- Determining the training methods (in class, in field, post-storm debriefing, etc.)
- Potentially having a current staff member train other staff, so as to add credibility and provide opportunity for follow-up questions and feedback.
- Evaluation of the training program (including the implementation of the training material).
- Assessing how much transfer of training occurred and the need for refresher courses.

The first step of training is to identify the learning goals, for example, LOS guidelines, principles of ice formation, chemistry of road salts, environmental impacts of road salts, to name a few. Annual training close to the onset the snow and ice season is desirable in order to ensure current learning goals are taught, reinforced and tested. The level of comprehension of the learning goals and compliance should be monitored throughout the snow and ice season. Refresher sessions are strongly recommended to reinforce the learning goals (TAC, 2003). The power of positive messaging has been proven effective in mitigating the adverse effects associated with adult training. For instance, utilizing statistical data to provide regular feedback to operators, such as posting annual material or cost savings, can reinforce the importance of their efforts. Operators should be encouraged to share information, experiment with new concepts, and challenge old ideas (TAC, 2003).

The successful implementation of salt management and maintenance strategies (e.g., pre-wetting and anti-icing) require acceptance and proper training of winter maintenance staff so that they understand the fundamental concepts underlying the practices (Smithson, 2004). Due to the diversity in chemical products, pavement surfaces, traffic and other conditions, there is still a lack of consensus in the appropriate application rate for a specific road weather scenario, which hinders the optimal use of deicers for snow and ice control. The NCHRP Report 577 provided guidelines for the selection of snow and ice control materials, including anti-icers, deicers, pre-wetting and abrasives (Levelton Consultants, 2007). Guidance on application rates for anti-icing, deicing and sanding has been provided by Blackburn *et al.* (2004) and Wisconsin Transportation Information Center (1996). The Salt Institute (2007) provided guidelines for salt application in *The Snowfighters Handbook: a Practical Guide for Snow and Ice Control*. Devries and Hodne (2006) discussed the findings of work done by the Iowa DOT and McHenry County (Illinois) Division of Transportation using blended anti-icing and deicing agents.

The American Public Works Association (APWA) developed a Winter Maintenance Supervisor Certificate training program with the goals of expanding knowledge and preparation, increase understanding of winter weather, better use of deicing and anti-icing products, available equipment and how to maintain it, enhancing communication with the public, and improving training; taught in a workshop format (APWA, 2013).

The important role of technology in staff training has been validated by agencies. One tool for training is the computer-based training (CBT), developed under the leadership of AASHTO and for the winter maintenance staff in state and local governments. The course consists of several lessons containing a total of about forty units, covering a host of topics about winter roadway management. The CBTs were updated with the latest research and operational techniques by 2010 and were converted to a web-based application in 2012 (Personal communication, L. Smithson, September 14, 2012).

Another advanced tool for training is the high-fidelity simulator, which has been utilized to enhance the performance of Utah DOT maintenance operators (snowplow drivers). In such a simulator, different scenarios have been developed to address the DOT user needs in managing incidents and to customize the training program. Overall, the simulator training was found to decrease the accidents ratio and reduce cost and fuel usage, when the performance of simulator trainees was compared against that of a control group (CTC & Associates, 2008). In MnDOT's Salt Solutions Program, plow drivers are trained in virtual snow plow cabs about how to use deicing products in "the right amount, at the right time, in the right way" (Leaner and Greener, 2012).

A recent survey conducted by the Western Transportation Institute found annual operator training and "snow universities" are an important tool to reduce the impacts of chloride deicers on the natural environment (Fay *et al*., in review). Many survey respondents agreed that the training helped their state or agency to mitigate or reduce the impacts of chloride deicers.

The Transportation Association of Canada set out the following learning goals and best practices related to winter operations and salt management training (TAC, 2003).

**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 deicers and anti-icers are used to prevent or break the bond between snow and ice.
- Know the chemical composition of rock salt, and other products used by the transportation agency.
- Understand that brine rather than the solid material melts the snow and ice.

- Understand the phase diagram for the chemicals that are used in the organization.
- Understand the implication of product concentrations greater than the eutectic concentration.
- Understand the criteria for the selection of de-icing and anti-icing chemicals.
- Understand the relationship between chemical concentrations and freeze point.
- Understand that dry and pre-wetted products 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 products, 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 solids.
- Understand the importance of quality control and product concentration.

**Pre-Wetting**

- Understand the benefits of pre-wetting, solid product 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 liquids.
- Understand the health, safety and environmental precautions that need to be taken when handling liquids.
- Understand how to measure brine concentrations.

**Plowing**

- Understand the timing of plowing operations so that products 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 (9.3 mph) 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 product.
- 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.

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## Appendix A – Acronyms

ABP – agricultural bi-product

ATR – automatic traffic recorders

AVL – Automatic Vehicle Location

BMP – best management practice

BOD – biological oxygen demand

Ca – calcium

$CaCl_2$ – calcium chloride

CCTV – closed circuit television

Cl- chloride

CMA – calcium magnesium acetate

CPU – central processing unit

DLA – direct liquid application

DO – dissolved oxygen

DOT – Department of Transportation

EDTM – efficient transportation decision making

EPA – Environmental Protection Agency

EPG – environmental planning group

ESS – Environmental Sensing Station

FAST – fixed automated spray technology

FHWA – Federal Highway Administration

Ft – foot

g/kg – grams per kilogram

GPS – Global Positioning System

Hr – hour

IRT – infrared thermometer

ITS – intelligent transportation system

KAc – potassium acetate

KFm – potassium formate

$Kg/gm^2$ – kilograms per square kilometer

KPM – key performance measures

Lbs/l-m – pounds per lane mile

LIBS – laser-induced breakdown spectroscopy

LIF – laser-induced fluorescence

LOS – level of service

M – meter

MCA – multiple classification analysis

MDS – material distribution systems

MDSS – Maintenance Decision Support System

Mg – magnesium

Mg/kg – milligram per kilogram

Mg/L – milligrams per liter

$MgCl_2$ – magnesium chloride

MLR – multimodal logistic regression

Na – sodium

NaAc – sodium acetate

NaCl – sodium chloride, salt

NaFm – sodium formate

NCAR – National Center for Atmospheric Research

PDO – property damage only

PSIC – pavement ice condition index

RITA – Research and Innovative Technology Administration

RPM – revolutions per minute

RPU – remote processing unit

RWIS – Road Weather Information System

SMP – Salt Management Plan

TAC – Transportation Association of Canada

WIM – weight in motion

# Revised Chapter 8, Winter Operations and Salt, Sand and Chemical Management, of the Final Report on NCHRP 25-25(04)

*Requested by:*

American Association of State Highway
and Transportation Officials (AASHTO)

Standing Committee on Highways



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# Table of Contents

## Abstract

This report documents and presents the results of updating Chapter 8, Winter Operations and Salt, Sand, and Chemical Management of the NCHRP Report 25-25(04) Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance. A comprehensive literature review, survey, and follow-up interviews were conducted to obtain new, updated, and other relevant information since the document's original publication in 2004.

## Summary

*Chapter 8, Winter Operations and Salt, Sand, and Chemical Management* of the *NCHRP Report 25-25(04) Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* was revised for this project. A comprehensive literature review, survey and follow-up interviews were conducted to obtain new, updated, and other relevant information since the document's original publication in 2004.

