Synthesis of Material Application Methodologies for Winter Operations

Washington State University

CLEAR ROADS
research for winter highway maintenance

Project 1001326/CR15-01
April 2019

Pooled Fund #TPF-5(218)
www.clearroads.org

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
CR15-01		

4. Title and Subtitle	5. Report Date
Synthesis of Material Application Methodologies for Winter Operations	April 2019
	6.

7. Author(s)	8. Performing Organization Report No.
Sen Du, Michelle Akin, Dave Bergner, Gang Xu, Xianming Shi	

9. Performing Organization Name and Address	10. Project/Task/Work Unit No.
Washington State University 405 Spokane St, Sloan 101, PO Box 755900 Pullman, WA 99164	TPF-5(218)
	11. Contract (C) or Grant (G) No. MnDOT No 1001326

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
Clear Roads Pooled Fund Study Lead State: Minnesota Department of Transportation Research Services & Library 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899	Final Report [April 2016 – April 2019]
	14. Sponsoring Agency Code

15. Supplementary Notes

Project completed for Clear Roads Pooled Fund program, TPF-5(218). See http://clearroads.org/ Project 15-01

16. Abstract (Limit: 250 words)

Winter roadway operations, commonly known as snow/ice control operations, are one of the most critical functions of state, provincial and local transportation agencies in cold regions. These operations aim to provide safety and mobility by timely and effective application of materials and plowing. The most common materials used are salt (sodium chloride, solid and brine), magnesium chloride-based, and calcium chloride-based deicers, agro-based additives and blends, and abrasives, with the specific choice and application method and rate dependent on temperature, precipitation type, level of service goals, budget, and environmental sustainability. Best practices of material application are designed to *apply the right type and amount of materials in the right place at the right time.* A companion document to this report, the "Material Application Methodologies Guidebook," synthesizes the use of materials, including application strategies, application rates, and application equipment. This report documents the literature review and agency interviews that were conducted to assemble the information for the Guidebook.

17. Document Analysis/Descriptors	18. Availability Statement
Winter Maintenance; Deicing; Anti-icing; Pre-wetting; Application Rates; Winter Operations Guidelines	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	108	-0-

SYNTHESIS OF MATERIAL APPLICATION METHODOLOGIES FOR WINTER OPERATIONS

FINAL REPORT

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April 2019

Published by:

Minnesota Department of Transportation
Research Services & Library
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of the Clear Roads Technical Advisory Committee for providing review, input, and comments on all tasks. A special thank you goes to Greg Waidley, the project coordinator from CTC & Associates. We would also like to thank all the states and agencies for their cooperation and sharing their experience during the interviews, and providing agency guidelines, documents and photographs.

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EXECUTIVE SUMMARY

Winter roadway operations, commonly known as snow/ice control operations, are one of the most critical functions of state, provincial and local transportation agencies in cold regions. These operations aim to provide safety and mobility by timely and effective application of materials and plowing. The most common materials used are salt (sodium chloride, solid and brine), magnesium chloride-based, and calcium chloride-based deicers, agro-based additives and blends, and abrasives, with the specific choice and application method and rate dependent on temperature, precipitation type, level of service goals, budget, and environmental sustainability. Best practices of material application are designed to *apply the right type and amount of materials in the right place at the right time.* A companion document to this report, the "Material Application Methodologies Guidebook," synthesizes the use of materials, including application strategies, application rates, and application equipment. This report documents the literature review and agency interviews that were conducted to assemble the information for the Guidebook.

CHAPTER 1: INTRODUCTION

Winter roadway maintenance agencies are continually challenged to provide a high level of service (LOS) and ensure safety and mobility in a cost-effective manner. Adopting best practices of material selection and application provides optimized material usage, more efficient operations, reduced cost and reduced environmental and corrosion/infrastructure impacts. Winter events present a variety of weather and pavement conditions that require various strategies, often a combination of mechanical removal, anti-icing, deicing and sanding to maintain the desired LOS of the roadway. Specifically, these best practices mean *applying the right type and amount of materials in the right place at the right time.*

As winter roadway operations have significantly improved over the past several decades, existing guidelines need updating with the latest information, especially regarding the increasing awareness and concerns of the negative impacts from winter maintenance materials (e.g., chloride-loading). This necessitates a new look into the methodologies and application rates of solid salt, salt brine, and other products used for snow and ice control operations. While under-applying salt could result in failing to achieve the desired LOS, over-applying salt leaves excessive residue on pavements therefore increasing the chloride content of roadside surface and groundwater and the corrosion of infrastructure.

Improvements in winter operations are due in large part to advances in the science and technology of materials, equipment, and weather forecasting. These include: state-of-the-art controllers, spreading systems, road weather information systems (RWISs), hydraulic components, weather forecasting systems, new deicing chemicals such as enhanced chloride blends and non-chlorides (e.g., agro-based products), fixed automated spray technology (FAST) systems, liquid-only plow routes, and slurry technology. During and post-storm treatment with liquids, in lieu of solid applications, is gaining momentum. New on-truck tools (e.g., zero velocity spreaders, modified spinners, and other delivery mechanisms) facilitate precise and effective applications of both solid and liquid materials. Advanced systems are available that use input from pavement surface condition sensors (friction, temperature, salinity etc.) to adjust the amount of material being applied “on the fly,” resulting in cost and environmental benefits. In addition, more accurate weather forecasting, automatic vehicle location (AVL) systems that track when and where trucks are plowing and spreading, and better knowledge and training on snow/ice control methods and practices greatly improve when and how materials are applied. The Federal Highway Administration (FHWA) developed the winter road maintenance decision support system (MDSS) to provide objective route-specific forecasts and treatment recommendations (Petty and Mahoney 2008).

Significant research has been conducted over the last several decades and has resulted in a wealth of information related to winter maintenance materials and application methodologies. Additionally, many agencies (DOTs and city/county road departments) have developed in-house material application rate guidelines based on their local, practical experiences. A companion document to this report, “Material Application Methodologies Guidebook” provides specific recommendations for conducting winter maintenance operations. This report provides the results of the tasks undertaken to develop the

Guidebook, including a literature review (Chapter 2) and interviews with winter maintenance personnel (Chapter 3).

CHAPTER 2: LITERATURE REVIEW

Winter road maintenance (WRM) is one of the most critical responsibilities of state departments of transportation (DOTs) in cold climates. Such maintenance operations often involve various strategies to improve the level of service (LOS) on roadways, such as plowing, deicing, anti-icing, sanding, and snow fencing. Generally, a combination of these strategies is adopted by transportation agencies, aiming at assuring the safety, mobility and productivity of roadways during winter weather. Among these strategies, the application of materials (chemicals or abrasives) plays a very important role. Best practices of material application aim to apply the right type and amount of materials in the right place at the right time, thus achieving an appropriate LOS under the given road weather scenarios with reduced cost and negative impacts. To this end, it is desirable to use the most recent advances in the selection and application of materials.

Currently, there is an urgent need to synthesize the renewed knowledge and localized agency experience in the use of chlorides, non-chlorides, and their blends. Common chemical products used for WRM operations include freezing point depressants with **chloride** (e.g., sodium chloride – NaCl, magnesium chloride – $MgCl_2$, and calcium chloride – $CaCl_2$), as well as non-chloride products such as **acetates** (e.g., calcium magnesium acetate – CMA and potassium acetate – KAc) and **agro-based byproducts** (e.g., proprietary products from beet, corn, beer brewing or cheese making). Application strategies include anti-icing (treating roads before snow falls) and deicing (during and post-snowfall so plows can effectively remove snow). **Anti-icing** is usually performed with liquid products, but prewet salt can also be used. **Deicing** is the most common strategy, and usually needed during most storms even if anti-icing is performed. Dry and prewet salt are the most common materials used but direct liquid application can also be used effectively, such storms with warmer temperatures and light snow fall and on routes with shorter cycle times (Peterson et al. 2010). **Prewetting** uses liquid chemical to prewet solid deicers or abrasives at the spinner just before application onto the road.

Approximately 70% of the US roads are located in snowy regions, with nearly 70% of the US population living in these regions (FHWA 2013). As such, great demand exists for effective strategies and tactics of winter road maintenance. In the last two decades, many regions have transitioned from wider use of chemicals instead of abrasives, and using anti-icing to reduce overall chemical usage and provide greater levels of service (Staples et al. 2004; Cui and Shi 2015). At extremely low temperatures (5°F and lower) plowing, sanding, and high salt applications tend to be used, despite poor performance of salt at low temperatures (Akin et al. 2013).

2.1 FACTORS THAT AFFECT MATERIAL APPLICATION

The key of WRM material application is to apply the right amount of the right material, in the right place and at the right time (TAC 2013). Many inter-related factors influence the choice or timing of material application, including: level of service (LOS), climatic conditions and predominant weather patterns, traffic, material cost, material availability, environmental concerns, corrosion to fleet and infrastructure, training, etc.

Providing a high LOS to the traveling public is a key objective for WRM operations (Veneziano et al. 2014). LOS in this context is a set of operational guidelines and procedures that establish the timing, type, and frequency of treatments. Clear specification of LOS requirements is an essential part of any salt management plan (SMP), as such requirements balance the need to maintain safe conditions for roadways against the economic, infrastructure and environmental effects of salting. At different highway sections, various maintenance actions are deployed to achieve specific pavement condition goals (Blackburn et al. 2004). Application rates will vary according to the winter storm temperatures, desired LOS, and application methods. Generally, application rates tend to increase as temperatures decrease or LOS increases. Application rates for deicing tend to be lower if either anti-icing was performed or prewet material is being applied (City of Toronto 2016; Minnesota Pollution Control Agency 2016). Low LOS goals or low temperatures may preclude the use of anti-icing (City of Brockville 2018).

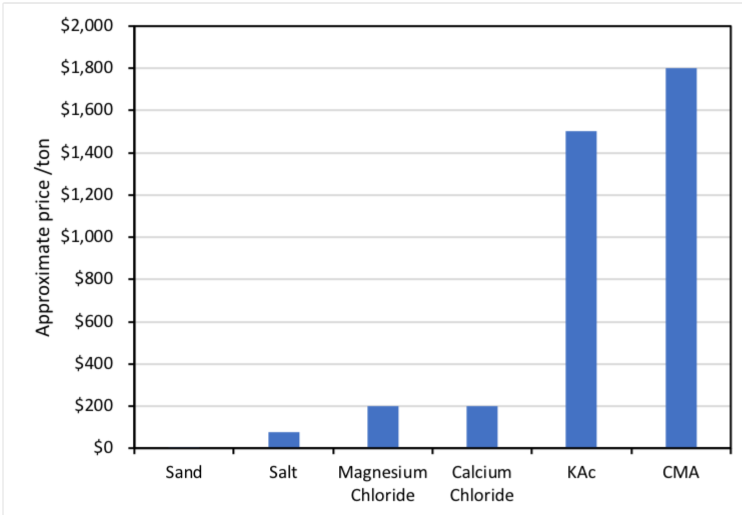
The climatology of a particular area defines the historical average of the type and amount of precipitation that can be expected during a typical winter (Blackburn et al. 2004). More importantly for WRM operations, the distribution of winter precipitation types in an area should be considered. Weather can be characterized by describing the meteorological elements associated with the storm events (Blackburn et al. 2004), such as precipitation type and amount, visibility, wind speed and direction, temperature, relative humidity, etc. For example, maintenance operations used in the early stage of a storm typically need to be modified during the course of the storm. Material application in a light snowfall interspersed with heavy snowfalls should differ from that in a single snowfall (Ketcham et al. 1996). Wind is another main weather pattern that influences the material application. Experience has shown that it is important to adjust the sprayer closer to pavement to achieve a desirable material application during windy conditions (Ketcham et al. 1996). If wind causes blowing and drifting snow to cross the road, then anti-icing should not be performed because the blowing snow will stick to the road instead of blowing across.

Understanding road weather is important for successful winter material application. Weather forecasting services can provide forecasts through using road-based information (TAC 2013). Precipitation can take many forms during winter storms, such as snow, frost, freezing rain, black ice, and sleet (MnDOT 2010). Black ice is a thin and clear layer of ice which forms on a non-frozen pavement surface when the air temperature is slightly below freezing (about 30°F). Freezing rain will cause a hard and generally thick layer of ice on pavement through liquid precipitating on the pavement with temperature below freezing (Blackburn & Associates 2014). Using the best available weather data is critical for the maintenance authority to choose materials effective for the local road temperatures, determine the best application methodology, and to plan for appropriate bulk materials for the anticipated season (Dindorf and Fortin 2014).

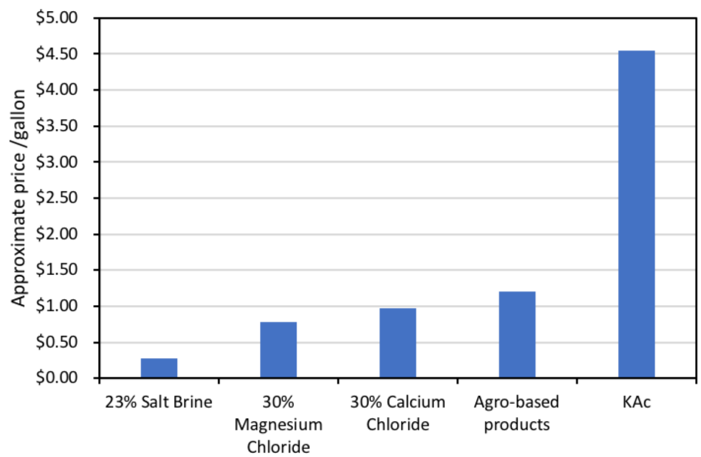
Traffic considerations include those related to operational difficulty and timing, as well as treatment effectiveness and longevity (Blackburn et al. 2004). For anti-icing, traffic rate and traffic volume may affect the longevity of the chemical product on pavement. It was reported that anti-icing operation with liquid product can be successful in both high-volume rush-hour traffic and low-volume middle-of-night traffic (Ketcham et al. 1996). When solid chemicals and abrasives are applied before precipitation, however, traffic can cause materials to be blown, scattered, and transported from the pavement surface (Blackburn et al. 2004). Conceptually, traffic can be beneficial for deicing operation. Specifically, traffic-related agitation can facilitate the melting of ice by the chemical product and subsequent penetration and undercutting of the ice layer by the liquid, helping to break the bond of ice (or compacted snow) to pavement.

Cycle time is primarily a function of number of personnel and amount of equipment available to treat the assigned roadway system (Blackburn et al. 2004). Longer cycle times allow more precipitation to accumulate on the roadway between treatments; as such, they would require more chemical to be applied to achieve equivalent effectiveness. Particularly, compared with salt brine alone, agro-based products were found to stay on the road surface longer, which therefore improve the ability to prolong performance of deicers and allow a longer cycle time (Muthumani et al. 2017). Too short cycle times may cause material to be plowed from the road before deicer penetration and undercutting sufficiently weakens compacted snow.