The Revised Chapter 8 presents information on recommended practices and strategic planning for reduced salt usage, highlights innovative DOT practices and programs that achieved reductions or improved environmental outcomes. Specific topics covered include;

- Basic information on the most commonly used snow and ice control materials, their impacts on the environment, and public concerns on the use of these products.
- Strategic planning and stewardship practices that can be used to reduce snow and ice material usage, such as anti-icing, utilizing available pavement and weather information, etc.
- Precision application methods and material distribution systems.
- The importance of record keeping and monitoring, management at winter operations facilities, and appropriate training of winter maintenance personnel.

Based on the findings from this work suggested research recommendations have been made to address knowledge gaps or areas with limited or little research on the topics discussed in Revised Chapter 8.

# Chapter 1 Background

## *Problem Statement and Research Objective*

Over seven years ago NCHRP Project 25-25(04) developed the *Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance* report. The extensive document presents information on how to incorporate environmental stewardship into the daily operations of construction and maintenance activities. Chapter 8, *Winter Operations and Salt, Sand and Chemical Management*, of this report, focused on recommended practices and strategic planning for reduced salt usage, highlights innovative DOT practices and programs that achieved reductions or improved environmental outcomes.

In the past seven years the field of winter maintenance has produced a wealth of research, including field trials and tests that can improve Chapter 8 *Winter Operations and Salt, Sand and Chemical Management.* Specifically there was a need to update Chapter 8 *Winter Operations and Salt, Sand and Chemical Management* in the areas of strategic planning to reduce salt usage with 1) examples of lessons learned based on real world experience, 2) highlight current and successful practices, and 3) inclusion of findings from cost-benefit studies, including the aspects of forgoing winter operations, and the “Triple Bottom Line” principle that considers economy, environment, and social equality.

The objective of this research was to prepare an updated version of Chapter 8 to replace the current chapter in the final report NCHRP Project 25-25(04).

## *Scope of Study*

The objective of this research project is to update Chapter 8 of NCHRP 25-25(04). The original scope of Chapter 8 includes:

- Description of commonly used snow and ice control products, their environmental impacts, and methods to minimize application.
- Practices that aid in reducing application rates of snow ice control products including anti-icing, precision application, and monitoring and record keeping supporting such practices.
- Stewardship practices for facility operations and management.
- The importance of appropriate training of personnel.

The original scope of Chapter 8 was used as the basis for Revised Chapter 8. Additionally all new and relevant changes within the following topics were updated.

- Anti-icing,
- Pre-wetting,
- RWIS,
- Brine Production,
- Staff Training,

- Monitoring and Keeping Records of Maintenance,
- Pavement Temperature,
- Equipment Calibration,
- Deicing, and
- Material Storage.

The scope of Revised Chapter 8 encompasses the methods, tools, and techniques originally discussed in Chapter 8, if still used and relevant, as well as those identified above. Additionally, Revised Chapter 8 presents information on recommended practices and strategic planning for reduced salt usage, highlighting innovative DOT practices and programs that achieved reductions or improved environmental outcomes.

# Chapter 2 Research Approach

A review of all available literature, surveys, and interviews were used to revise *Chapter 8, Winter Operations and Salt, Sand and Chemical Management*. Details on each of these tasks are presented as follows.

An extensive literature review was conducted to gather information relevant to the state of practice of environmental stewardship, and procedures and policies used to achieve this in winter maintenance operations. Technical documents, government reports, journal publications, conference presentations and proceedings were used initially to identify pertinent information, and from local, state, federal, and international governments and organizations as well as organizations that work to promote winter maintenance effective practices, in the form of webpages, manuals, field guides, reports, and published specifications, etc. Information gained from the literature review was used to update the chapter and to create the survey questionnaire.

A survey questionnaire was developed and sent to members of the American Association of State Highway Transportation Officials (AASHTO) Subcommittee on Maintenance and Standing Committee on the Environment. Thirty two responses were received (31 from the U.S. and 1 from Canada).

Information gained from the survey responses was reported in the body of the text of Revised Chapter 8 where relevant, used as information sources, and provided the basis for interviews discussed next. Survey questions and responses are provided in Appendix A.

Interviews were conducted to gain additional information on specific topics relevant to the revision of Chapter 8, specifically current and successful practices that have been implemented by winter maintenance practitioners. Six interviews were conducted and information gained from the interviews was used to provide resources and information utilized in the revision of Chapter 8, and was converted into case examples on 1) Maintenance Decision Support Systems (MDSS), 2) Salt Management Model, 3) Salt Use and Application Matrix, 4) use of friction measurements as an indicator of product performance, and 5) pre-wet slurry technology. The case examples can be found in Appendix B.

# Chapter 3 Findings and Applications

Revised *Chapter 8, Winter Operations and Salt, Sand and Chemical Management* is provided as an attachment to this Final Report. Below is a general outline of the findings presented in Revised Chapter 8.

DOTs are working to incorporate sustainable practices through the use of newer technology to realize cost savings while maintaining the same or better level of service. Winter maintenance practitioners identified the following technology, tools, and methods as having been implemented in the last ten years for cost saving purposes, which have had the side benefit of reducing the amount of the snow and ice control chemical usage:

- Anti-icing
- Pre-wetting
- RWIS
- Brine Production
- Staff Training
- Monitoring and Keeping Records of Maintenance
- Pavement Temperature
- Equipment Calibration
- Deicing
- Material Storage.

The following practices were specifically identified as being successful in reducing snow and ice control products application;

- Reducing application rates
- Anti-icing
- Pre-wetting
- Calibrating equipment
- Utilizing additional information sources (road weather forecasts, RWIS, MDSS, pavement and/or vehicle sensors, etc.

All available information on the topics listed above have been included in Revised Chapter 8. Topics that had a wealth of new publications in the last ten years include:

- Environmental impacts of snow and ice control products
- Strategic methods to reduce sand usage
- Winter maintenance practices effects on mobility
- Specific stewardship practices to reduce salt, sand and chemical use (all topics listed above).
    - Updated anti-icing and pre-wetting practices.
    - Increased use of RWIS, pavement sensors, infrared thermometers, friction measurements, residual chemical measurements, MDSS, road weather forecasts, living snow fences, tools for precision application of snow and ice control products, FAST, equipment calibration, etc.
- Environmental and non-environmental performance measures for winter operations
- Training practitioners for salt management and winter maintenance operations.

Topics that had little or no new information published in the last ten years have been suggested as future research topics in Chapter 4 Suggested Research.

For DOTs, the transition to reduced salt usage has been facilitated by great improvements in 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. Many DOTs are also taking a closer look at environmentally sensitive areas, for special consideration and/or altered practices.

# Chapter 4 Conclusions and Suggested Research

## *Conclusions*

A literature review, survey and interviews were utilized to update Chapter 8, *Winter Operations and Salt, Sand and Chemical Management* of the NCHRP Report 25-25(04) *Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance*.

Revised Chapter 8 presents information on the most commonly used snow and ice control materials, recommended practices and strategic planning for reduced salt usage, highlights innovative DOT practices and programs that achieved reductions or improved environmental outcomes.

- Basic information on the most commonly used snow and ice control materials, their impacts on the environment, and public concerns on the use of these products.
- Strategic planning and stewardship practices that can be used to reduce snow and ice material usage, such as anti-icing, utilizing available pavement and weather information, etc.
- Precision application methods and material distribution systems.
- The importance of record keeping and monitoring, management at winter operations facilities, and appropriate training of winter maintenance personnel.

The identified practices, or proactive approaches, can be used alone or in conjunction with one another to reduce the amount of winter maintenance products used, lost or wasted.

## *Suggested Research*

Many of the topics presented in Revised Chapter 8 have had extensive research and publications made in the last seven years. A few topics have had limited or no new information published in the last seven years and are the basis for following suggested future research.

- Developing a consistent and sound method to determine product performance in the field.
- Identifying common performance measures in winter maintenance operations (including environmental performance measures), and developing methods to assess them.
- Conducting benefit-cost analysis for pre-wetting slurry technology, and many of the other new emerging technologies or tools.
- Developing a best practices guide on Winter Operations Facilities Management.
- Developing a best practices guide on Monitoring and Record Keeping of Winter Maintenance Operations.
- Analysis of the environmental benefits (including reducing salt use) of snow plowing, plow types and techniques, and blade types.

- Developing a current practices guide for front and side discharge spreader technologies.

# Appendix A. Survey Questionnaire & Survey Results

## *Survey Questionnaire*

### Revised Chapter 8, Winter Operations and Salt, Sand, and Chemical Management

**Introduction**

This survey is being conducted for the NCHRP 2007/Task 318. This project will revise Chapter 8, Winter Operations and Salt, Sand and Chemical Management of the report "Environmental Stewardship Practices, Procedures and Policies for Highway Construction and Maintenance" that was developed under NCHRP Project 2525/Task 4 in 2004 (link to document on http://environment.transportation.org/ website). The purpose of this survey is to gather information on effective practices that have been developed and or improved upon since the completion of the report some 7 years ago. This information will be used to prepare an updated chapter to replace the current Chapter 8 of the report. This survey will take approximately 20 minutes to complete. Survey respondents who believe they have an example of a new practice or an improvement to an older practice within the scope of Winter Operations and Salt, Sand and Chemical Management are invited to share this information in a follow-up interview. If you are interested please indicate your willingness and you will be contacted individually by the researchers. Participation is voluntary and you can choose to not answer any questions you do not want to answer and/or you can stop at any time.

1. Demographic Information
Name:
Organization:
City/Town:
State/Province:
Country:

2. Who conducts your winter maintenance operations?

- □ We conduct all of our own winter road maintenance operations
- □ We conduct some winter road maintenance operations and use contractors as well (please specify what operations are contracted out in the comment box)
- □ Contractors conduct all of our winter road maintenance operations
  Comment Box: Please specify what operations are contracted out.

3. Please check the following winter maintenance products you or your organization use (please check all that apply).

- □ Salt (solid, NaCl)
- □ Rock salt with agriculturally based liquid pre-applied at the stockpile
- □ Rock salt with other liquid pre-applied at the stockpile
- □ Brine (liquid, NaCl)
- □ Salt brine with agricultural additive

- ☐ Sand, grit or traction material
- ☐ Magnesium chloride (solid, $MgCl_2$)
- ☐ Magnesium chloride (liquid, $MgCl_2$)
- ☐ Magnesium chloride brine with agricultural additive
- ☐ Calcium chloride (solid, $CaCl_2$)
- ☐ Calcium chloride (liquid, $CaCl_2$)
- ☐ Calcium chloride brine with agricultural additive
- ☐ Agriculturally derived or bio-based (liquid)
- ☐ Agriculturally derived or bio-based (solid)
- ☐ Other (please specify)

4. How do you or your organization use the winter maintenance products checked above?

| | Salt (solid, NaCl) | Rock salt with agriculturally based liquid pre-applied at the stockpile | Rock salt with other liquid pre-applied at the stockpile | Brine (liquid, NaCl) | Salt brine with agricultural additive | Sand, grit or traction material | Magnesium chloride (solid, $MgCl_2$) | Magnesium chloride (liquid, $MgCl_2$) | Magnesium chloride brine with agricultural additive | Calcium chloride (solid, $CaCl_2$) | Calcium chloride (liquid, $CaCl_2$) | Calcium chloride brine with agricultural additive | Agriculturally derived or bio-based (liquid) | Agriculturally derived or bio-based (solid) | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anti-icing | | | | | | | | | | | | | | | |
| Deicing | | | | | | | | | | | | | | | |
| Pre-wetting | | | | | | | | | | | | | | | |
| Dry placement for traction | | | | | | | | | | | | | | | |
| Other | | | | | | | | | | | | | | | |

Other (please specify):

5. Have you or your agency/organization made any efforts in the last 10 years to reduce the amount of winter maintenance products applied during winter maintenance operations while maintaining the same or better level of service (LOS)? If so, please select all the options below that apply and state why in the comment box (e.g., a cost reduction measure, mandate for environmental purposes, to deal with corrosion of infrastructure, fleet damage, etc.).

- □ Reducing application rates
- □ Anti-icing
- □ Pre-wetting
- □ Calibrating equipment
- □ Utilizing additional information sources (road weather forecasts, RWIS, MDSS, pavement and/or vehicle sensors, etc.)
- □ Other (please specify)
- □ No

Comment box: If yes, please explain why

6. If you answered yes to the previous question, have these efforts been documented in reports, publications, or conference proceedings? If so, can you please provide a title, author name and or link to this information.

Comment box:

7. Have you or your agency/organization made any official or unofficial policy changes in the last 10 years which encourage a reduction of impacts from winter maintenance operations on the natural environment while maintaining the same or better level of service (LOS)?

- □ Yes
- □ No

Comment box: If yes or no please explain why

8. Have you or your agency implemented or modified any of the following practices in the last 10 years? If so, please check those that apply.

- □ Anti-icing
- □ Deicing
- □ Pre-wetting
- □ Product performance
- □ Nowcasting
- □ Utilizing traffic information
- □ Maintenance Decision Support Systems (MDSS)
- □ Road Weather Information Systems (RWIS)
- □ Pavement temperature
- □ Pavement sensors or thermal mapping
- □ Infrared thermometers
- □ Friction measuring devices

- ☐ Residual chemical measurements
- ☐ Precision application of products
- ☐ Fixed Automated Spray Technology (FAST)
- ☐ Salt management plan
- ☐ Staff training
- ☐ Monitoring/keep records of material use
- ☐ Design and operations of maintenance yards
- ☐ Material storage
- ☐ Brine production
- ☐ Using recycled water for brine production
- ☐ Equipment calibration
- ☐ Snow storage and disposal
- ☐ How patrol are run
- ☐ Plowing techniques

    Comment box: Other (please specify)

9. Has your organization conducted any benefit-cost analyses on any of the practices mentioned in Question 8 or on the topics of salt, sand or chemical management for winter maintenance operations? If yes, please explain the benefit-cost analyses conducted and if available the published document title and web address.

    Comment box:

10. This survey asks if you have experience using the practices listed above to reduce the impacts of products used for winter maintenance on the natural environment while maintaining the same or better level of service (LOS). In any of the answers you provided above, were the practices originally put in place for reasons other than reducing the impacts of deicers on the natural environment?
If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of a reduced impact (e.g., reducing application rate of deicers for cost savings).

- ☐ Yes
- ☐ No

    Comment box: If yes, please explain

11. Do you have an example of a new practice, or an improvement to an older practice that reduces the quantity of material applied or the impacts of winter maintenance products on the natural environment while maintaining the same or better level of service (LOS)? If so please explain and provide information on the level of implementation.