The cost and availability of materials often play an important role in the selection of material application methodology for WRM operations. Figure 1 illustrates the up-to-date approximate average price of commonly used snow and ice control materials using the data from the literature search and personal communications, details of which are included in APPENDIX A: Direct cost for various solid and liquid materials. These are only one aspect of the direct cost (purchase price) of materials, which is highly dependent on local availability and transportation costs. Other considerations regarding material type include operational costs (labor and equipment) and application rates. For example, sand has the lowest purchase price, but factoring in the higher application rate means more material needs to be purchased and more labor and equipment hours are needed to apply it (and clean it up in the spring)– all of which increase the total direct cost of sand. A Washington State DOT study demonstrated with several case studies that traditional deicing operations using sand/salt mixture costs 3 to 12 times more than an anti-icing operation using liquid $MgCl_2$ and provides worse road conditions (Dye et al. 1996). Moreover, the overall cost of applying materials on the road should be considered, which includes the direct costs for material, labor and equipment, and indirect costs associated with damage to the environment, vehicles and infrastructure caused by the applied material. For example, the overall cost of salt was estimated up to $1,026/ton while the direct cost for salt was only $73/ton in Twin Cities Metro Area in Minnesota (Dindorf and Fortin 2014).



(a)



(b)

Figure 1: Approximate price of snow and ice control materials: (a) solid and (b) liquid (actual price depends on local availability and transportation costs).

While providing many benefits to winter traffic mobility, once the snow and ice control materials leave the roadway they can pose negative impacts on the natural environment, particularly with respect to surface water, groundwater, soil, vegetation, aquatic biota, and wildlife (Fischel 2001). Abrasives impact the environment mainly through air pollution caused by PM-10 particles and water pollution by increased turbidity and reduced oxygen concentration in water bodies (Staples et al. 2004). In contrast, chloride salts impart different impacts to the environment, through rising concentration of chlorides and the associated cations (Na^+, Mg^{2+}, Ca^{2+}) in water bodies and soils, mobilization of heavy metals, impacts to roadside vegetation, and wildlife (Fay and Shi 2012). It is believed that 10–60% of the applied road salts enter shallow subsurface waters (Environment Canada 2002). The gradual increases in sodium (Na^+) and chloride (Cl^-) concentrations by 130% and 243%, respectively, measured in a New York river over a fifty-year study period are attributed to deicing salts (Goodwin 2003). Higher Na^+ and Cl^- concentrations in lakes have been observed in winter and spring, while lower concentrations have been observed in summer and fall (Novotny et al. 2008). This can be attributed to road salt use in winter and flushing by rainfall. For glycols, acetates, formates, or agro-based deicers, the high organic content may lead to temporary anaerobic soil conditions and localized depletion of dissolved oxygen in aquatic ecosystems (Fay et al. 2014). An investigation of common airport runway deicers showed that formates feature low biological oxygen demand (BOD) and chemical oxygen demand (COD) but long biodegradation time, while acetates and glycerol have high BOD and COD but short degradation time (Schweigert 2016).

The risk of corrosion to maintenance vehicles and infrastructure by snow and ice control materials should also be a factor that influences the choice of material type and its appropriate application. The detrimental effects of chemicals on concrete and reinforcing steel within concrete are generally more serious than those on exposed equipment. Corrosion inhibitors are often added to anti-icing or deicing materials to reduce their corrosivity to bare metals (Fischel 2001) and they may also slow down the corrosion initiation of embedded rebar and dowel bar (Shi et al. 2009c). Generally, road salt (NaCl, without any inhibitor) is more corrosive than other chemical products, if tested under continuous immersion conditions. Under exposure conditions with wet/dry cycles, however, $MgCl_2$ can be more corrosive to steel than NaCl (Xi and Oisgard 2000; Shi et al. 2009a). The corrosion risk of various deicers is also a function of metal type and washing practices (Honarvar et al. 2017).

It is usually recommended that a training program should be developed for operators and managers of agencies conducting or considering anti-icing or deicing operations for winter road maintenance. Proper training may prevent over application of material. For instance, application rates for salt are significantly lower than sand because sand only provides temporary traction increase and does not melt snow, thus requiring multiple applications to remain effective (provide traction) throughout a storm. Thus if an agency transitions from abrasives to chemicals, training should be conducted on material application equipment and rates. For anti-icing operation, the training should explain when anti-icing is appropriate and what decision should be made according to various scenarios (Kahl 2002).

2.2 MATERIALS USED FOR WRM OPERATIONS

Chemical deicers and abrasives have been used for snow and ice control in the United States since the 1930s (Fischel 2001). Presently, the most common freezing point depressants (FPDs) used for roadway winter operations are NaCl, $MgCl_2$, and $CaCl_2$, and, to a much lesser extent, CMA and KAc. Chloride salts are the most readily available and widely used, in either solid or liquid form (Shi et al. 2009b). While these materials enable many roads to remain open during winter storms, numerous studies have indicated that they can impose harmful effects to motor vehicles (Li et al. 2013; Johnson 2000), transportation infrastructure (Sutter et al. 2008; Xie et al. 2016) and the environment (Fay and Shi 2012; Zhang et al. 2013). However, these snow and ice control materials are still widely used in winter road maintenance because of their beneficial impact of increasing safety of winter driving. Fay et al. (2008) reported that most winter maintenance agencies still relied on chlorides and abrasives for snow and ice control. In practice, the search for “greener” materials for WRM operations is an ongoing effort.

2.2.1 Abrasives

Abrasives applied on roads can provide traction enhancement when it is too cold for chemicals to work effectively or on snow pack/ice surfaces that are too thick for chemicals to penetrate (Blackburn et al. 2004). When temperatures are below 12°F, abrasives are typically used because chemicals may be ineffective at such low temperatures (Gerbino-Bevins 2011). It should be noted that abrasives provide no ice-melting capabilities (Levelton Consultants 2007), but some salt is usually added during storage (3 – 10 percent is common) to prevent it from freezing. Use of abrasives instead of chemicals is more common on routes with lower LOS. Particle size and shape contribute to their effectiveness as traction enhancement and their impacts on the environment. Crushed or angular particles larger than US mesh size 50 (0.3 mm) are recommended. Smaller particles do not significantly increase the skid resistance of road surfaces. British Columbia Ministry of Transportation uses sand and gravel up to ½" particle size on highways because smaller sizes are too easily blown off the road or freeze over more quickly (BC Ministry of Trans. 2001). Particles larger than 0.5 inch can damage motor vehicles and injure pedestrians (Boselly 2008).Wisconsin uses gravel/sand up to ⅜" particle size, but only applies to intersections, curves and hills (Stantec 2012) (Wisconsin, Abrasives are typically applied at higher rates than chemicals requiring shorter routes. Also, because sand is easily carried off by traffic it requires more frequent reapplication.

A frequent finding in surveys and interviews of winter maintenance personnel is that many states have transitioned to using more chemicals than abrasives, and have also indicated a related shift from solid materials to using more liquids (Conger 2005). However, sand is still used by many states, particularly during extremely cold temperatures and on low-volume, lower LOS routes. According to Clear Roads annual winter data survey, even during the 2016–17 winter season, very few states applied no amount of abrasives. Using coarser (up to ⅜") uniformly-graded aggregate can improve traction longevity, reduce airborne particulates and increase sweeping recovery than sand that is too fine.

2.2.2 Chlorides

Sodium chloride, or salt, is the most commonly used material for WRM because it has been traditionally abundant and cheap (Fischel 2001). Both solid and liquid forms of salt are used with strategies ranging from deicing, anti-icing, prewetting, or mixing with abrasives or other products. Generally, NaCl costs less than $CaCl_2$ and $MgCl_2$ but does not work well at low temperatures (Gerbino-Bevins 2011). Moreover, NaCl can accelerate the corrosion processes of both automobiles and steel reinforced concrete under some specific circumstances (Zhang et al. 2007). $MgCl_2$ and $CaCl_2$ are common alternatives in liquid form for anti-icing or pre-wetting to NaCl. However, both $CaCl_2$ and $MgCl_2$ are also corrosive to metal in addition to their deleterious effects on concrete, which range from expansive cracking and spalling, increased permeability, and significant loss in compressive strength (Sutter et al. 2008).

Solid salt is used for deicing because it penetrates and undercuts compacted snow so it can be removed by plowing (Kuhl et al. 1999). Generally, a solid chemical must first dissolve in water, creating brine, before it can melt snow and ice. However, the lag time need for the material to dissolve , penetrate and melt snow needs to be considered when determining cycle times (TAC 2013). Even when only a thin layer of ice or compacted snow is on a roadway, solid deicers work better than liquid deicers because they can penetrate the ice, whereas liquid deicers are easily diluted and freeze (Kuhl et al. 1999). Solids are sometimes used for anti-icing to prevent snow from bonding to the pavement. Pre-wet solids can be applied prior to precipitation, but dry solids for anti-icing should only be applied at the onset of precipitation to avoid bounce and scatter loss of material (TAC 2013).

Liquid materials are popular because they stick to the road surface for effective anti-icing and can coat solid salt to reduce bounce and scatter and more quickly activate ice melting. Salt brine is commonly used because of its well understood performance and easy production from rock salt (TAC 2013). For anti-icing operation, salt brine is typically applied to pavements (Mitchell et al. 2003) prior to a storm and will usually evaporate leaving very fine salt crystal residue (TAC 2013). $MgCl_2$ and $CaCl_2$ are also used for anti-icing but are hygroscopic so tend to keep the road wet, and wet roads have lower friction than dry roads. In temperatures above freezing with relative humidity greater than 40%, $MgCl_2$ and $CaCl_2$ residue from anti-icing can result in dangerous, slippery conditions in certain circumstances (CTC & Associates LLC 2009; Salt Institute 2016). In order to avoid such undesirable conditions, $MgCl_2$ and $CaCl_2$ should not be applied on a warm road (above 28°F pavement temperature). Higher application rates are also associated with lower friction values (Leggett & Sdoutz 2000). At lower temperatures, water vapor in the air is low even at 100% RH and both $CaCl_2$ and $MgCl_2$ brine solutions work well (Staples et al. 2004). However, extended low humidity conditions could cause $CaCl_2$ and $MgCl_2$ to dry out and create even lower drops in friction during the transition (Leggett & Sdoutz 2000), although this scenario hasn't been widely observed in the field. $MgCl_2$ and $CaCl_2$ remain effective down to -10°F and -20°F, respectively, while only down to 15°F for NaCl (Ketcham et al. 1996). Liquid $MgCl_2$ can offer many benefits over salt brine including better efficiency, lower maintenance cost, and less negative effects on the environment (Xi and Xie 2002). Unfortunately, $MgCl_2$ is more corrosive to automobile components than NaCl under humid environments (Xi and Xie 2002). Liquid NaCl, $MgCl_2$ or $CaCl_2$ are also used as pre-wetting agents.

2.2.3 Acetates

The use of chloride-free chemicals, such as acetate-based products, has been recommended in recent years in order to deal with the detrimental impacts to infrastructure and the environment caused by chloride-based deicers. CMA can be used as an alternative to chloride-based deicers in environmentally sensitive regions (Staples et al. 2004), but only when the temperatures are over 23°F and/or on thin accumulations of snow and ice (Wegner and Yaggi 2001) and it requires about 50 percent greater application rates than salt to achieve the same LOS. CMA is available in flake and pellet form for solid application and as a liquid. KAc is a liquid product that can melt ice or snow quickly at much lower temperatures than CMA (Staples et al. 2004). As a liquid it can also be used as a pre-wetting agent for solid salt, sand and CMA (MDOT Strom Water Management Team & Tetra Tech 2006). KAc is frequently used on runways at airports because it is more effective than urea and has less environmental impacts than glycol-based deicers (Zhang et al. 2007). KAc is generally considered non-corrosive to carbon steel and environmentally benign, but it can be corrosive to galvanized steel (Fay and Shi 2011)and may increase the emulsification risk of asphalt concrete (Pan et al. 2008). A report conducted by the

Michigan DOT showed that KAc may cause reduced oxygen levels in waterbodies (MDOT Strom Water Management Team & Tetra Tech 2006). In fact, there is research indicating a greater negative impact of acetates than generally perceived, impacting pavements, structures and water quality (Fay et al. 2008). Because of their high cost, CMA and KAc are not commonly used on roads, but KAc is common in FAST systems.

2.2.4 Agro-Based Products

In recent years, agro-based deicers developed from agricultural by-products have been introduced for snow and ice control operations. It was reported that agro-based deicers performed better and were more environmentally friendly and less corrosive than conventional anti-icing and deicing materials (Kahl 2002). In practice, agro-based deicers are only used in conjunction with chloride-based chemicals to act as corrosion inhibitors or performance enhancers (Levelton Consultants 2007). Agro-based additives into chloride salts have been found to lower the freezing point of salt brine, provide enhanced ice melting capacity, reduced corrosivity, and/or extended action time once applied on pavement (Fischel 2001; Kahl 2002; Muthumani et al. 2017). For instance, when agro-based solutions are blended with $MgCl_2$ and then applied to pavement, the road surface can become tacky, which facilitates the longevity of agro-based products on pavement (MDOT Strom Water Management Team & Tetra Tech 2006). Additionally, agro-based additives for NaCl brine was reported to significantly reduce corrosivity to carbon steel (Muthumani and Shi 2017).

Disadvantages of agro-based chemicals were reported to include high cost (in some cases), toxicity to aquatic ecosystems, and quality control issues (Fischel 2001; Pilgrim 2013). While many of the agro-based chemicals are naturally occurring and renewable, they contain hundreds of components of varying levels depending on the source and batch. Some of them may contain undesirable ingredients with high organic content, causing biological degradation and high biological oxygen demand (BOD) or chemical oxygen demand (COD) issues. In recent years, new approaches to develop effective agro-based chemicals with low molecular weight carbohydrates and inorganic freezing point depressants have been proposed, which still maintain the deicing and anti-corrosion performance levels (Hartley and Wood 2001, 2006; Bytnar 2009).

2.2.5 Temperature Effectiveness

The performance of anti-icing and deicing materials at low temperatures is commonly determined by the eutectic temperature (determined from lab tests, such as ASTM D1177) and lowest effective temperature (typically determined from field observations and anecdotal evidence of performance). The term "eutectic temperature" is defined as the lowest freezing point, and has a corresponding eutectic concentration (Keep and Parker 2000). This can be seen clearly through a phase diagram (such as the NaCl-water system shown in Figure 2). The freezing point of the solution drops as the concentration increases until the eutectic point is reached. For NaCl, this occurs at a temperature of -6°F and 23.3% solution (Nixon and Williams 2001). A chemical with a low eutectic temperature is expected to have high miscibility or solubility in water. In anti-icing and deicing practice, the larger difference between eutectic temperature and ambient temperature, the faster the snow and ice melt (Fischel 2001). Therefore, it is ideal for the chemicals to have a eutectic temperature well below the expected ambient temperature, resulting in a rapid dissolution speed of chemicals and a low freezing point of brine solution. Most chemicals cease to be effective before the eutectic temperature is reached. For instance, NaCl is rarely used when ambient temperature is below 15°F, even though its eutectic temperature is -6°F (Nixon and Williams 2001). Thus, it is necessary to introduce the effective temperature, which is used to describe the lowest temperature for chemicals in practical use (Fischel 2001), which takes into consideration melting speed and application quantities. Nixon and Williams (2001) suggest the lowest effective temperature is the temperature on the phase diagram corresponding to a soluton concentration that is half of the eutectic concentration (11.65% and 18°F for NaCl). The lowest practical pavement temperatures for common chloride and acetate-based deicers as reported by many sources is shown in Table 1. Generally, it is expected that anti-icing and deicing chemicals with low eutectic and effective temperatures work better at low temperatures.

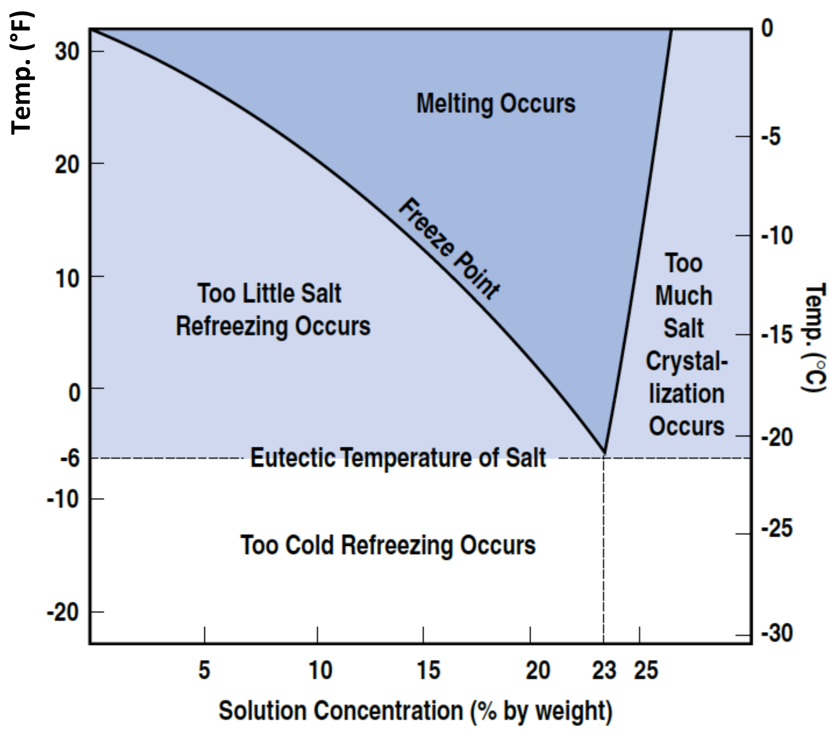


Figure 2: Phase diagram for the salt-water system (Salt Institute 2016)

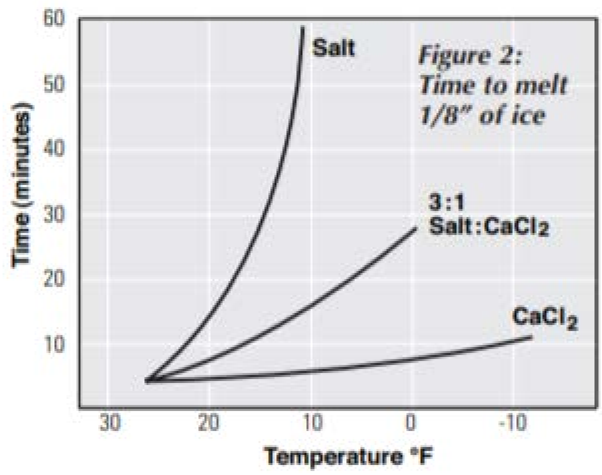


Figure 3: Time to melt 1/8" of ice (Wisconsin TIC 2005)

Table 1: Practical or effective working temperatures of chloride- and acetate-based materials

Lowest practical working temperature (°F)	Reference	Lowest practical working temperature (°F)	Reference
NaCl: Average 16°F, Most Common 15°F		**$MgCl_2$: Average 0°F, Most Common 5°F**	
15	Salt Institute (2003)	-10	MN PCA (2016)
15	MN PCA (2016)	-4	Resource Concepts Inc (1992)
15	MnDOT (2010)	0	MnDOT (2010)
15	Ketcham et al (1996)	5	Salt Institute (2003)
15	Fischel (2001)	5	NH Dept Env Services (2016)
17.6	Norem (2009)	5	Fischel (2001)
18	Nixon (2008)	**KAc: Average -15°F, Most Common -15°F**	
$CaCl_2$: Average -17°F, Most Common -20°F		-15	NH Dept Env Services (2016)
-31	Resource Concepts Inc (1992)	-15	MN PCA (2016)
-25	Fischel (2001)	-15	Fischel (2001)
-20	Salt Institute (2003)	**CMA: Average 20°F, Most Common 20°F**	
-20	NH Dept Env Services (2016)	14	Resource Concepts Inc (1992)
-20	MN PCA (2016)	20	NH Dept Env Services (2016)
-5	Nixon (2008)	20	MN PCA (2016)
0	MnDOT (2010)	20	Fischel (2001)
		21	Salt Institute (2003)
		23	TRB Committee (1991)

2.3 MATERIAL APPLICATION METHODOLOGIES

Various material application methodologies are available for applying snow and ice control materials to roadways, including anti-icing, deicing, abrasive use, and pre-wetting. Depending on climatic conditions, site-specific factors, local rules of practice, resources available and LOS goals, an agency's decision will be one of these methodologies, or a combination (Levelton Consultants 2007). There are two distinct material application methodologies that make use of chemical freezing-point depressants: anti-icing and deicing. They differ in their fundamental objectives where anti-icing is a preemptive strategy of applying chemicals to prevent snow/ice from bonding to the pavement and deicing is a reactive strategy needed to break bonds between snow/ice and pavement. Some agencies (less now than 20 years ago) still use abrasives as temporary traction improvement when snow/ice is bonded strongly to the pavement, either during very low temperatures or until warmer temperatures permit effective plowing. Pre-wetting solid deicers with liquid chemicals can be used for either anti-icing or deicing strategies. Pre-wetting abrasives help reduce bounce and scatter and improve the longevity of abrasives.

2.3.1 Anti-Icing

Many field tests and documented agency experience has proven anti-icing as a successful strategy for WRM. Anti-icing practice is a preventive operation that applies a chemical freezing-point depressant onto pavement at the start of a winter storm, or even prior to the beginning of precipitation to inhibit the development of a bond between snow or ice and pavement surface (Ketcham et al. 1996). Furthermore, moderate and periodic reapplication of chemicals during the storm can continue this effect. Once applied, chemicals will remain on pavement to work through the next storm event until they are diluted out by precipitation. As a result, anti-icing leads to improved LOS, reduced need for chemicals, cost savings and benefits in safety and mobility relative to deicing and sanding (Conger 2005; CTC & Associates LLC 2009; Ketcham et al. 1996). A typical anti-icing operation on dry pavement by using streamer nozzles before a predicted frost or snow event is shown in Figure 3. A recent study indicated a 10%-40% improvement in friction level by anti-icing treatments (Hosseini et al. 2014). It has also been proven that anti-icing operation can be very effective at preventing bridge deck and pavement frost (Wisconsin TIC 2005). In recent years, anti-icing practices have been widely adopted by state agencies across the U.S., using a variety of materials (Rubin et al. 2010).

Anti-icing is commonly performed with liquid materials, although it is possible to use dry and prewet solid granular materials (Nixon and Williams 2001; TAC 2013). This is because liquids can attach onto dry pavement better while solid materials will be dispersed by traffic action (Kahl 2002). In practice, liquid anti-icing operations should be conducted when temperatures are above 15–20°F (Wisconsin TIC 2005; Peterson et al. 2010). However, it was found that anti-icing materials can improve the ability of a plow to remove snow from the pavement surface, even at temperatures lower than 14°F (Cuelho et al. 2010). Reliable and accurate information on weather and pavement conditions, such as that provided by RWIS, and weather forecasts are key to effective anti-icing operation (Mitchell et al. 2003; Venner Consulting and Brinckerhoff 2004). One report suggested anti-icing on a regular basis (e.g., twice per week) is a recent trend (Mitchell et al. 2006).

Figure 4: A typical anti-icing operation on dry pavement (Connecticut DOT)

2.3.2 Deicing

In contrast to anti-icing operation, traditional deicing practice involves plowing and chemical treatment after an inch or more of snow has accumulated, and is often already compacted and bonded to the pavement. In order to destroy or weaken this bond, a large quantity of chemical products is usually required to penetrate to the snow/pavement interface. (Ketcham et al. 1996). When a thin layer of chemical solution spreads at the interface between ice and pavement, the ice-pavement bond is eventually weakened (Cuelho et al. 2010). Once the bond is broken, the layer of snow and ice can be easily removed by mechanical means such as snowplows.

Since deicing operation is a reactive (vs. pro-active) strategy to manage the changing condition on pavements, it often provides less safety, at higher cost, than anti-icing operation. One concern about deicing operation without prior anti-icing is the increased potential for accidents due to poor road conditions prior to and during maintenance activities (Cuelho et al. 2010). Deicing through extended storm periods may require large quantity of materials and labor hours to maintain the desirable LOS (O'Keefe and Shi 2005). However, deicing may be required for roadways with long intervals between treatments or in situations when weather forecasts are inaccurate or anti-icing operation is ineffective by itself (Ketcham et al. 1996). Deicing is actually critical for maintaining safety and mobility during storms of long duration or extended periods of cold, drifting conditions. In fact, deicing operation with solid chemicals is the most effective method for thick snow accumulations (Cuelho et al. 2010). Moreover, deicing is more effective compared with snowplowing alone (Fischel 2001).

In recent years, agencies have explored the use of liquid materials for deicing, called direct liquid application (DLA) where only liquid materials are used before, during and after a storm (Fortin Consulting 2017). When employed in conditions with pavement temperatures above 20°F and thin snow cover, DLA has the benefits of reduced application rates, reduced loss of materials, faster post-storm cleanup, quicker effect, and lower corrosion effects (Peterson et al. 2010) because liquids are fully retained on the pavement and begin melting immediately (TAC 2013). While DLA is especially effective at removing frost or thin layers of snow/ice, it can easily cause a slick layer of melting/refreezing on the surface of compacted snow and ice if applied incorrectly (Fortin Consulting 2017).

2.3.3 Pre-Wetting

2.3.3.1 Pre-Wetting Salt

Pre-wetting salt with a liquid chemical right before it is spread on pavement aims to improve performance by accelerating the process of solid chemical particles going into solution and keeping material on pavement by reducing the loss or waste from bouncing, blowing, sliding, and traffic action (TAC 2013; Burtwell 2004). For example one field test showed 80% of pre-wetted salt remained on a road surface after 100 vehicles traveling at 38 mph, while only 15% remained for dry salt (Evans 2008). Moreover, it was reported that pre-wetted rock salts could melt precipitation immediately (Kahl 2002). An increased snow and ice melting capacity may be seen due to the combination of solid and liquid chemicals being used (Alger and Haase 2006). As a result, pre-wetting may provide significant potential for reduction in chemical use, with typical savings of 25–30 percent commonly reported (Burtwell 2004; Maine DOT 2003).

In practice, it has been found that 10 to 12 gallons of 23 wt.% of NaCl solution will be sufficient for 1 ton of dry chemicals of coarse gradation (Blackburn et al. 2004). Field studies in Ontario of pre-wetted salt with liquid $CaCl_2$ and $MgCl_2$, as expected, outperformed dry salt in most test cases, with $CaCl_2$ outperforming $MgCl_2$ (Fu et al. 2006). Pre-wetting rates of 7% and 15% of the solid salt mass (corresponding to about 15 and 30 gal/ton) were included.

Pretreating salt stockpiles or truck loads with liquids, is an alternative to onboard pre-wetting. Laboratory testing of various pretreat chemicals and rates found no benefit in ice melting capacity with increasing amounts of liquid chemicals added to rock salt piles from 6 to 10 gallon per ton (Alger and Haase 2006). Field testing of dry, pretreated and pre-wet salt in Ontario over two winter seasons demonstrated pretreated salt can be applied at application rates of 15% lower than dry salt, whereas pre-wet salt application rates can be 30% less than dry salt (MTO 2018; Radaell & Dizaji 2017).

2.3.3.2 Pre-Wetting Sand

Pre-wetting sand helps keep abrasives on the road surface, attributed to the liquid coating on the sand melting just enough of the snow pack to allow the abrasives to embed into the surface providing a roughened sand-paper-like surface (Nixon 2001). For pre-wetting abrasives, the reduction in the amount applied can be as much as 50% in low temperatures (Williams 2003). An alternative to liquid chemicals for pre-wetting abrasives has been demonstrated in Norway and Nova Scotia with the use of very hot water. In such practice, material spreaders are equipped with water tanks that make it possible to heat water to 203°F and then the hot water is mixed with sand at the spreading disk (Wisconsin TIC 2005; Vaa 2004; Perchanok et al. 2010). The hot abrasives melt a small quantity of snow or ice as the abrasives hit the road (Nixon 2001). Hot water sanding (HWS) technology could not only help prevent the sand from being blown away from the road surface by traffic but also reduce the quantity of road salt and winter sand needed compared with conventional methods. As with most new practices, special equipment and operational and safety issues must be addressed when implementing new technology (Nixon 2009).

2.3.4 Sanding

Abrasives are applied onto roadways to temporarily increase friction coefficient, especially at low temperatures when chemical action is slow and in conditions where strongly bonded snow and ice is hard to remove. Generally, the increase in friction has limited duration because traffic will rapidly disperse abrasives, particularly when traffic speeds are greater than 30 mph (Levelton Consultants 2007). In fact, abrasives, especially those not pre-wetted, have limited effectiveness on roads with higher vehicle speeds and their use will not necessarily improve operations or mobility on many roads (CTC & Associates LLC 2009). The performance of abrasives could be enhanced by pre-wetting with liquid chemicals or hot water, or heating the abrasives (Klein-Paste and Sinha 2006; Lysbakken and Stotterud 2006; O'Keefe and Shi 2005; Perchanok 2008; Vaa and Sivertsen 2008). Pre-wetting with hot water or heating abrasives maintained higher friction in Norway even after 2,000 cars passed by, but has only been tested experimentally in the US. (Dahlen and Vaa 2001).

Abrasives are primarily applied on snow-packed and icy roads in rural areas, as well as on other types of roads when pavement temperatures are too low for chemicals to be effective. Chemicals are usually mixed with abrasives to prevent stockpiles from freezing, keep truck or hopper loads flowable, and help abrasives stay on the snow or ice surface (Boselly 2008). Additionally, research conducted by the Ontario Ministry of Transport showed that more salt/abrasives mixtures were required to achieve the same LOS than straight use of salt (Conger 2005). In anti-icing operations, it was found that there are no significant advantages gained from the application of abrasives. The combined application of abrasives and chemicals in an anti-icing operation was no more effective in increasing the friction or improving the pavement condition than the same amount of chemicals alone — it even appeared that the use of abrasives can be detrimental to the effectiveness of the chemical products (Ketcham et al. 1996). Additionally, abrasives also have their limitations such as negative impacts on water quality and aquatic species, air quality, vegetation, and soil and the cost of cleanup (Staples et al. 2004). Very fine sand particles are considered carcinogenic and contributors of lung disease and air pollution (Fischel 2001). Sand impacts water quality and threaten aquatic species habitat, particularly during spring runoff (Staples et al. 2004). Even after sweeping/vacuuming, 50 to 90 percent of sand remains somewhere in the environment (Parker 1997). Higher applications of abrasives, with less LOS benefits and more environmental impacts than chlorides make it less desirable than salt (Salt Institute 2016).