    Comment box

12. If you have an example of a new practice or an improvement to an older practice mentioned in Question 11 or in any other part of this questionnaire you are invited to

share this information in a follow-up interview. Please provide your contact information so that we can set up a phone interview to discuss this.

Please provide a brief description of the improvement you would like to share
Name
Organization
Address
City
State/Province
Country
Phone
Email

**Thank you for your participation.**

If you have any questions, comments, or additional resources please contact

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### Survey Respondents

Alberta Transportation - Canada
Arizona DOT
Arkansas Highway & Transportation Department
Caltrans (California DOT)
Connecticut DOT
Delaware DOT
Georgia DOT
Idaho Transportation Department
Illinois DOT
Indiana DOT
Iowa DOT
Kentucky Department of Highways
Maryland State Highway Administration
Michigan DOT
Michigan DOT
Minnesota DOT
Missouri DOT
Nevada DOT
New Hampshire DOT
New Jersey DOT
New York State DOT
Oregon DOT
Pennsylvania DOT
Rhode Island DOT
South Dakota DOT
Utah DOT
Virginia DOT
Vermont Agency of Transportation
State of Vermont
Wisconsin DOT
Washington State DOT

## *Survey Results*

The survey was sent to members of the American Association of State Highway Transportation Officials (AASHTO) Subcommittee on Maintenance and Standing Committee on the Environment. Thirty two responses were received (31 from the U.S. and 1 from Canada).

**2. Who conducts your winter maintenance operations?**

- □ **We conduct all of our own winter road maintenance operations**

- □ **We conduct some winter road maintenance operations and use contractors as well (please specify what operations are contracted out in the comment box)**
- □ **Contractors conduct all of our winter road maintenance operations**
- □ **Comment Box: Please specify what operations are contracted out.**

Survey respondents indicated that 53 percent conduct all of their own winter maintenance operations (Figure 1). Alberta Transportation of Canada contracts out all of their winter maintenance operations.

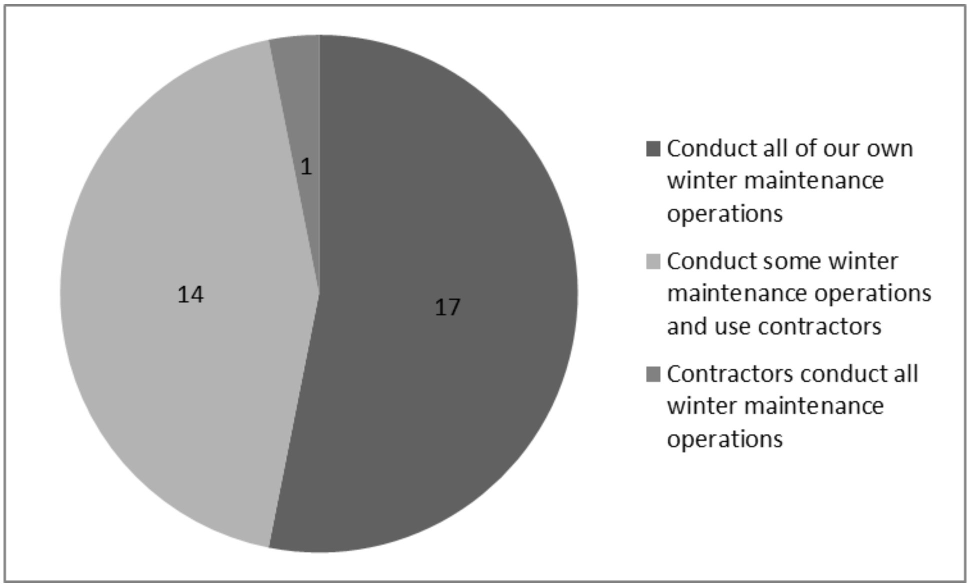


**Figure 1 Survey responses to Question 2.**

Forty four percent of survey respondents indicated they conduct some winter maintenance operations and contract out some services. The following are services that were listed as being contracted out winter maintenance services:

- Hire contractor equipment with operators to supplement agency workforce (Virginia DOT).
- Contract out routine maintenance to 66 counties and 170 cities. Have 29 of their own maintenance garages and perform routine maintenance on 25 percent of truckline (Michigan DOT).
- On some routes contract plowing and salting operations (South Dakota DOT and Maryland State Highway Administration).
- All maintenance is conducted by county highway departments under actual cost agreements (Wisconsin DOT).
- Utilize hired trucks on an hourly basis that work in conjunction with our trucks and are under our direct supervision (New Hampshire DOT).
- Use municipal contractors on some state highways, but we do not use private contractors for snow and ice control (New York State DOT).

- Use contractors support for – materials (salt, sand, and liquids), plowing, sanding, equipment repairs, loaders, and temporary stockpile covers (Rhode Island DOT).
- We contract some plowing in extreme weather events (Arkansas Highway & Transportation Department).
- Hourly rate contracts for equipment and operators to help on large storms (Missouri DOT).
- Ninety five percent plowing is by contract, 90 percent of spreading is by DOT. Most push back and cleanup work after main roads are clear is done by DOT (New Jersey DOT).
- Contract with Wyoming DOT for winter snow removal on SR-150 for about 5 miles and with Canyons Ski Resort on SF-224 where the road runs through their property – contract at their request for $0 (Utah DOT).
- Use contractors with assigned routes to plowing and spreading operations – generally in more urban areas (Pennsylvania DOT).
- MDOT is responsible for winter maintenance on nearly 32,000 lane miles. Of which 7,500 lane miles are maintained utilizing MDOT employees the remaining lane miles are maintained under contract with local agencies. MDOT has maintenance contracts with 65 county road commissions and 173 municipalities (Michigan DOT).

**3. Please check the following winter maintenance products you or your organization use (please check all that apply)?**

The most commonly used winter maintenance product is solid salt, followed by salt brine and then sand, grit or traction material (Figure 2). Liquid magnesium chloride and liquid calcium chloride were selected as being used by approximately 60 percent of respondents. The two products listed in the other category were - salt/sand mixed with potassium acetate and calcium magnesium acetate flakes for bridges.