2.3.5 Plowing

Under most conditions involving snow on the road, material application methodologies are an aid to snow plowing – deicers are not used to melt all the snow – they are applied to improve plowing. When plowing is employed at the appropriate timing and frequency, synergistic effects can be achieved between different methodologies, resulting in a cost-effective and environmentally sustainable solution. If snow and ice are removed by effective plowing practices before they bond to the pavement, the need for deicers significantly decreases.

The implementation of plowing best practices can maximize snow removal from roadways and reduce costs such as operator and vehicle hours, fuel usage, and amount of product used (TAC 2013). A case study in Otterburn Park, Quebec reported a significant salt reduction of 73% through the implementation of effective plowing practices and improved training. Most agencies establish plow routes based on factors such as traffic volume, emergency services, and local characteristics to improve snow removal efficiency (Conger 2005).

The timing of snow plowing operations is critical to the overall effectiveness of snow removal. Depending on local policy, snow plowing operations are usually most successful when initiated after one to two inches of snow have fallen on the roadways. After the storm event has concluded, a final clean-up plowing procedure is usually recommended with light salt application if necessary (NHDOT 2014) However, this greatly depends on local conditions. The highest level of service can be achieved if snow plowing operations begins before the snow is able to bond to the road surface, which is usually before heavy traffic occurs. If deicing chemicals are applied, sufficient time is needed for the melting action to occur before a snow plow can remove the compacted snow and ice. In addition, the more time a deicer remains on the roadway, the more traffic can assist in breaking the bond between the snow and the pavement (Wisconsin TIC 2005).

2.4 MATERIAL APPLICATION RATES

The application rate of deicers depends on a variety of factors including application methodologies, air and pavement temperature, amount of snow on the ground, and steepness of the roadway. There are two main tactics involving application of chemicals, namely, deicing and anti-icing, each of which may involve pre-wetted solids. Generally, deicing operations typically require more amount (sometimes 5 times or more) of chemicals than that anti-icing operations require (Levelton Consultants 2007). This is due to significant loss of materials to the roadside environment by traffic action and the significant dilution effect by the snow lasting for hours or days, which is typically involved in deicing operation. Pre-wetted salt works quicker, at lower temperatures, and at reduced application rates, while pre-wetted abrasives tend to have less material loss from the pavement via bounce and scatter. In fact, pre-wetting can increase material retention on the roadway by 26% (O'Keefe and Shi 2005).

Regardless of the treatment methodologies being selected, the optimal application rate always depends on the material type, pavement temperature, dilution potential, the presence or absence of ice/pavement bond, plow circuit time, and LOS requirements. The surface temperature of a snow- or ice-covered road is particularly critical because it determines the snow melting capacity and dissolution and penetration rates of the chemicals. As temperatures decrease, the amount of deicer needed to melt a given quantity of snow/ice increases significantly (Salt Institute 2016). The effectiveness of operations is sensitive to small differences in pavement temperatures and each chemical is effective only within a specific range of temperature. For anti-icing, temperatures below 20°F, strong winds, and heavy snowfall or freezing rain conditions all make anti-icing problematic or ineffective (Ketcham et al. 1996). It is best to apply anti-icing before snow events at temperatures higher than 20°F (Blackburn et al. 2004; Peterson et al. 2010).

Recently, the number of factors that influence the material application rate have been reduced to a level which appears to be more acceptable by winter maintenance personnel than the current application rate format (Blackburn & Associates 2014). Currently, most DOTs use guidance for making application decisions based on many factors, such as pavement temperature, road surface conditions, precipitation type, and traffic condition, which makes it complicated to provide a suggested application rate (Latimer et al. 2015). The new refined decision of material application rate tabulated it as a function of a range of winter weather events (light snow, moderate snow, heavy snow, freezing rain, sleet, and frost/black ice) and the pavement temperature (Blackburn & Associates 2014).

Material application rate guidelines and tables were collected from multiple sources and are provided in APPENDIX B: Agency Application Rate Guidelines.

2.5 MATERIAL APPLICATION EQUIPMENT

Innovative equipment and technologies in road winter maintenance have developed significantly recent years. In fact, many different vendors have invested significant resources in developing state-of-the-art controllers, spreading systems, RWISs, hydraulic components, weather forecasting systems, and new generation chemicals for snow/ice control operations. Relatively new maintenance practices such as fixed automated spray technology (FAST) systems, DLA and slurry technology have been successfully explored as well. New on-truck tools (e.g., zero velocity spreaders, modified spinners, and other delivery mechanisms) facilitate precise and effective applications of both solid and liquid materials (Figure 4). Advanced systems use input from pavement surface condition sensors (friction, temperature, salinity etc.) to adjust the amount of material being applied “on the fly”, resulting in cost and environmental benefits. In addition, operations managers now have more accurate weather predictions, global positioning system (GPS)/automatic vehicle location (AVL) systems that track when and where trucks are plowing and spreading, and more knowledge and training on snow/ice control methods and practices available to managers, supervisors and field operators. FHWA developed a winter road maintenance decision support system (MDSS) “to provide objective guidance to winter control decisions concerning appropriate strategies” (Petty and Mahoney 2008). MDSS uses environmental and road condition information available to recommend proper treatment of roadways during winter maintenance activities. Several state DOTs have been developing a highway maintenance concept vehicle (HMCV) that incorporates some of the latest technologies, including: temperature sensors, friction sensors, freeze point sensors, high intensity lights, GPS/AVL, ground speed spreaders, pre-wetting equipment, liquid spreaders, power boosters, and underbody plows (Kroeger and Sinhaa 2004). This technology seems to be most beneficial on high volume roads that experience frequent road closures from winter weather (Cuelho and Kack 2002). This section gives an overview on technology developments related to snowplows, spreaders, liquid applicators, and those mentioned systems.

Figure 5: Snowplows with hopper-type spreaders (right lanes) and “all-liquid” truck (center lane). Photo courtesy of Utah DOT

2.5.1 Plows

The technologies of snowplows and other winter maintenance equipment have been under continual innovation driven by the need for improved effectiveness and efficiency. Various innovative plow configurations and designs have been developed in order to accommodate specific maintenance needs. The common plow types used in WRM include front end plow, side-wing or wing plow, underbody plow, tow plow, tandem or close echelon plow, V-plow, and icebreaker. The configuration of these plows is detailed in APPENDIX C: Plow configuration.

A number of past studies have investigated the cost and benefit of different snowplow configurations. Two alternative plow options, namely, wider front plow (14-ft) and tow plow, were evaluated for their costs (Lannert 2008). The cost of the conversion was under $400 per foot of plow and the benefits included reduced passes, fuel savings and labor reduction. Tow plows allow a single truck and operator to clear 24 feet of lane at high speeds and can reduce an agency’s capital investment needs by 20–30%. It was found that a plow truck equipped with a reversible plow and wing was better than having dedicated left-hand cast plows and wings, which are limited to use on multi-lane, wide-median highways (Macfariane 2001). The New Brunswick Ministry of Transportation experimented with reversible plows and wings and found many benefits, including improved efficiency and visibility and reduced collisions, while the limitations included disorientation, extra attention needed to ensure left-hand wings didn’t hang over the centerline, and needing to reverse the plows in a shop and not mid-route. Recent work has quantified visibility improvements from deflectors placed over snowplow blades (Thompson and Nakhla 2002).

In addition to plow configuration, the type of cutting edge must be selected properly to achieve the desired performance. Sufficient plow weight helps plows cut through snow and ice and can provide near-bare-surface or meet LOS requirements with minimum salt applications. Shoes or castors on plows operated at high-speeds can limit blades catching on obstructions. Additionally, plows should be fitted with a tripping mechanism to reduce damage to the plow if it impacts catch basin or manhole covers, curbing or other obstructions and prevent the truck from being violently deflected from its traffic lane (TAC 2013). Heavily packed snow and ice benefits from a cutting angle of 75°, whereas 55° is more efficient for removing large amounts of snow and reducing the snow plume that reduces visibility in front of a truck. A rubber extension flap fitted to the top of the moldboard of a front mounted plow, which extends well past the cutting edge, has been shown to effectively improve the operators' visibility by trapping some of the snow cloud kicked up by the cutting edge (TAC 2013).

In addition to improving plow combinations and designs, another active development related to plows is improved operating environment. It is well recognized that operating a plow truck is a challenging task during storm events due to reduced visibility of road surface and environment. New sensors for collision avoidance and vision enhancement are designed to relieve some of the burden from vehicle operators, allowing them to shift their focus from aspects of vehicle operations to aspects of winter maintenance, such as chemical application. This trend toward more automation has appeal for transportation agencies as a way to improve winter maintenance efficiency, protect the safety of agency staff and road users, and reduce maintenance costs and environmental footprint.

2.5.2 Solid Material Spreader

Material placement systems have evolved with advanced of technologies for controlling material applications and types. The common solid material spreaders include hopper spreader, tailgate spreader, side-discharge spreader, dual dump spreader, and multi-purpose spreader, of which more detailed information is provided in APPENDIX D: Solid spreader configuration.

During the past few years there has been an increased dependence on global positioning system (GPS)/automatic vehicle location (AVL) technologies to track equipment movements along with the operational data from the vehicle's controller (TAC 2013). Generally, there are many tools and equipment involved in the systems, including truck controllers, data collection devices, communication devices, plow sensors, and software that allow agencies to manage and analyze their winter maintenance operations. GPS/AVL systems for winter maintenance vehicles can provide real-time information, which may include type of applied material, application rate, vehicle location, road surface condition, plow position, and pavement temperature (McCullouch et al. 2009). By adopting the GPS/AVL systems, numerous benefits are found from related literatures, such as improved driver/operator accountability, material and labor cost savings, more accurate audits of material use, improved treatment recommendations, etc. (Potter et al. 2016). Many agencies were reported to use GPS/AVL mobile data collection systems to gather information and improve services and efficiency for their winter maintenance operations (Potter et al. 2016). A 2011 survey of 33 states indicated AVL is widely implemented with multiple vendors for hardware and software exist. Common problems found included cellular dead zones, software malfunctions, hardware problems, and compatibility issues.

Solutions from the survey included implementing more differential GPS, using raw truck data, and specifying certain vendors while avoiding others (Venner 2011a). Clear Roads and the Minnesota DOT first looked at GPS/AVL with a synthesis project completed in 2016 and followed it with a another project highlighting utilization with case studies completed in 2018 (Potter et al. 2016; Lee and Nelson 2018).

Maintenance decision support system (MDSS) is a software tool that can be used by maintenance operators that integrates RWIS and other weather data to make route- and segment-specific real-time treatment recommendations. There are multiple commercialized versions that typically include modules for pavement weather forecasts, pavement chemical concentration algorithms, pavement temperature models, and anti-icing rules of practice, to combine new and established technology and practices (Smithson 2018, Albrecht et al 2018). Case studies and demonstrations of the federally-funded prototypes have repeatedly shown MDSS to offer favorable benefit-cost ratios and salt reductions (Shi & Fu 2018)):

- Indiana saved 188,274 tons ($9,978,536) during 2008–09 winter, normalized for winter severity (McClellan et al. 2009).
- A sub-district in Indiana calculated a benefit-cost ratio of 1.6 with MDSS implementation (Veneziano et al. 2014).
- Maine case study for 12 storms verified positive effects (Cluett and Jenq 2007)
- An analysis of MDSS implementation in New Hampshire, Minnesota, and Colorado found reduced material use, improved safety and mobility, and cost savings with resulting benefit–cost ratios of 1.33 to 8.67 (Ye et al. 2009)
- The City and County of Denver, Colorado found MDSS is to be more effective in crew deployment over the 2007–09 winters (Cluett and Gopalakrishna 2009).

The integration of location data (GPS/AVL), on-board sensor devices, and friction measurements with an automatic material spreader system is particularly intriguing (Doherty and Kalbfleisch 2005). Studies have been done to test spreader control systems that automatically adjust spreading rate based on friction measurements from on-vehicle friction sensors (Erdogan et al. 2010; McCall and Kroeger 2001; Blackburn et al. 2008). The potential savings of such precision-controlled systems could be significant (e.g., $1.2 million annually in WSDOT, $500,000 in Nova Scotia (Venner 2012), and $3 million annually, or 10% of agency costs, for Michigan DOT (Venner 2011b; Ye et al. 2012)). Geo-fencing is another technology that could be integrated into a GPS-equipped spreader to prevent unintentional material application overlap from multiple trucks traveling the same route, or highlight boundaries of environmentally sensitive areas that should be treated with reduced material applications (MassDOT 2012).

2.5.3 Liquid Material Sprayer

Application of liquid chemicals in anti-icing operation usually requires liquid sprayer tanker trucks. Streamer or pencil nozzles or holes in the spray bar should be used to apply strips of chemicals to pavement surface so dry pavement interspersed with wet pavement can minimize slipperiness caused by hygroscopic chemicals (Blackburn et al. 2004). By spacing in the range of 8 to 15.5 inch, the streamer nozzles can cooperate with each other to apply liquid chemicals on pavement uniformly (Figure 5). Such spacing distance can also prevent misting or atomizing liquid chemicals, which reduces waste from blowing away and failing to reach the road surface (TAC 2013).

Figure 6: Application of anti-icing solution by nozzles (MDOT Strom Water Management Team & Tetra Tech 2006)

Some anti-icing operations can be conducted remotely using automated sprayers. Such systems have been used mostly on bridge decks that are more prone to icing, and may need more frequent application of anti-icing and de-icing operations (Staples et al. 2004). These sprayers are usually used in a system called the fixed automated spray technology (FAST) system. FAST system is a permanent installation of a pump, a tank, nozzles, and a controller that dispenses anti-icing chemicals directly on a predetermined area of pavement. This system can initiate chemical application either on manual command or be integrated with RWIS to operate automatically based on detected highway conditions (Waldman 2004). Figure 6 shows a spray head in action from a FAST system. Generally, there are three main reasons for using or considering the use of a FAST system in snow and ice control operations: remoteness of location, high levels of traffic volume and significant congestion, and major safety concerns in winter weather (Bell et al. 2006). FAST system permits timely, localized, and repeated anti-icing treatments with the optimum amount of anti-icing chemicals and without the deployment of typical winter maintenance equipment and personnel. However, a study reported that FAST must be supplemented with plowing and coordination of subsequent application of chemicals (Roosevelt 2004).

Figure 7: Spray head in action from a FAST system (Zhang et al. 2007)

2.5.4 Pre-Wetting Spreader

Pre-wetting spreader uses an on-board spreader spray system. It is critical to adjust the spray nozzles (Figure 8) in the pre-wetting system to ensure most liquid is hitting the solid material, and not being sprayed onto the road (TAC 2013). A recent report showed that pre-wetting at approximately 7 to 10 gallons of brine per ton of salt had been successful (Ohio DOT 2011).