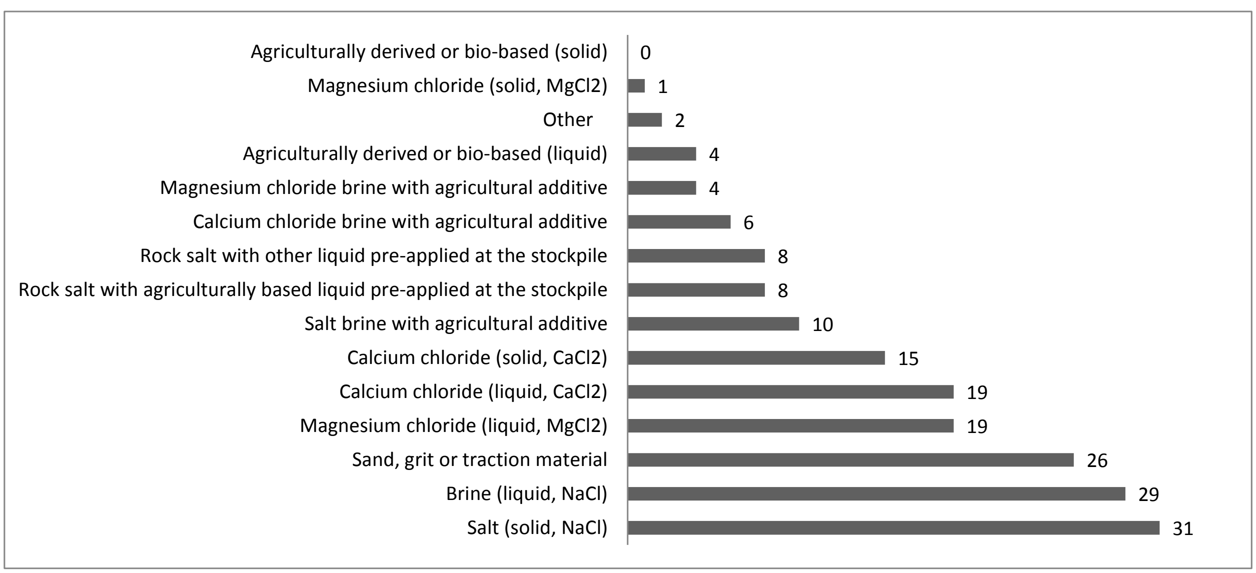


**Figure 2 Survey responses to Question. 3.**

**4. How do you or your organization use the winter maintenance products checked above?**

Survey respondents were asked what products they use for various application methods and techniques. Table 1 shows (in **bold**) for anti-icing salt brine (liquid, NaCl), for deicing salt (solid, NaCl), for pre-wetting salt brine (liquid, NaCl), and for dry placement for traction sand, grit or traction material are most commonly used by survey respondents.
Other products frequently used (in *italics*) for anti-icing included salt (solid, NaCl) and magnesium chloride (liquid, $MgCl_2$). Deicing includes rock salt with other liquid pre-applied at the stockpile, salt brine (liquid, NaCl), magnesium chloride (liquid, $MgCl_2$), calcium chloride (solid, $CaCl_2$) and (liquid, $CaCl_2$). Pre-wetting includes magnesium chloride (liquid, $MgCl_2$) and calcium chloride (liquid, $CaCl_2$).

**Table 1 Survey responses to Question 4.**

| | Salt (solid, NaCl) | Rock salt with agriculturally based liquid pre-applied at the stockpile | Rock salt with other liquid pre-applied at the stockpile | Brine (liquid, NaCl) | Salt brine with agricultural additive | Sand, grit or traction material | Magnesium chloride (solid, $MgCl_2$) | Magnesium chloride (liquid, $MgCl_2$) | Magnesium chloride brine with agricultural additive | Calcium chloride (solid, $CaCl_2$) | Calcium chloride (liquid, $CaCl_2$) | Calcium chloride brine with agricultural additive | Agriculturally derived or bio-based (liquid) | Agriculturally derived or bio-based (solid) | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anti-icing | *13* | 1 | 4 | **28** | 6 | 1 | 0 | *12* | 4 | 0 | 8 | 3 | 3 | 0 | 2 |
| Deicing | **28** | 6 | *10* | *13* | 9 | 6 | 1 | *12* | 3 | *13* | *13* | 5 | 4 | 0 | 2 |
| Pre-wetting | 4 | 0 | 1 | **21** | 6 | 1 | 0 | *14* | 5 | 1 | *10* | 4 | 2 | 0 | 0 |
| Dry placement for traction | 3 | 0 | 1 | 1 | 0 | **22** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Other | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |

Survey respondents who selected the other categories offered the following comments:

- Rock salt with liquid pre-applied is done at the contractor's facility and delivered pre-mixed. We do not treat dry salt stockpiles with liquids. Solid $CaCl_2$ used for melting frozen culverts (New York State DOT).
- Sand is used predominantly to serve as a diluting agent for solid salt so that salt application rates may be reduced (Rhode Island DOT).
- For De-icing, we use rock salt that is wetted at the spinner or when loaded into the bed, depending on if the truck is equipped with an on-board wetting system or not (New Jersey DOT).
- Using slurry technology, which is a solid salt pre-wetted with all selected liquids at high rates (Washington State DOT).
- Dry $CaCl_2$ used on some bridge decks and trouble intersections (Kentucky Department of Highways).
- The agriculturally derived or bio-based product used is potassium acetate (Nevada DOT).

**5. Have you or your agency/organization made any efforts in the last 10 years to reduce the amount of winter maintenance products applied during winter maintenance operations while maintaining the same or better level of service (LOS)? If so, please select all the options below that apply and state why in the comment box (e.g. a cost reduction measure, mandate for environmental purposes, to deal with corrosion of infrastructure, fleet damage, etc.).**

- □ **Reducing application rates**
- □ **Anti-icing**
- □ **Pre-wetting**
- □ **Calibrating equipment**
- □ **Utilizing additional information sources (road weather forecasts, RWIS, MDSS, pavement and/or vehicle sensors, etc.)**
- □ **Other (please specify)**
- □ **No**
- □ **Comment box: If yes, please explain why**

The majority of survey respondents (75 percent or greater) indicted they have implemented the strategies presented in Table 2 in the last 10 years that allow for reduced product application while maintaining or improving LOS. Two survey respondents indicated that their agency/organization has not made any efforts in the last 10 years to reduce product application while maintaining or improving LOS (Arkansas DOT and Oregon DOT). The reason Oregon DOT gave was, "*We were slow to start using deicer products and we are still increasing where we use it and how, we are not a salt state*".

**Table 2 Survey responses to Question 5.**

| | Number of respondents (n) | Percent of total (%) |
|---|---|---|
| Reducing application rates | 24 | 75 |
| Anti-icing | 25 | 78 |
| Pre-wetting | 28 | 88 |
| Calibrating equipment | 26 | 81 |
| Utilizing additional information sources (road weather forecasts, RWIS, MDSS, pavement and/or vehicle sensors, etc.) | 24 | 75 |
| Other | 3 | 9 |
| No | 2 | 6 |

Survey respondents who selected the other category provided the following comments:

- We have started shifting to more brine usage, when applicable we use much less rock salt and are getting the same or better results (Caltrans).
- These are all best practices for us. Our state is a leader in MDSS and RWIS (Minnesota DOT).
- Reducing speed of trucks while applying deicing material yields significant savings (Michigan DOT).

- These items were done in an effort to address all of the items that you mention (Cost reduction, environmental, corrosion reduction, etc.) (South Dakota DOT).
- Implemented MDSS statewide and are in the process of equipping all trucks with AVL/GPS (Wisconsin DOT).
- Mandated by Environmental Protection Agency (EPA)/ Department of Environmental Services (DES) in one location as well as a cost savings in other locations (New Hampshire DOT).
- The primary purpose for the reductions was environmental stewardship (Maryland State Highway Administration).
- Cost reduction measures and to reduce chemical infiltration into the environment (New York State DOT).
- To reduce operating costs and reduce adverse environmental impacts of chlorides and sand (Rhode Island DOT).
- We are using new technologies to help keep our LOS (or make it better) for the same costs. Using equipment such as the tow plow (State of Vermont).
- These strategies have been employed primarily for cost control. The environmental benefits and reduced corrosion of infrastructure and fleet has also been a benefit (Missouri DOT).
- Historically we have used a large quantity of sand/grit for traction. We are now transitioning to greater efforts of anti-icing using chlorides in lieu of sand/grit resulting in a reduction of the application of solid materials from our spreaders. Additionally, as we transition to a greater use of chlorides, we are now using RWIS and weather forecasts to provide us with data for using these products at the right time (Idaho Transportation Department).
- Our expected LOS has risen. In order to adjust, we have actually increased our application rates, frequency and time of application (New Jersey DOT).
- Costs (Delaware DOT)
- To more efficiently manage personnel and materials (Kentucky Department of Highways).
- Reduce application rates to save money and protect the environment, only use the minimum needed. Anti-icing is done to help prevent the bond of snow and ice to the pavement and for frost and black ice prevention. Pre-wetting allows us to use less material because wet material has less bounce keeping more material on the road and moisture is needed to activate the salt which aids in removing the snow and ice quicker. We calibrate every year and throughout the year as needed. We use RWIS and MDSS as well as vehicle mounted sensors. Pavement temperature is the key into understanding application rates and how well the material will perform (Indiana DOT).
- Applying brine and or magnesium chloride to roadway before the onset of storm. Changed our mixing of salt and sand from 5-to-1 to 3-to-1 (Nevada DOT).
- Using straight salt in place of premix (1:1 Salt/Grit) as standard application. Net salt use has been reduced. We also use slurry spreaders and directional spreaders on mountain passes to keep climbing lanes at a higher LOS so that trucks spin out less often (Utah DOT).

- We have moved from reactive to proactive winter maintenance strategies, such as anti-icing, in an effort to reduce the amount of effort and materials required to maintain our roadways during winter storms (Pennsylvania DOT).
- MDOT has implemented all of the above methods to reduce costs and/or improve level of service for winter maintenance (Michigan DOT).

From the comments provided by survey respondents cost saving (n=10) and then reducing the impacts to the environment (n=5) were most commonly stated as the reason for change.

**6. If you answered yes to the previous question, have these efforts been documented in reports, publications, or conference proceedings? If so, can you please provide a title, author name and or link to this information.**

Michigan DOT – Bounce and scatter of salt at various application speeds. 2012. (http://www.michigan.gov/documents/mdot/Final_ReportNov2012_404228_7.pdf)
Agricultural By-Products For Anti-icing and Deicing in Michigan, Steve Kahl, 2002. (http://www.michigan.gov/documents/mdot/MDOT_Research_Report_R1418_245018_7.pdf)

Calibration Accuracy of Manual and Ground-Speed-Controlled Salters, Blackburn and Associates, Final Report for Clear Roads, 2008 (http://clearroads.org/research-projects/05-02calibration.html)

No accumulation, SDDOT cuts winter tools and remains effective. Greg Fuller – Feb. 2011 Roads and Bridges Magazine (http://www.roadsbridges.com/sites/default/files/48_sddot%20winter%20maintenance%200211RB.pdf).

Cost and Benefit Study Associated with Outsourcing Roadway Maintenance Activities, Halcrow, Inc. and Asset Management Associates, A final report for Nevada DOT, 2011. (http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&ved=0CCMQFjAB&url=http%3A%2F%2Fwww.nevadadot.com%2FAbout_NDOT%2FNDOT_Divisions%2FOperations%2FMaintenance%2FHalcrow_NDOT_Cost_and_Benefit_Study_Associated_with_Outsourcing_Roadway_Maintenance_Activities.aspx&ei=CFaZULLsDozQigKPi4GIBg&usg=AFQjCNGmdJQJkPtbHWC_B_IvsWmVnmwp8Q)

Integrating Maintenance Management Systems with Maintenance Decision Support System, Paul Pisano, William Hoffman and Andrew Stern, Transportation Research Circular – Miantenance Management 2009, Presentation from the 12th AASHTO-TRB Maintenance Management Conference. July 2009 (pg. 245) (http://onlinepubs.trb.org/onlinepubs/circulars/ec135.pdf).

**7. Have you or your agency/organization made any official or unofficial policy changes in the last 10 years which encourage a reduction of impacts from winter**

**maintenance operations on the natural environment while maintaining the same or better level of service (LOS)?**

- □ Yes
- □ No
- □ Comment box: If yes or no please explain why

Fifty percent of the survey respondents replied yes (n=16), while approximately 40 percent replied no (n=13), three did not respond to the question. 50 percent of responding agencies have made official or unofficial policy changes to reduce the impacts of winter maintenance products on the natural environment, implying a more holistic view of the pros and cons of winter maintenance products. However, the number of negative responses shows there is still a need to further educate the agencies/ organizations on not only the pros of winter maintenance products, but also the cons and how this impacts the agencies/organizations – financially, etc. The following comments were provided by survey respondents in Table 3 and Table 4.

**Table 3 Survey respondent comments for Question 7 who answered in the affirmative.**

| | | |
|---|---|---|
| Michigan DOT | Yes | We are encouraging everyone to prewet and calibrate their equipment. We have encouraged all garages and contract agencies to utilize liquids for prewetting and anti-icing. We have also stressed the importance of spreader equipment calibration |
| Oregon DOT | Yes | We started using liquid mag chloride to reduce the amount of sanding material that was entering the streams and for air quality |
| New York State DOT | Yes | Reduced initial salt application rates for snow events by 10% statewide |
| Rhode Island DOT | Yes | Installation of closed loop spreader calibration controls in 2012 for State equipment and introduction of vendor incentives for installing similar equipment |
| Missouri DOT | Yes | Our strategies to reduce application of salt has reduced the impact on the natural environment |
| Washington State DOT | Yes | Established policy that all solid salt applications will be pre-wet with a minimum of 10 gallons per ton of inhibited liquid anti-icers. This encourages better application performance and lessens corrosion |
| Indiana DOT | Yes | We continue to monitor materials and test the effects that they have on the environment and we continue to look for cost effective ways of providing a safe and adequate level of service |
| Nevada DOT | Yes | The use of brine before storms |
| Utah DOT | Yes | We have reduced grit use at temperatures above 20 deg F to limit pm10 and pm2.5 emissions. We consciously changed deicing practice to use non-NaCl agents in watershed canyons. We have built stockpile runoff retention basins at all our facilities to prevent salt-laden discharges in the environment. We have built 75 salt storage buildings (20 more are needed for 100% dry storage) to reduce stockpile leaching |
| Pennsylvania DOT | Yes | We implemented our Strategic Environmental Management Program (SEMP) as part of our ISO registration. The program has 6 primary principles designed to protect the environment, prevent pollution and use resources efficiently, follow sound environmental practices in all activities, comply with requirements, continually improve, and provide measurable benefits |

| | | |
|---|---|---|
| Alberta Transportation | Yes | Use of Pre-wetting and limited use of Anti-icing at ring roads |

**Table 4 Survey respondents comments for Question 7 who answered in the negative.**

| | | |
|---|---|---|
| Wisconsin DOT | No | The environment is always a consideration but the current political forces are placing higher priorities on keeping traffic flowing under all conditions |
| New Hampshire DOT | No | Changes to application rate while keeping the same LOS typically requires a financial commitment that currently is not available. We have used some earmarked funds in specific locations but regular funding does not support wholesale changes |
| New Jersey DOT | No | Cost prohibitive |
| Iowa DOT | No | Not specifically for natural environment |

**8. Have you or your agency implemented or modified any of the following practices in the last 10 years? If so, please check those that apply.**

- □ **Anti-icing**
- □ **Deicing**
- □ **Pre-wetting**
- □ **Product performance**
- □ **Nowcasting**
- □ **Utilizing traffic information**
- □ **Maintenance Decision Support Systems (MDSS)**
- □ **Road Weather Information Systems (RWIS)**
- □ **Pavement temperature**
- □ **Pavement sensors or thermal mapping**
- □ **Infrared thermometers**
- □ **Friction measuring devices**
- □ **Residual chemical measurements**
- □ **Precision application of products**
- □ **Fixed Automated Spray Technology (FAST)**
- □ **Salt management plan**
- □ **Staff training**
- □ **Monitoring/keep records of material use**
- □ **Design and operations of maintenance yards**
- □ **Material storage**
- □ **Brine production**
- □ **Using recycled water for brine production**
- □ **Equipment calibration**
- □ **Snow storage and disposal**
- □ **How patrols are run**
- □ **Plowing techniques**
- □ **Comment box: Other (please specify)**

Figure 3 shows practices that have been implemented or modified by agencies/organization in the last 10 years. The ten most common practices (outlined in the red box) that have been implemented or modified by agencies/organization are:

- Anti-icing
- Pre-wetting
- RWIS
- Brine production
- Staff training
- Monitoring/keeping records of maintenance
- Pavement temperature
- Equipment calibration
- Deicing
- Material storage.