Figure 8: Spray nozzles in the spreader chute of a pre-wetting system (Thompson Engineering Company 2014)

2.5.5 Zero Velocity Spreaders

Zero velocity spreaders apply material rearward to cancel the forward velocity of the vehicle and ultimately reduce bounce and scatter loss (TAC 2013). Figure 9 shows a zero-velocity spreader equipped on a truck. Using a zero velocity spreader with pre-wet salt can further increase the percentage of applied material that is retained on the road at high speeds (TAC 2013). Nantung (2001) 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 and faster vehicle speeds (up to 35 mph), improving operation efficiency and increasing safety (Venner Consulting and Brinckerhoff 2004). Coshocton County, Ohio calculated salt reductions of 70% and faster bare pavement returns after implanting zero-velocity spreaders and pre-wetting practices (Mitchell et al. 2006). Zero-velocity spreaders are only be used for salt, not sand (TAC 2013).

Figure 9: Zero-velocity spreader equipped on a truck (Thompson Engineering Company 2014)

2.5.6 Location of material

The common operation of solid material application is using a spinner to spread material evenly across the road surface. Broadcast spread patterns are usually applied in the situations where the broad material coverage is needed immediately, which typically occurs on roads where melting over the entire surface is required (TAC 2013). In practice, when there is freezing rain or black ice on the road and applying sand on road, broadcast spreading is the appropriate pattern. However, in certain circumstances, it is better to windrow the material into a relatively small strip on the road surface, thus providing a much higher local concentration of material in a limited location on the road surface (Nixon 2009).

In most cases, the continuous narrow windrow application of solid or pre-wetted salt is achieved by dropping the material from a chute into the centerline of the road (TAC 2013). This operation can minimize the loss of material due to bouncing or blowing off the road by passing traffic. However, if the entire road surface is slippery and deicing is required immediately, then salt need to be spread across all traffic lanes to improve the road safety (TAC 2013). A typical effective windrow pattern is applying material in a 4–8-ft strip along the centerline of a two-lane pavement with a low to medium traffic volume, while spinning spreading pattern is most often used on multiple-lane pavements with medium to high traffic volumes (Salt Institute 2016).

2.5.7 Equipment Calibration

Calibration of liquid and solid material spreaders is widely recognized as the greatest first step towards reduced salt use and greater efficiency (Nixon & DeVries 2015, Fay et al 2015). More information and details are provided in APPENDIX E: Equipment calibration.

2.6 KEY FINDINGS AND MAJOR TRENDS

Major trends in snow and ice control material application found during the literature review include:

- Anti-icing has been widely adopted as a viable strategy for snow and ice control on highways in North America, with several variations, including anti-icing on a regular basis regardless of forecast.
- The consideration of too many factors when deciding on material type and application rate is too complicated – a new trend is considering less factors, which seems to be more acceptable to winter maintenance personnel.
- To make the best use of available material and equipment, experienced decision-makers in winter maintenance operations need information to support their judgment. A number of tools are available to help provide the required information, including road weather information systems (RWIS), global positioning system/automatic vehicle location (GPS/AVL), and maintenance decision support system (MDSS).

2.7 CONCLUDING REMARKS

In order to update material application guidelines and synthesize the relevant best practices, this review highlights current practices, innovative practices, and trends related to materials used, their application rates, application methodologies, and the equipment used in winter roadway maintenance. The reviewed materials mainly focus on the products commonly used by highway agencies during their anti-icing, deicing, sanding, and pre-wetting operations, including solid salts, chloride brines and non-chloride liquids applied directly or as additives to abrasives and chemicals. By deeply reviewing the related literatures from the past decade or two, some concluding remarks can be drawn as follows.

- Many special factors influence the choice or timing of the material application, including climate conditions and predominant weather patterns, traffic, level of service, cycle times, material cost, material availability, environmental concerns, corrosion to fleet and infrastructure, training, etc.

- The widely used snow and ice control material are NaCl, $CaCl_2$, $MgCl_2$, Agro-based products and abrasives, with abrasive use falling and agro-based products increasing; and select use of KAc and CMA on new concrete or environmentally sensitive areas.
- The anti-icing and deicing effectiveness of certain materials is mainly determined by their eutectic and effective temperatures and the amount of such materials remain on road surface. Generally, it is expected that anti-icing and deicing agents with low eutectic and effective temperatures work better at low temperatures. The higher the deicer concentration on the pavement, the better the protection against freezing.
- Depending on weather condition, site-specific factors, and LOS goals, an agency's decision should consider one appropriate or a combination of the snow and ice control material application methodologies: anti-icing, deicing, and sanding. Pre-wetting should almost always be used unless temperature and moisture conditions are adequate for dry solid application.
- Equipment incorporated with new methods and technology developments is now available to reduce salt use, control environment impact, improve winter travel conditions, safety and mobility, and reduce overall costs. In such developments, more and more "smart" or automatic technologies have been used in the winter road maintenance operations.

CHAPTER 3: AGENCY INTERVIEWS

Interviews were conducted with winter maintenance personnel over phone and in-person to gather information about the material application methodologies across various transportation agencies. The interview questions were developed based on knowledge learned from the literature review and designed to capture the experience and insights of the winter maintenance community/practitioners. The 21-questions asked during each interview are available in APPENDIX F: Interview Questions and included the following important research questions: how material applications have evolved over time, which methods agencies have found most useful, whether they have developed tailored/custom application guidelines for snow and ice control (if not, which documents or reports are referenced to choose application methods/rates), how guidelines are evaluated internally or shared with the public, and how internal or external pressures influence changes in guidelines for winter operations.

3.1 INTERVIEWEES

A total of 26 completed responses were collected during the interview process with a response rate of 63%. State DOT winter maintenance personnel were the most common type of interviewee (16 people from 15 states: AK, CO, CT, IA, KS, MI, MT, NY, OR, PA, RI, VT, WS, WI, WY), followed by city/county governments (8 total, Denver, CO, Dubuque, IA, Des Moines, IA, McHenry County, IL, Olathe, KS, Lexington, MA, Minneapolis, MN, and Crystal, MN). One Canadian province (Ontario) and one European country (Norway) participated in interviews. A map showing the distribution of interviewees is shown in Figure 10 and the percentage of each type of interviewee is shown in Figure 11.

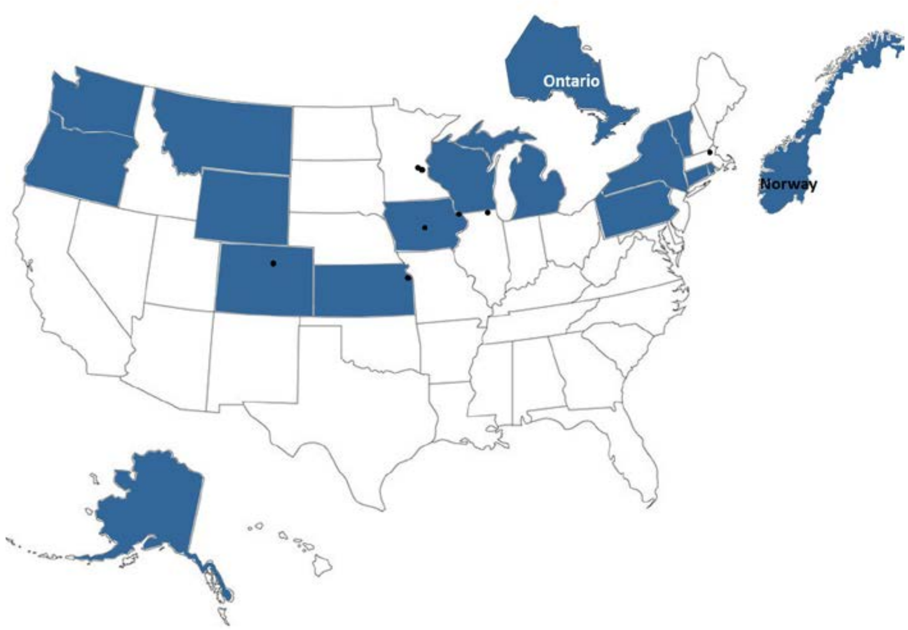


Figure 10: Map of Interviewee locations

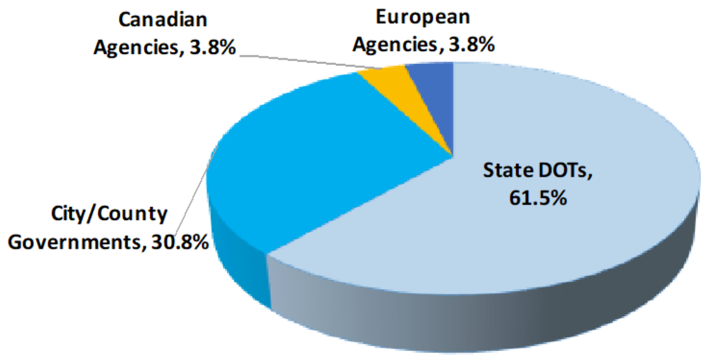


Figure 11: Distribution of Agency Category

3.2 PRIORITIES AND GOALS

Interviewees were asked to rank the following factors in priority order when managing their agency's equipment, material usage, and application methodologies:

- Traffic (mobility of freight and passenger vehicles)
- Level of service commitments (include traffic) and route priorities
- Material & other cost
- Material availability and stockpile locations
- Environmental concerns
- Cycle times
- Corrosion to fleet, infrastructure, vehicles
- Training
- Climate conditions and predominant weather patterns
- Others (responses included tourist season and special weather conditions)

A ranking evaluation was performed by rating different goals from 5 (most important) to 1 (least important). The distribution of results indicates traffic, LOS, material cost, and material availability have higher priority than environment, corrosion, training, cycle time and climate (Figure 12).

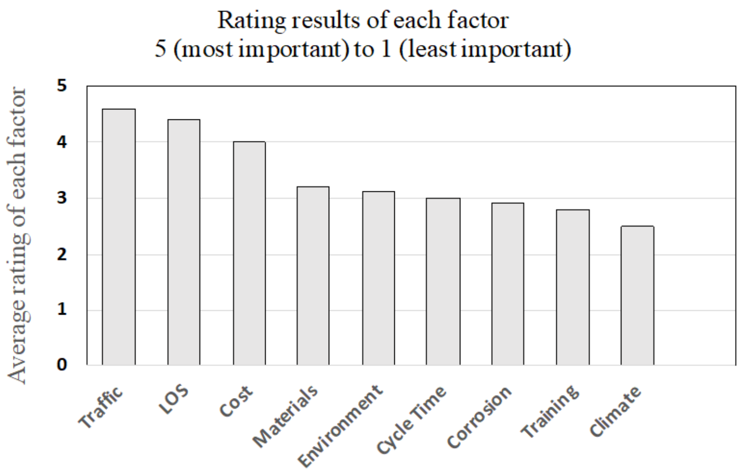


Figure 12: Ranking of factors according to agency's priorities when managing equipment, material application methodologies and material usage for snow and ice control

Agencies were asked to rate the following goals according to their agency's priorities when determining equipment, material application methodologies and material usage for snow and ice control.

- Performance improvement
- Mitigate environmental impacts
- Reduce corrosion
- Reduce or control costs
- Other

The distribution of responses is shown in Figure 13 with the average rating of each goal as follows: reduce or control costs, 4.5; performance improvement, 4.2; mitigate environmental impacts, 3.3; reduce corrosion 3.0.

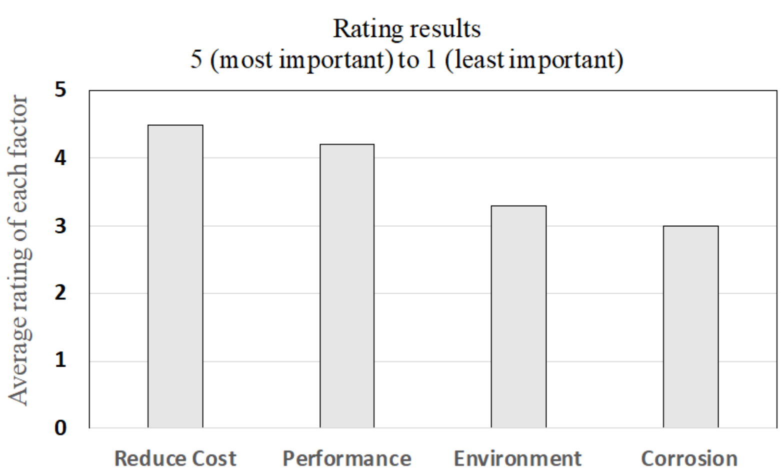


Figure 13: Ranking of goals according to agency's priorities when managing equipment, material application methodologies and material usage for snow and ice control

3.3 STRATEGIES & TACTICS FOR MATERIALS, EQUIPMENT & TECHNOLOGIES

In the general sense, a strategy is a careful plan or method directed at achieving a specific goal or goals. Tactics, on the other hand, are the systematic employment of available means or resources to accomplish a desired end condition of a strategy. For purposes of these guidelines, strategies and tactics refer to the combination of material, equipment, and methods, including both chemical and physical, which are used in snow and ice control operations to achieve a defined level of service. Most agencies responded that current practices, chemicals and equipment meet their demand and they perform very well. However, some agencies mentioned that they need less corrosive deicing chemicals, chemicals more effective in low temperatures, and longer-lasting snowplow blades designed with new materials to improve their winter maintenance.

The most commonly used chemical for anti-icing and deicing is salt (NaCl) in solid and liquid form. However, most agencies also use $MgCl_2$, $CaCl_2$, and/or organic-based chemicals during some winter events (e.g., solid NaCl prewet with $MgCl_2$, or solid NaCl prewet with a brine composed of 90% salt brine and 10% $CaCl_2$ plus organic chemical). The equipment used for anti-icing and deicing typically includes truck with tank, truck or tractor trailer equipped with spreader.

The most commonly used chemical for prewetting is salt brine. Typically, it is applied at the spinner, but some agencies treat at the stockpile or when loading trucks. At least half of interviewees mentioned using additives or alternative liquids, particularly during colder temperatures (primarily $MgCl_2$, $CaCl_2$, and agro-based products). Several agencies are transitioning to using 100 percent prewet solids and phasing out use of dry solids.

During the last 10 years, most agencies experienced major changes in material application methodologies. General trends included

- efficiency of salt chemical application is improved;
- shifting from solid chemicals to liquid chemicals;
- shifting from abrasives priority to chemical priority (51 percent of DOTs)
- snow plows move to stainless steel or other materials to minimize corrosion;
- chemicals more effective in lower temperature are used, such as organic-based chemicals.

The cost of applying applications/materials for snow and ice control varies from agency to agency. However, a consensus was noticed in the survey that training is important to minimize the cost while achieving the same benefit.

Most responding agencies use technologies such as RWIS, AVL or MDSS. These responding agencies also evaluated the cost-effectiveness or efficiency of different snow/ice control materials and application methodologies. Most agencies have conducted their own testing of materials, but more in the form of spot-checking, some agencies have materials labs, which can perform in-depth tests. The results of evaluation vary from agencies to agencies (refer to efficiency analysis reports developed by different agencies). Some agencies actually conducted field trials to evaluate the effectiveness of different snow/ice control materials and material application methodologies.

The best practices for material applications usually related to implementing advanced technologies and newly-designed equipment, such as AVL, webcams and computer-assisted management tools, which can greatly improve the performance of material application. The remaining knowledge gaps include: future research for developing training modules, in-depth testing of alternative chemicals, extreme cold weather options for winter maintenance, and public outreach enhancement.

3.4 GUIDELINES AND DOCUMENTS, GAPS AND NEEDS

Most agencies developed tailored material application guidelines, e.g., MNDOT uses "Minnesota Snow and Ice Control Field Handbook" and INDOT follows MDSS recommendations.

The references and documents mentioned by multiple agencies includes

- AASHTO's Guide for Snow and Ice Control; AASHTO Standard Specifications (T255 for salt moisture, T27 for salt particle size)
- Pacific Northwest Snowfighters Snow and Ice Control Chemical Products; PNS Qualified Product Listing
- Clear Roads documents
- NCHRP and FHWA research documents

Agencies also develop their own specification and memoranda for material applications. Several interviewees also mentioned equipment vendors for technology, network with other agencies and the APWA events as the source of information for new products, equipment and methods.

As for the communication of successes, all agencies showed various ways to communicate internally and with the public. Many agencies mentioned that social media has greatly increased the capability of agencies to communicate with the public, and allows the public to provide feedback on performance, which also help agencies to improve material application methodologies.

Due to the advancement of chemicals, equipment and technology, most agencies developed new or revised existing guidelines over the past 10 years. Commonly reported changes include following:

- Increase LOS for interstate and limited-access highways.
- Shift from abrasive to chemical priority
- Implement guidelines for liquid and organic-based deicer uses
- Develop new maintenance handbook
- Include descriptive figures in manuals to illustrate abstract LOS

CHAPTER 4: GUIDEBOOK DEVELOPMENT

A companion document "Material Application Methodologies Guidebook" was developed to provide succinct and specific recommendations for material application methodologies and application rates.

The information in the Guidebook was assembled based on the information collected during the literature review and agency interviews. While this final report provides a myriad of references to scholarly and other work, references were not included in the Guidebook to improve the readability and ease-of-use of that document.

CHAPTER 5: RECOMMENDATIONS

5.1 RECOMMENDATIONS FOR THE GUIDEBOOK

The Guidebook developed during this project provides targeted information on material application for supervisors and operators. Maintenance personnel should read the guidebook and compare the recommendations on material type and methods to their current practices, and consider trying new materials or methods to improve level of service or reduce material use. The guidebook provides a starting point – agencies should adapt material use to their local conditions. Adopting new equipment is best done gradually to avoid an entire fleet aging uniformly – this can help minimize the risk of trying something new, and promote acceptance of new techniques.

5.2 RECOMMENDED SOURCES FOR FURTHER INFORMATION

The following literature are recommended sources of information about winter maintenance material application:

- NCHRP Report 526 *Snow and Ice Control: Guidelines for Materials and Methods* (Blackburn et al. 2004)
- NCHRP Report 577 *Guidelines for the Selection of Snow and Ice Control Materials to Mitigate Environmental Impacts* (Leveloton Consultants 2007)
- Transportation Association of Canada's *Synthesis of Best Practices – Road Salt Management*, particularly Section 5 *Pavements and Salt Management* and Section 9 *Winter Maintenance Equipment and Technologies* (TAC 2013)
- Salt Institute's *The Snowfighter's Handbook: A Practical Guide for Snow and Ice Control* (2013)
- FHWA's *Manual of Practice for an Effective Anti-Icing Program* (Ketcham et al 1996)
- Clear Roads Project Final Report *Understanding the Effectiveness of Non-Chloride Liquid Agricultural By-Products and Solid Complex Chloride/Mineral Products* (Muthumani et al 2015)
- *Sustainable Winter Road Operations* Edited by Xianming Shi and Liping Fu, John Wiley & Sons, Hoboken, NJ (2018)

5.3 SUGGESTIONS FOR FURTHER RESEARCH

The following aspects of material application are suggested areas of further research:

- Materials:
    - <u>Enhanced or Agro-blended brines:</u> There are many different types of additives that can be blended with salt brine. The relationship between additive chemical composition, blending rate, and the resulting brine's effective temperature range and recommended field application rate is unclear, for both anti-icing and pre-wetting. Storage and handling of these deicers should be better documented, such as mixing requirements, viscosity at different temperatures, chemical incompatibilities, and degradation during

storage. Finally, impacts on infrastructure (especially concrete and metal) should be studied.

- Practices
  - Application Rates of Pre-Wet Salt: it is commonly understood that pre-wet salt can be applied at application rates of about 30% less than dry salt, but scientific field tests comparing dry and pre-wet salt are limited. Another aspect of pre-wetting that warrants additional research is the use of liquids with lower freezing points ($CaCl_2$, $MgCl_2$, enhanced or agro-blended brines) to pre-wet salt at temperatures below 15°F. Pre-wetting with alternatives to NaCl changes the chemical composition only slightly—it's still mostly NaCl—which is generally reported as impractical below 15°F. If it works, then looking at why and how well is warranted, followed by providing specific guidance. Another aspect of pre-wetting that should be examined is higher liquid-to-solid application rates (over 30 gal/ton to create a slurry), looking at both short-term performance and residual or persistence on the road
  - Salt-Additive Rate to Abrasives: Many states still use abrasives and the amount of salt added varies from as low as 3 percent to as high as 50 percent. The relationship between salt additive rate, field application rate, salt and abrasive particle size gradation, and effect on traction remains unclear, particularly at temperatures below 15°F.
  - Field Testing of Unique Road Weather Conditions: Field investigations of freezing rain, blowing snow and extremely cold conditions should be conducted to identify best practices for these specific scenarios.
- Equipment
  - Automated Application Rate Spreaders: Spreaders that can adjust application rates (and possibly material type) based on real-time sensor data (pavement temperature, friction) and location information (shade, hills, environment-sensitive areas, corrosion-sensitive structures) should be developed.

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APPENDIX A: DIRECT COST FOR VARIOUS SOLID AND LIQUID MATERIALS

Generally, sand has the lowest direct cost per unit weight at approximately $0.6-16/ton, depending on the transportation distance etc. For instance, during the winter of 2016-17, the average cost for sand used in MnDOT District 1 (headquartered in Duluth and Virginia) was $7/ton (MnDOT 2018). Among the solid chemical materials, NaCl has the lowest direct cost at $34-160/ton with the average cost of $76/ton (WisDOT 2017), whereas acetate-based deicers (e.g., calcium magnesium acetate – CMA and potassium acetate – KAc) have the highest cost averaged at $1,100 – 1500/ton (Kelting and Laxson 2010). A more recent cost of CMA found in the winter maintenance in Connecticut in 2014 was about $1800 per ton (Frisman and Analyst 2015). $MgCl_2$ and $CaCl_2$ are typically around $120-200/ton, with their cost falling closer to NaCl than acetates (Levelton Consultants 2007).

Direct cost of liquid products ranges from $0.05/gallon for non-corrosion-inhibited 23% NaCl to $0.40 – 0.50/gallon for 30% $CaCl_2$ or 30% $MgCl_2$ to $ 1.2/gallon for agro-based products to about $2.50/gallon for KAc (Kahl 2002). The prices of several common used liquid deicers obtained through personal communications with Clear Roads members over the phone/email in 2018 are as follows: NaCl at $0.12 – 0.45/gallon, $MgCl_2$ at $0.55 – 1/gallon, $CaCl_2$ at $0.94 – 1.27/gallon, and KAc at $4.50 – 5.87/gallon.

APPENDIX B: AGENCY APPLICATION RATE GUIDELINES

The need to control salt application rate for effective snow and ice control has stimulated a large amount of past efforts to develop winter maintenance guidelines including those for salt application. Application rate guidelines have been developed on the basis of a quantitative understanding of the snow melting performance of salt under specific winter snowstorm conditions (Blackburn et al. 2004).

The FHWA provides guidance on the application rate of anti-icing materials, including liquid chemicals, solids and prewetted solids in its "Manual of Practice for an Effective Anti-icing Program" (Ketcham et al. 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. For light snow, anti-icers should be applied at rates of 100 to 200 pounds per lane mile depending on pavement surface and temperature conditions. Light snow with periods of moderate to heavy snow application rates ranged from 100 to 225 pounds per lane mile depending on pavement surface and temperature conditions. Moderate to heavy snow application rates ranged from 100 to 250 pounds per lane mile depending on pavement surface and temperature conditions. Frost and black ice application rates ranged from 25 to 200 pounds per lane mile depending on pavement surface and temperature conditions.

The Salt Institute (2016) provided guidelines for salt application in *The Snowfighter's Handbook: A Practical Guide for Snow and Ice Control*. Depending on weather, road surface and temperature conditions, recommended application rates ranged between 100 and 400 pounds per lane mile. When salt treated abrasives were employed, a range of 750 to 1000 pounds per lane mile was recommended. Field tests conducted in Michigan revealed that doubling the application rate of a commercially available liquid $CaCl_2$ product from 30 gal/lane-mile to 60 gal/lane-mile 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.

The NCHRP Report 577 provided guidelines for the selection of snow and ice control materials, including anti-icers, deicers and abrasives (Levelton Consultants 2007). Depending on the pavement temperature, an anti-icing application rate of 65 to 400 pounds per lane mile was recommended. For deicing, an application rate of 200 to 700 pounds per lane mile was recommended. For abrasives (pre-wetted, dry, or mixed with road salt), an application rate of 500 to 600 pounds per lane mile was recommended. Such guidance was based on information provided by (Blackburn et al. 2004) and Wisconsin TIC (2005).

Deicer application guidelines from the following agencies are included in this appendix:

- Colorado DOT
- Connecticut DOT
- Illinois DOT
- Iowa DOT
- Kentucky DOT
- Minnesota Local Road Research Board
- Missouri DOT

- New York DOT
- Oregon DOT
- Ohio DOT
- Washington State DOT

Colorado DOT (1 page)

Before & During Shift, Consult MDSS/Meridian <u>BEFORE</u> Applying ANY Chemicals or Materials!

MATERIAL SELECTION/RATE CHART (Pre-Wet Every Load)

BASIC SAND/SALT Application Rate Recommendation Chart

Pavement Temp		Weather Conditions	Pounds Per 2-Lane Mile: 100% Salt	50/50	Stock-pile	Actions & Recommendations
Above 30°	↑	Snow	150-300	N/R	N/R	Plow & Treat HAZARDS Only!
		Frz Rain	150-300	N/R	N/R	Apply As Needed
	↓	Snow	200-400	N/R	N/R	Plow & Apply As Needed
		Frz Rain	200-400	N/R	N/R	Apply As Needed
25° to 30°	↑	Snow	200-400	N/R	N/R	Plow & Apply As Needed
		Frz Rain	200-400	N/R	N/R	Apply As Needed
	↓	Snow	300-500	N/R	N/R	Plow & Apply As Needed
		Frz Rain	300-500	500-750	N/R	Apply As Needed
20° to 25°	↑	Frz Rain	300-500	500-750	N/R	Apply As Needed
	↓	Snow	300-500	N/R	N/R	Plow & Apply As Needed
		Frz Rain	400-500	500-750	N/R	Apply As Needed
15° to 20°	↑	Snow	300-500	N/R	N/R	Plow & Apply As Needed
		Frz Rain	400-500	500-750	N/R	Apply As Needed
	↓	Snow	400-500	500-750	500-750	Plow & Apply As Needed
Below 15°		Snow	N/R	N/R	500-750	Plow & Treat HAZARDS Only!

FROST: 15°F & Rising: Treat by ANTI-ICING (Brine @ 20-40G/LM) or 15°F &Falling: 100% SALT (150#/LM)

WIND CONDITIONS: Plow, Treat TROUBLE SPOTS ONLY! 50/50@300#/LM or Stockpile @ 200-400#/LM

If Temperatures will RISE during shift/event, use SALT; FALL, use SAND.

Before & During Shift, Consult MDSS/Meridian <u>BEFORE</u> Applying ANY Chemicals or Materials!

MATERIAL SELECTION/RATE CHART (Pre-Wet Every Load)

ALTERNATIVE CHEMICALS Application Rate Recommendation Chart

Pavement Temp		Weather Conditions	Pounds Per 2-Lane Mile: RG8 Salt	RG8 Sand	Clearlane	Actions & Recommendations
Above 30°	↑	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
		Frz Rain	N/R	N/R	N/R	Use Salt/Brine
	↓	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
		Frz Rain	N/R	N/R	N/R	Use Salt/Brine
25° to 30°	↑	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
		Frz Rain	N/R	N/R	N/R	Use Salt/Brine
	↓	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
		Frz Rain	N/R	N/R	N/R	Use Salt/Brine
20° to 25°	↑	Frz Rain	N/R	N/R	N/R	Use Salt/Brine
	↓	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
		Frz Rain	300-350	350-500	N/R	Use Salt/Brine
15° to 20°	↑	Snow	200-350	N/R	100-250	Plow, use Salt or Sand with Brine
		Frz Rain	300-350	350-500	200-300	Use Salt/Brine
	↓	Snow	300-350	350-500	300-500	Plow, use Salt or Sand with Brine
Below 15°		Snow	350-500	350-500	300-500	Plow & treat HAZARDS only

FROST: 15°F & Rising: Treat by ANTI-ICING (*BRINE*@20-40G/LM) or 15°F &Falling: RG8 SALT@100#/LM or RG8 SAND@200#/LM

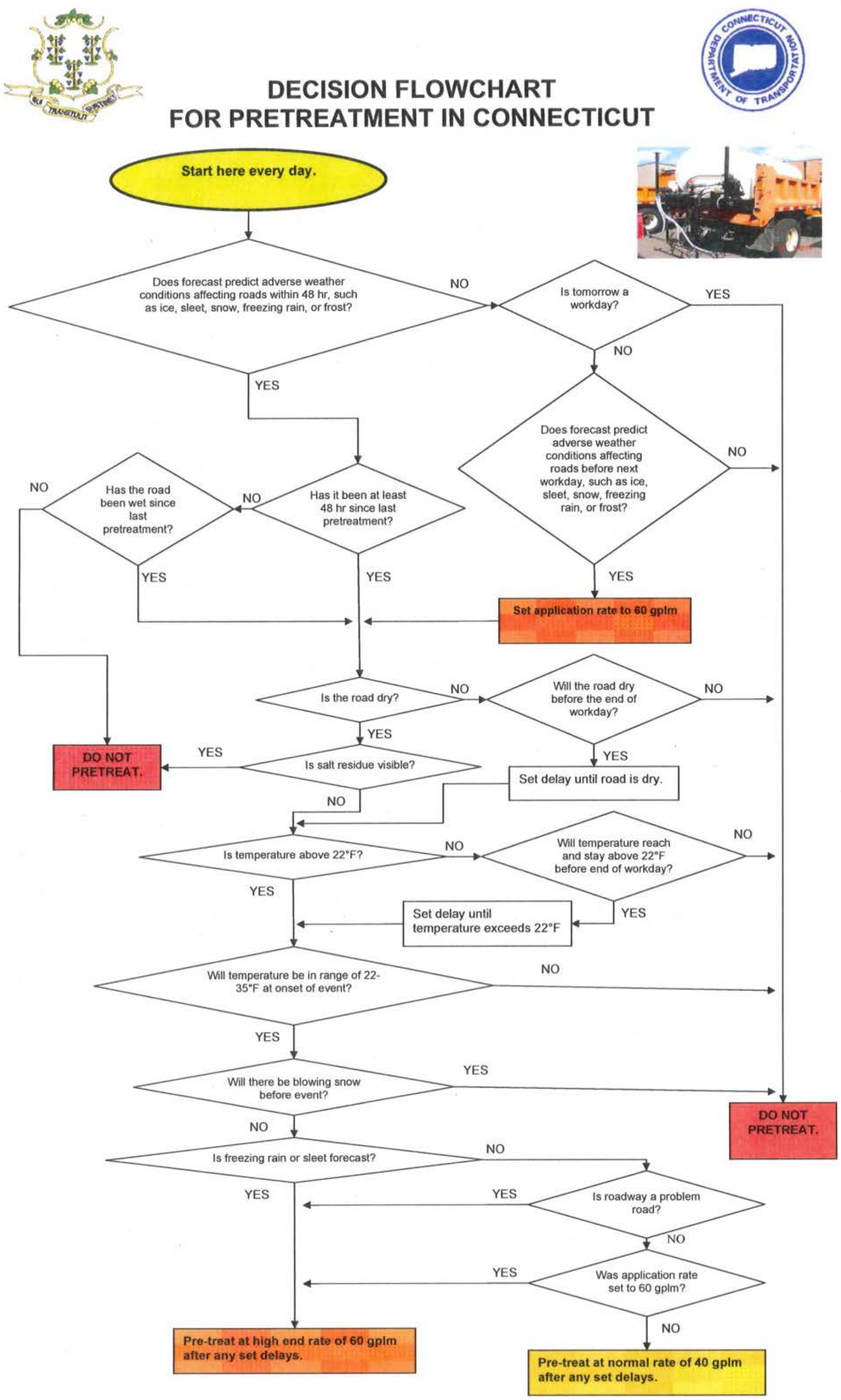
WIND CONDITIONS: Plow, Treat TROUBLE SPOTS ONLY! @100#-200#/LM

If Temperatures will RISE during shift/event, use SALT; if exected to FALL, use SAND.