Other practices that were mentioned by survey respondents include: TowPlows (Wisconsin DOT), Automatic Vehicle Location (AVL) technology (Arizona DOT), and road condition cameras in remote, hard to observe locations (Utah DOT).

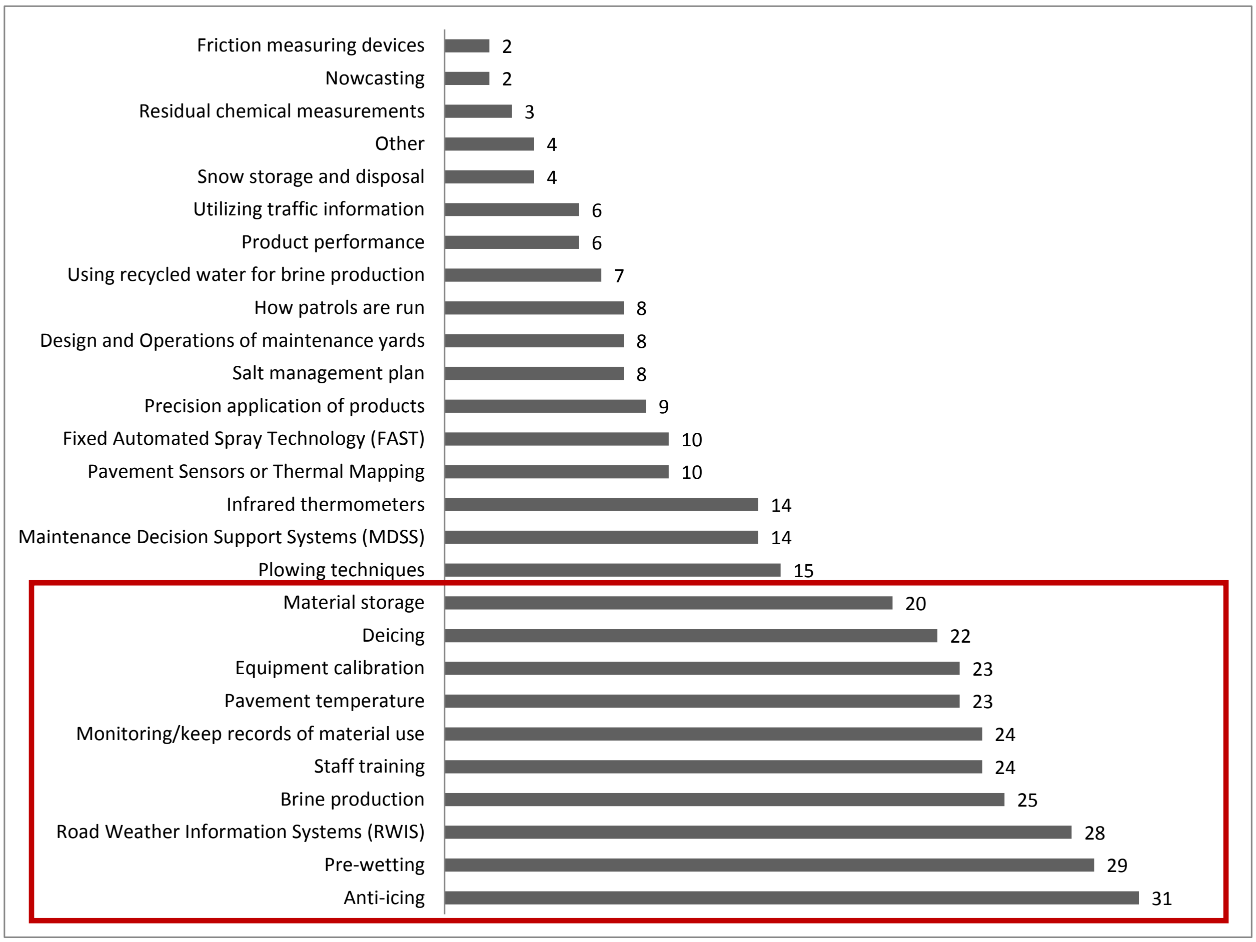


**Figure 3 Survey responses to Question 8.**

**9. Has your organization conducted any benefit-cost analyses on any of the practices mentioned in Question 8 or on the topics of salt, sand or chemical management for winter maintenance operations? If yes, please explain the benefit-cost analyses conducted and if available the published document title and web address.**
This question was left blank by almost 50 percent of the survey respondents (n=14). Of the survey respondents that did provide an answer there were seven negative responses. Six survey respondents indicated their agency/organization had done internal benefit-cost analysis, but this information has not been published.

Michigan DOT – previously sent, look up.

Wisconsin DOT – MDSS & TowPlows

Analysis of Maintenance Decision Support System (MDSS) Benefits & Costs, Study SD2006-10 Final Report. May 2009. Western Transportation Institute and Iteris, Inc. (http://www.meridian-enviro.com/mdss/pfs/files/WTI-4W1408_Final_Report.pdf)

Evaluation of Performance of Automatic Vehicle Location and TowPlow for Winter Maintenance Operations in Wisconsin, Kelvin Santiago-Chaparro, Madhav Chitturi, Todd Szymkowski, and David Noyce. Transportation Research Record: Journal of the Transportation Research Board, No. 2272, Transportation Research Board of the National Academies, Washington, D.C., 2012, pg. 136-143. (http://trb.metapress.com/content/f467np14kl7151q6/fulltext.pdf)

TowPlow, Closeout Report Submitted by the AASHTO TIG Lead States Team, March 6, 2012 (http://tig.transportation.org/Documents/TowPlow/TowPlow-Team-Closeout-Report.pdf)

Rhode Island DOT – Closed loop spreader controls & Salt brine

Cost-Benefit Toolkit Phase II-WTI (status)

New Jersey DOT – FAST system

**10. This survey asks if you have experience using the practices listed above to reduce the impacts of products used for winter maintenance on the natural environment while maintaining the same or better level of service (LOS). In any of the answers you provided above, were the practices originally put in place for reasons other than reducing the impacts of deicers on the natural environment? If yes, please explain the original reason for installation or implementation and explain how it has the secondary benefit of a reduced impact (e.g. reducing application rate of deicers for cost savings).**

- □ **Yes**
- □ **No**

□ **Comment box: If yes, please explain**

Sixty six percent (n=21) responded yes, the practices used by agencies that reduce the impacts of winter maintenance products on the natural environment were originally put in place for other reasons. Comments provided for affirmative responses can be found in Table 5. Over 50 percent of the respondents stated that at least part the original reason the practice was put in place was due for cost saving purposes.

**Table 5 Comments provided by survey respondents with affirmative answers.**

| | | |
|---|---|---|
| Virginia DOT | Yes | Improved effectiveness in snow removal and road clearing operations. |
| Caltrans | Yes | The brine was put into place as an anti-icer but have found to be a great new tool in deicing as it starts to work immediately not having to put in the moister first to start the melting process using less salt was a plus not the reason we went to it. |
| Michigan DOT | Yes | To reduce winter maintenance expenses. |
| South DOT | Yes | Primarily, the changes were made to reduce costs. A secondary benefit was benefits to the environment |
| Wisconsin DOT | Yes | Everything we do is in an attempt to maintain the same LOS with less cost. |
| Oregon DOT | Yes | Storing the product with a containment system in case the tank or fittings break, and training and calibration of equipment helps to make sure we use the minimum amount that is effective |
| New York State DOT | Yes | Cost savings due to budget constraints. |
| Illinois DOT | Yes | Cost saving |
| Rhode Island DOT | Yes | Reducing application rate of deicers for cost savings. |
| State of Vermont | Yes | Trying to maintain the same LOS within the rising costs to do business. |
| Missouri DOT | Yes | The original reason for these changes was to reduce costs and reduce the amount of material that was being wasted i.e., blown or bounced off the roadway onto the shoulder. |
| Idaho Transportation Department | Yes | New practices were implemented as a measure to reduce overall costs. |
| Arizona DOT | Yes | Improve the LOS. |
| New Jersey DOT | Yes | Safety of the motoring public and efficiency of operation. |
| Delaware DOT | Yes | Costs |
| Washington State DOT | Yes | Pre-wet policy originally intended to address corrosion. Superior performance was a secondary benefit. |
| Iowa DOT | Yes | More so for resource allocations and efficiencies. |
| Indiana DOT | Yes | Lowering the overall operational cost. |
| Nevada DOT | Yes | Went from the use and production of brine, from a department built system to a new automated system and from gravity feed spray system on water trucks to using a spray tonic insert tank in a 10 wheel truck that is calibrated. |
| Utah DOT | Yes | Original reason for cameras - reduce overtime and off-hour callouts. Operators are less likely to put out product if they are not on the road. They do not like unloading their trucks when they come back full. |

# Appendix B. Case Study Interviews

Interviews were conducted based on information provided in the survey. Six interviews were conducted on varying topics and are presented below.

*Iowa DOT Salt Model*

The Iowa DOT developed a salt model to allocate salt to garages based on weather conditions and policy usage requirements (personal communication, A. Dunn, October 23, 2012). They needed a way for field personnel to understand how much salt they used. To accomplish this, Iowa DOT developed an algorithm that looked at the past five years of weather information at the garage level, specific parameters from the two closest RWIS stations to each garage, as well as garage lane-miles and LOS, precipitation type and start and end times, snow fall estimates, salt usage, salt ordered and salt received, and actual hours. They used this information to create a *salt budget* for each garage. Each garage is then allowed a certain amount salt for the season and if they need more they have to justify why to the central office. Any excess salt is kept for the next year.

Iowa DOT also developed an easy-to-use dash board, or user interface, that shows how much salt each garage has used versus what the algorithm predicted. This allows Iowa DOT to track how much salt they have at each garage, how much salt was purchased and how much was used. This newly developed tool is designed to assist field management staff in monitoring their salt usage. The dashboard allows for closer management of resources with outcomes and targets.

*Kentucky Department of Highways Salt Matrix and Pre-set Spreader Application Rates*

Kentucky Department of Highways developed a salt matrix to reduce application of salt while maintaining the same or better level of service (LOS) (personal communication, M. Williams, October 25, 2012). The developed salt matrices consider the pavement temperature and the heating or cooling trend, the road condition at the time of service, available maintenance strategies/actions, and provide recommended applications for liquid and solid products for both the initial treatment and subsequent treatments for four storm scenarios (light snow, moderate snow, heavy snow, and freezing rain). Reference sheets of the salt matrices are provided to county foremen.

Currently they are using a commercially available pre-wet solid product spreader system that is pre-set at four application rates (200, 400, 600, and 800 lbs/l-m). The drivers then use their judgment and the provided salt matrices to determine which application rate is needed for the given conditions.

*Kentucky Department of Highways Participation in the MDSS Pooled Fund Project*

The Kentucky Department of Highways is entering into its fourth year as a participant in the Maintenance Decisions Support System (MDSS) pooled fund study. Kentucky Department of Highways tested MDSS in the Lexington and Northern Kentucky areas and is currently expanding its use to include three sample routes within each of its 12 Highway districts. The MDSS tool provides a pavement level weather forecast for specific road segments and can help to identify the probability of bridge frost. In

addition, the MDSS program will assist managers with the task of deciding when to activate personnel to respond to an approaching winter event.
To utilizing the MDSS forecasts and treatment recommendations, they will have AVL units on approximately 120 trucks that will transmit plow status, pavement and air temperature, and application rate information.

*Washington State DOT and Maine DOT Salt Spreader Slurry Technology*
Salt spreader slurry technology is essentially pre-wetting at a high ratio 70/30 percent (solid/liquid). This works out to be approximately 200 lbs/l-m of solid with 9 gal of liquid added. The slurry comes out with an oatmeal consistency. The solid salt grains are extremely saturated with this technique because the liquid is introduced at multiple locations. In the case of WSDOT the commercially available equipment adds liquid at multiple locations in the truck bed using an auger and at the spinner. WSDOT has observed the slurry going into action much quicker on the road, acting immediately and lasting longer on the road (up to 5 days under the right conditions) (personal communication, M. Mills, October 10, 2012).
Maine DOT utilized existing equipment and retrofitted their trucks with a similar system they made in-house (personal communication, B. Burn, October 10, 2012). With the in-house developed product Maine DOT has not been able to achieve the full extent of the commercially available products. Maine DOT published an evaluation of six retrofit designs and determined the approximate cost to be $7500 (2006 US dollars) per unit (Maine DOT, 2007). Maine DOT found an average savings of 7.8% per mile in product, with estimated cost savings of $1329 per unit when comparing the slurry system to control vehicles. Interviewed employees stated that they found the 70/30 slurry mix to out-perform typical pre-wetting methods (liquid application of 6, 8, or 10 gal per ton) while also minimizing bounce and scatter of product. Crews also stated that using a "heavier application on the first application followed by smaller applications", worked best and allowed for product savings. Crews also stated the importance of getting out early in the storm.

*Colorado Department of Transportation*
Friction measurements have been identified as an indicator of road condition that can be used to measure performance (Maze *et al*., 2007; Fay *et al*., 2010). Colorado DOT is currently testing the use of non-contact friction measuring devices to assess winter maintenance product performance (personal communication, P. Anderle, March 22, 2012). Since installation on traffic poles CDOT personnel have noticed an initial performance difference between winter maintenance products, as well as a difference in bare pavement regain time. Bare pavement regain time is the performance measure used by Colorado DOT to assess product performance and is an assessment of longer term product performance. This suggests that the non-contact friction measurements provide a good estimate of both short and long term product performance. Based on these results, CDOT has been able to reduce winter maintenance product application rates for one of the products and still satisfy the bare pavement regain time performance measure that is targeted for CDOT's current funding level. Similar research is being conducted at four other sites in the US and Canada (personal communication, J. Trujillo, December 13, 2012).