ALTERNATIVES are used <u>only</u> when temps are too cold for salt to work (see chart). Do NOT get road surface wet in sub-zero conditions! Over application will result in residual tracking and refreeze issues down the road.

RG8 SALT is mixed at <u>5-8G/T</u> of Road Salt, applied at rates above.
RG8 SAND is mixed at <u>3-5G/T</u> of Stockpile (10%) Sand, applied at rates above.

Connecticut DOT (1 page)



November 15, 1999

Table 1

Light Snow Storm

	INITIAL OPERATIONS				**ONGOING OPERATIONS**			
			Spread Rate Range (Per Lane Mile)			Spread Rate Range (Per Lane Mile)		
PAVEMENT TEMPERATURE RANGE AND TREND	Initial Surface Conditions	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	**COMMENTS**
Above 32 F --- Steady or Rising	Dry, wet, slush or light snow cover	NONE See comments			NONE See comments			Monitor pavement temperatures closely for drops to and below 32 F
Above 32 F --- 32 or lower is imminent	Dry	Apply pre-wet salt	100 to 150 lbs.	See Comment #1	Reapply chemicals as needed, plow as needed	100 to 150 lbs.	150 to 200 lbs.	#1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100% #2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates.
20 to 32 F --- temperatures staying in this range	Wet, slush or light snow cover	Apply pre-wet or dry salt	100 to 150 lbs.	150 to 250 lbs.	Reapply chemicals as needed, plow as needed	100 to 150 lbs.	150 to 250 lbs.	
5 to 20 F --- temperatures staying in this range	Dry, Wet, Slush or light snow cover	Apply salt pre-wetted with calcium chloride	150 to 250 lbs.	See Comment #3	Reapply chemicals as needed, plow as needed	150 to 250 lbs.	See Comment #3	# 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider.
Below 5 F --- Steady or falling temperatures	Dry or light snow cover	Plow as needed – see comments			Plow as needed – see comments			Abrasives or abrasive mixes can be used to enhance traction as required.

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

November 15, 1999

Table 1

Light Snow Storm with Period(s) of Moderate or Heavy Snow

	INITIAL OPERATIONS				ONGOING OPERATIONS			
			Spread Rate Range (Per Lane Mile)			Spread Rate Range (Per Lane Mile)		
PAVEMENT TEMPERATURE RANGE AND TREND	Initial Surface Conditions	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	**COMMENTS**
Above 32 F --- Steady or Rising	Dry, wet, slush or light snow cover	NONE See comments			NONE See comments			Monitor pavement temperatures closely for drops to and below 32 F
Above 32 F --- 32 or lower is imminent	Dry	Apply pre-wet salt	100 to 150 lbs.	See Comment #1	Reapply chemicals as needed, plow as needed	100 to 200 lbs.	200 to 300 lbs.	#1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100% #2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates.
20 to 32 F --- temperatures staying in this range	Wet, slush or light snow cover	Apply pre-wet or dry salt	200 to 250 lbs.	250 to 350 lbs.	Reapply chemicals as needed, plow as needed	200 to 250 lbs.	250 to 350 lbs.	
5 to 20 F --- temperatures staying in this range	Dry, wet, slush or light snow cover	Apply salt pre-wetted with calcium chloride	150 to 250 lbs.	See Comment #3	Reapply chemicals as needed, plow as needed	250 to 350 lbs.	See Comment #3	# 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider.
Below 5 F --- Steady or falling temperatures	Dry or light snow cover	Plow as needed – see comments			Plow as needed – see comments			Abrasives or abrasive mixes can be used to enhance traction as required.

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

-6-24

November 15, 1999

Table 1

Moderate or Heavy Snow Storm

	INITIAL OPERATIONS				ONGOING OPERATIONS			
			Spread Rate Range (Per Lane Mile)			Spread Rate Range (Per Lane Mile)		
PAVEMENT TEMPERATURE RANGE AND TREND	Initial Surface Conditions	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	**COMMENTS**
Above 32 F --- Steady or Rising	Dry, wet, slush or light snow cover	NONE See comments			NONE See comments			Monitor pavement temperatures closely for drops to and below 32 F
Above 32 F --- 32 or lower is imminent	Dry	Apply pre-wet salt	100 to 150 lbs.	See Comment #1	Reapply chemicals as needed, plow as needed	100 to 150 lbs.	150 to 200 lbs.	#1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100% #2 Application rates and frequencies will need to be increased at lower pavement temperatures and higher snowfall rates.
20 to 32 F --- temperatures staying in this range	Wet, slush or light snow cover	Apply pre-wet or dry salt	200 to 250 lbs.	250 to 400 lbs.	Reapply chemicals as needed, plow as needed	200 to 250 lbs.	250 to 400 lbs.	
5 to 20 F --- temperatures staying in this range	Dry, Wet, Slush or light snow cover	Apply salt pre-wetted with Calcium Chloride	250 to 500 lbs.	See Comment #3	Reapply chemicals as needed, plow as needed	250 to 500 lbs.	See Comment #3	# 3 Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider.
Below 5 F --- Steady or falling temperatures	Dry or light snow cover	Plow as needed – see comments			Plow as needed – see comments			Abrasives or abrasive mixes can be used to enhance traction as required.

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

November 15, 1999

- **Table 1**

Freezing Rain or Sleet Storm

	INITIAL OPERATIONS				ONGOING OPERATIONS			
			Spread Rate Range (Per Lane Mile)			Spread Rate Range (Per Lane Mile)		
PAVEMENT TEMPERATURE RANGE AND TREND	Initial Surface Conditions	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	**COMMENTS**
Above 32 F --- Steady or Rising	Dry, wet,	NONE See comments			NONE See comments			Monitor pavement temperatures closely for drops to and below 32 F
Above 32 F --- 32 or lower is imminent	Dry, wet	Apply pre-wet or dry salt	75 to 150 lbs.	100 to 200 on wet pavement See note #1	Reapply chemicals as needed.	75 to 150 lbs.	100 to 200 lbs. on wet pavement. See note #1	#1 Application of dry salt to dry pavement should be avoided. If deemed necessary increase the pre-wet rate 100%
20 to 32 F --- temperatures staying in this range	Wet, slush or light ice cover	Apply pre-wet or dry salt	100 to 350 lbs.	150 to 350 lbs.	Reapply chemicals as needed.	150 to 350 lbs.	150 to 400 lbs.	
5 to 20 F --- temperatures staying in this range	Wet, slush or ice covered	Apply salt pre-wetted with Calcium Chloride	250 to 500 lbs.	500 lbs.	Reapply chemicals as needed.	250 to 500 lbs.	500 lbs.	Effectiveness of salt declines significantly when pavement temperatures drop below 20 F. If Calcium Chloride is not available, higher rates of salt or pre-wetted salt are both options to consider.

*Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

November 15, 1999

Table 1

Frost Control

	INITIAL OPERATIONS				ONGOING OPERATIONS			
			Spread Rate Range (Per Lane Mile)			Spread Rate Range (Per Lane Mile)		
PAVEMENT TEMPERATURE FORECAST and RELATION TO DEW POINT TEMPERATURE RANGE AND TREND	Traffic Conditions	Suggested Actions	* Liquid Salt Solution	Pre-wet Solid Salt	Suggested Actions	Pre-wet Solid Salt**	Dry Salt	**COMMENTS**
Above 32 F --- Steady or Rising	All	See comments		N/A	See comments			Monitor pavement temperature and weather forecasts closely for drops to and below 32 F and frost potential
28 to 32 F --- temperatures staying in range and equal to or below dew point		Apply salt brine to bridge decks and frost prone locations 2 to 3 times weekly	20 to 50 gal. per mile		Apply chemicals as needed.	75 to 150 lbs.	100 to 200 lbs.	
20 to 28 F --- temperatures staying in this range and equal to or below dew point		Apply salt brine to bridge decks and frost prone locations 2 to 3 times weekly	30 to 60 gal. per mile		Apply chemicals as needed.	150 to 350 lbs.	150 to 400 lbs.	It is not advisable to apply Liquid Salt Solution when pavement temperatures drop below 20 F
10 to 20 F --- temperatures staying in this range and equal to or below dew point		N/A			Apply chemicals as needed.	250 to 500 lbs.	500 lbs.	

*Application rate for 28% solution

**Pre-wet with 23% salt solution at 7 to 8 gallon per ton of dry salt

-6-27

Iowa DOT (1 page)

Salt Application Rate Guidelines GPC60150 9/14/04

Prewetted Salt @ 12' wide lane (assume 2-hour route)

Roadway Surface Temp - Fahrenheit		32-30	29-27	26-24	23-21	20-18	17-15
Pounds of Salt	Heavy Frost Mist Light Snow	50	75	95	120	140	170
	Drizzle Medium Snow (1/2" per hour)	75	100	120	145	165	200
	Light Rain Heavy Snow (1" per hour)	100	140	182	250	300	350

Prewetted Salt @ 12' wide lane (assume 3-hour route)

Roadway Surface Temp - Fahrenheit		32-30	29-27	26-24	23-21	20-18	17-15
Pounds of Salt	Heavy Frost Mist Light Snow	75	115	145	180	210	255
	Drizzle Medium Snow (1/2" per hour)	115	150	180	220	250	300
	Light Rain Heavy Snow (1" per hour)	150	210	275	375	450	525

Kentucky Snow and Ice Treatment Recommendations
Light Snow Storm

Road Temperature Range	Initial Operation: Road Surface at Time of Initial Operation	Initial Operation: Maintenance Action	Initial Operation: Product Rate: Brine Gallons /lane mile	Initial Operation: Product Rate: Salt Pounds /lane mile	Subsequent operations: Maintenance Action	Subsequent operations: Product Rate: Brine Gallons /lane mile	Subsequent operations: Product Rate: Salt Pounds /lane mile	Comments
Above 32^{0}F, steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1. Monitor road temps closely for drops toward 32^{0}F and below. 2. Treat icy patches with salt, if needed, at 150 lbs/lane mile; plow if needed.
Above 32^{0}F, 32^{0}F or below is imminent ALSO 20 to 32^{0}F remaining in range	Dry	Apply brine or prewetted salt	45	125-200	Plow as needed, reapply salt when needed		125-200	1. Applications will need to be more frequent at lower temps and higher snowfall rates 2. Do not apply salt brine when the pavement temp drops below 20^{0}F. 3. Do not direct apply salt brine onto heavy snow accumulation or packed snow. 4. Once road temps fall to 25^{0}F, prewet salt with CaCl.
	Wet, slush or light snow cover	Apply salt		125-200			125-200	
15 to 20^{0}F remaining in range	Dry, wet, slush or light snow cover	Apply prewetted salt		200	Plow as needed, Reapply pre-wetted salt when needed		200	
Below 15^{0}F, steady or falling	Dry or light snow cover	Plow as needed			Plow as needed			1. It is not recommended that salt be applied in this temperature range. If an application is warranted, the salt must be prewetted with CaCl. 2. Abrasives can be applied to enhance traction.

NOTES: **Salt Applications** (1) Time initial and subsequent salt applications to prevent deteriorating conditions or development of packed and bonded snow. (2) Apply salt ahead of traffic rush hour periods occurring during storm. **Plowing** - If needed, plow before salt applications so that excess snow, slush or ice is removed and pavement is wet, slushy or lightly snow covered when treated.

Kentucky Snow and Ice Treatment Recommendations
Light Snow Storm With Periods of Moderate to Heavy Snow

Road Temperature Range	Initial Operation: Road Surface at Time of Initial Operation	Initial Operation: Maintenance Action	Initial Operation: Product Rate: Brine Gallons /lane mile	Initial Operation: Product Rate: Salt Pounds /lane mile	Subsequent operations: Maintenance Action	Subsequent operations: Product rate: Light Snow: Salt Pounds /lane mile	Subsequent operations: Product rate: Heavy Snow: Salt Pounds /lane mile	Comments
Above 32^0 F, steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1. Monitor road temps closely for drops toward 32^0F and below. 2. Treat icy patches with salt, if needed, at 150 lbs/lane mile; plow if needed.
Above 32^0F, 32^0F or below is imminent ALSO 25 to 32^0F remaining in range	Dry	Apply brine or prewetted salt	45	125-200	Plow as needed, reapply salt when needed	200	250	1. Applications will need to be more frequent at lower temps and higher snowfall rates 2. Do not apply salt brine when the pavement temp drops below 20^0F. 3. After heavy snow periods and during light snowfall, reduce salt rates to 200 lb/lane mile continue to plow and apply salt as needed. 4. Once road temps fall to 25^0F, prewet salt with CaCl.
	Wet, slush or light snow cover	Apply salt		125-200				
15 to 25^0F remaining in range	Dry, wet, slush or light snow cover	Apply prewetted salt		250	Plow as needed, Reapply pre-wetted salt when needed	250	300	1. Reduce salt rate to 250 lb/lane mile after heavier snow periods and during light snowfall. Continue to plow and apply salt as needed.
Below 15^0F, steady or falling	Dry or light snow cover	Plow as needed			Plow as needed			1. It is not recommended that salt be applied in this temperature range. If an application is warranted, the salt must be prewetted with CaCl. 2. Abrasives can be applied to enhance traction.

NOTES: **Salt Applications** (1) Time initial and subsequent salt applications to prevent deteriorating conditions or development of packed and bonded snow. (2) Anticipate increases in snowfall intensity. Apply higher salt rates prior to or at the beginning of heavier snow periods to prevent development of packed and bonded snow. (3) Apply salt ahead of traffic rush hour periods occurring during storm. **Plowing** - If needed, plow before salt applications so that excess snow, slush or ice is removed and pavement is wet , slushy or lightly snow covered when treated.

Kentucky Snow and Ice Treatment Recommendations

Moderate or Heavy Snow Storm

Road Temperature Range	Initial Operation: Road Surface at Time of Initial Operation	Initial Operation: Maintenance Action	Initial Operation: Product Rate: Brine Gallons /lane mile	Initial Operation: Product Rate: Salt Pounds /lane mile	Subsequent operations: Maintenance Action	Subsequent operations: Product Rate: Brine Gallons /lane mile	Subsequent operations: Product Rate: Salt Pounds /lane mile	Comments
Above 32^0F, steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1. Monitor road temps closely for drops toward 32^0F and below. 2. Treat icy patches with salt, if needed, at 150 lbs/lane mile; plow if needed.
Above 32^0F, 32^0F or below is imminent ALSO 30 to 32^0F remaining in range	Dry	Apply brine or prewetted salt	45	125-200	Plow as needed, reapply salt when needed		125-200	1. If the desired plowing/treatment frequency cannot be maintained, the salt rate can be increased to 250 lb/lane mile for longer turnaround times on routes. 2. Do not direct apply salt brine onto heavy snow accumulation or packed snow. 3. Once road temps fall to 25^0F, prewet salt with CaCl
	Wet, slush or light snow cover	Apply salt		125-200				
25 to 30^0F remaining in range	Dry	Apply brine or prewetted salt	45	180-250	Plow as needed, Reapply pre-wetted salt when needed		250	If the desired plowing/treatment frequency cannot be maintained, the salt rate can be increased to 400 lb/lane mile for longer turnaround times on routes.
	Wet, slush or light snow cover	Apply salt		180-250				
15 to 25^0F remaining in range	Dry, wet, slush or light snow cover	Apply salt		250	Plow as needed, Reapply pre-wetted salt when needed		300	If the desired plowing/treatment frequency cannot be maintained, the salt rate can be increased to 500 lb/lane mile for longer turnaround times on routes.
Below 15^0F, steady or falling	Dry or light snow cover	Plow as needed			Plow as needed			1. It is not recommended that salt be applied in this temperature range. If an application is warranted, the salt must be prewetted with CaCl. 2. Abrasives can be applied to enhance traction.

NOTES: **Salt Applications** (1) Time initial and subsequent salt applications to prevent deteriorating conditions or development of packed and bonded snow. Timing and frequency of subsequent applications will be determined primarily by plowing requirements.
(2) Apply higher salt rates prior to or at the beginning of heavier snow periods

Plowing - Plow before salt applications so that excess snow, slush or ice is removed and pavement is wet, slushy or lightly snow covered when treated.

Kentucky Snow and Ice Treatment Recommendations

Freezing Rain Storm

Road Temperature Range	Initial Operation: Maintenance Action	Initial Operation: Salt Application Rate (lb/lane mile)	Subsequent operations: Maintenance Action	Subsequent operations: Salt Application Rate (lb/lane mile)	Comments
Above 32°F, steady or rising	None, see comments		None, see comments		1. Monitor pavement temperature closely for drops toward 32°F and below. 2. Treat icy patches if needed with prewetted salt at 150 lbs/lane mile.
Above 32°F, 32°F or below is imminent	Apply prewetted salt*	180-200	Reapply prewetted salt as needed	180-200	Monitor pavement temperature and precipitation closely.
20 to 32°F remaining in range	Apply prewetted salt*	200-250	Reapply prewetted salt as needed	200-250	1. Monitor pavement temperature and precipitation closely 2. Increase application rate to higher rate if pavement temp drops or intensity of freezing rain increases. 3. Decrease application rate to lower rate if pavement temp rises or intensity of freezing rain decreases.
15 to 20°F remaining in range	Apply prewetted salt*	250-400	Reapply prewetted salt as needed	250-400	1. Monitor precipitation closely. 2. Increase application rate toward higher rate if intensity of freezing rain increases. 3. Decrease application rate toward lower rate if intensity of freezing rain decreases.
Below 15°F, steady or falling	Apply abrasives			Apply abrasives as needed	It is recommended that salt NOT be applied in this temperature range. However, if an application is warranted, the salt must be prewetted with CaCl.

Notes: Salt Applications: (1) Time initial and subsequent salt applications to prevent glaze ice conditions.

(2) Apply salt ahead of traffic rush hour periods occurring during storm.

* Once road temps drop to 25°F or below, prewet salt with CaCl.

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Minnesota Snow and Ice Control: field handbook for snowplow operators, 2nd revision, October 2012

Anti-icing Application Rate Guidelines

These guidelines are a starting point. Reduce or increase rates incrementally based on your experience.

Condition		Gallons/Lane Mile		
	$CaCl_2$	$MgCl_2$	Salt Brine	Other Products
1. Regularly scheduled applications	15 – 25	15 – 25	20 – 40	Follow manufacturers' recommendations.
2. Prior to frost or black ice event	15 – 25	15 – 25	20 – 40	
3. Prior to light or moderate snow	15 – 25	15 – 25	20 – 50	

Deicing Application Rate Guidelines

24' of pavement (typical two-lane road)

These rates are not fixed values, but rather the low end of a range to be selected and adjusted by an agency according to its local conditions and experience.

Pavement Temp. (°F) and Trend (↑↓)	Weather Condition	Maintenance Actions	Lbs/ two-lane mile			
			Salt Prewetted/ Pretreated With Salt Brine	Salt Prewetted/ Pretreated With Other Blends	Dry Salt*	Winter Sand (abrasives)
>30° ↑	Snow	Plow, treat intersections only	80 (40/lane mile)	70	100*	Not recommended
	Frz. rain	Apply chemical	80 – 160	70 – 140	100 – 200*	Not recommended
30° ↓	Snow	Plow & apply chemical	80 – 160	70 – 140	100 – 200*	Not recommended
	Frz. rain	Apply chemical	150 – 200	130 – 180	180 – 240*	Not recommended
25 - 30° ↑	Snow	Plow & apply chemical	120 – 160	100 – 140	150 – 200*	Not recommended
	Frz. rain	Apply chemical	150 – 200	130 – 180	180 – 240*	Not recommended
25 - 30° ↓	Snow	Plow & apply chemical	120 – 160	100 – 140	150 – 200*	Not recommended
	Frz. rain	Apply chemical	160 – 240	140 – 210	200 – 300*	400
20 - 25° ↑	Snow or frz. rain	Plow & apply chemical	160 – 240	140 – 210	200 – 300*	400
20 - 25° ↓	Snow	Plow & apply chemical	200 – 280	175 – 250	250 – 350*	Not recommended
	Frz. rain	Apply chemical	240 – 320	210 – 280	300 – 400*	400
15 - 20° ↑	Snow	Plow & apply chemical	200 – 280	175 – 250	250 – 350*	Not recommended
	Frz. rain	Apply chemical	240 – 320	210 – 280	300 – 400*	400
15 - 20° ↓	Snow or Frz. rain	Plow & apply chemical	240 – 320	210 – 280	300 – 400*	500 for frz. rain
0 to 15° ↑↓	Snow	Plow, treat with blends, sand hazardous areas	Not recommended	300 – 400	Not recommended	500 – 750 spot treat as needed
< 0°	Snow	Plow, treat with blends, sand hazardous areas	Not recommended	400 – 600**	Not recommended	500 – 750 spot treat as needed

*Dry salt is not recommended. It is likely to blow off the road before it melts ice.

**A blend of 6 – 8 gal/ton $MgCl_2$ or $CaCl_2$ added to NaCl can melt ice as low as -10°.

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Anoka County Minnesota:

BEFORE & DURING SHIFT, CONSULT RWIS™ BEFORE APPLYING *ANY* CHEMICALS OR MATERIALS!					
Application Rate Recommendation Chart (Pre-wet Material Chart)					
Pavement Temp	Weather Conditions	Pounds Per Two (2) Lane Mile			Actions & Application Recommendation
		100% Salt	50% Salt	Stock Pile	
Above 30° ↑↓	Snow	150-300	Not Recommended	Not Recommended	Plow, Treat Hazards ONLY
	Freezing Rain	150-300	Not Recommended	Not Recommended	Apply As Needed
	Snow	200-400	Not Recommended	Not Recommended	Plow & Apply As Needed
	Freezing Rain	200-400	Not Recommended	Not Recommended	Apply As Needed
25° to 30° ↑↓	Snow	200-400	Not Recommended	Not Recommended	Plow & Apply As Needed
	Freezing Rain	200-400	Not Recommended	Not Recommended	Apply As Needed
	Snow	300-500	Not Recommended	Not Recommended	Plow & Apply As Needed
	Freezing Rain	300-500	500-750	Not Recommended	Apply As Needed
20° to 25° ↑↓	Snow/ Frz Rain	300-500	500-750	Not Recommended	Plow & Apply As Needed
	Snow	300-500	Not Recommended	Not Recommended	Plow & Apply As Needed
	Freezing Rain	400-500	500-750	Not Recommended	Apply As Needed
15° to 20° ↑↓	Snow	300-500	Not Recommended	Not Recommended	Plow & Apply As Needed
	Freezing Rain	400-500	500-750	Not Recommended	Apply As Needed
	Snow/ Frz Rain	400-500	500-750	Not Recommended	Plow & Apply As Needed
Below 15°	Snow	Not Recommended	Not Recommended	500-750	Plow, Treat Hazards w/ Stockpile
FROST: 15° & RISING: TREAT BY ANTI-ICING (Brine 20-40 G/LM) or 15° & FALLING: 100% SALT @ 150 #/LM					
WIND CONDITIONS: PLOW, TREAT (TROUBLE SPOTS ONLY!) WITH 50/50 @ 300#/LM OR STOCKPILE @ 200-400 #/LM					
IF EVENT/SHIFT TEMPERATURES WILL *RISE*, USE SALT INSTEAD OF SAND (& vise versa as temps fall)					

Table 133.5.3.6.5 Continuous Operations Routes

Type 1 Winter Event: More than 12 in. of snow in 24 hours OR more than ¾ in. of ice

PAVEMENT TEMPERATURE RANGE AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	Pavement surface at time of initial operation	Maintenance action	Salt spread rates: Pre-wetted solid salt (lb/ln-mi)	Salt spread rates: Brine (gal/ln-mi)	Maintenance action	Salt spread rates: Pre-wetted solid salt (lb/ln-mi)	Salt spread rates: Brine (gal/ln-mi)	
Above 32ºF steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1) Monitor pavement temperature closely for drops toward 32ºF and below 2) Treat slick patches if needed with pre-wetted salt at 100 lb/lane-mi or with brine at 44 gal/ln-mi; plow if needed
Above 32ºF, 32ºF or below is imminent; *ALSO* 30 to 32ºF, remaining in range	Dry	Apply brine or pre-wetted solid salt	100	44	Plow accumulation and reapply brine or solid salt as needed	100	44	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 200 lb/lane-mi to accommodate longer operational cycles 2) Do not apply brine onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply brine or pre-wetted solid salt	100	44				
20 to 30ºF remaining in range	Dry	Apply brine or pre-wetted solid salt	150-200	65-87	Plow accumulation and reapply brine or solid salt as needed	200	87	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 400 lb/lane-mi to accommodate longer operational cycles 2) Do not apply brine onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply brine or pre-wetted solid salt	150-200	65-87				
10 to 20ºF, remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wetted solid salt	200		Plow accumulation and reapply brine or solid salt as needed	250		1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 500 lb/lane-mi to accommodate longer operational cycles 2) Liquid calcium chloride may be used for pre-wetting salt at colder temperatures
Below 10ºF, steady or falling	Dry or light snow cover	Plow as needed			Plow accumulation as needed	250		1) As pavement becomes slick apply salt/abrasive mix to enhance traction. Salt will have limited melting power in this temperature range.

Notes: SALT APPLICATIONS. (1) Time initial and subsequent salt applications to *prevent* deteriorating conditions or development of packed and bonded snow-- ***timing and frequency of subsequent applications will be determined primarily by plowing requirements***. (2) Apply salt ahead of traffic rush periods occurring during storm. **PLOWING.** *Plow before chemical applications* so that excess snow, slush, or ice is removed and pavement is wet, slushy, or lightly snow covered when treated.

Table 133.5.3.6.4 Continuous Operations Routes

Type 2 Winter Event: 6 – 12 in. of snow in 24 hours OR ½ to ¾ in. of ice

PAVEMENT TEMPERATURE RANGE AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	Pavement surface at time of initial operation	Maintenance action	Salt spread rates: Pre-wetted solid salt (lb/ln-mi)	Salt spread rates: Brine (gal/ln-mi)	Maintenance action	Salt spread rates: Pre-wetted solid salt (lb/ln-mi)	Salt spread rates: Brine (gal/ln-mi)	
Above 32ºF steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1) Monitor pavement temperature closely for drops toward 32ºF and below 2) Treat slick patches if needed with pre-wetted salt at 100 lb/lane-mi or with brine at 44 gal/ln-mi; plow if needed
Above 32ºF, 32ºF or below is imminent; *ALSO* 30 to 32ºF, remaining in range	Dry	Apply brine or pre-wetted solid salt	100	44	Plow accumulation and reapply brine or solid salt as needed	100	44	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 200 lb/lane-mi to accommodate longer operational cycles 2) Do not apply brine onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply brine or pre-wetted solid salt	100	44				
20 to 30ºF remaining in range	Dry	Apply brine or pre-wetted solid salt	150-200	65-87	Plow accumulation and reapply brine or solid salt as needed	200	87	1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 400 lb/lane-mi to accommodate longer operational cycles 2) Do not apply brine onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply brine or pre-wetted solid salt	150-200	65-87				
10 to 20ºF, remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wetted solid salt	200		Plow accumulation and reapply brine or solid salt as needed	250		1) If the desired plowing/treatment frequency cannot be maintained, the spread rate can be increased to 500 lb/lane-mi to accommodate longer operational cycles 2) Liquid calcium chloride may be used for pre-wetting salt at colder temperatures
Below 10ºF, steady or falling	Dry or light snow cover	Plow as needed			Plow accumulation as needed	250		1) As pavement becomes slick apply salt/abrasive mix to enhance traction. Salt will have limited melting power in this temperature range.

Notes: **SALT APPLICATIONS.** (1) Time initial and subsequent salt applications to *prevent* deteriorating conditions or development of packed and bonded snow-- ***timing and frequency of subsequent applications will be determined primarily by plowing requirements***. (2) Apply salt ahead of traffic rush periods occurring during storm. **PLOWING.** *Plow before chemical applications* so that excess snow, slush, or ice is removed and pavement is wet, slushy, or lightly snow covered when treated.

Table 133.5.3.6.3 Continuous Operations Routes

Type 3 Winter Event: 1 – 6 in. of snow/frozen precipitation in 24 hours OR a trace to 1/2 in. of ice

PAVEMENT TEMPERATURE RANGE AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS					COMMENTS
	Pavement surface at time of initial operation	Maintenance action	Salt spread rates		Maintenance action	Salt spread rates				
			Pre-wetted solid salt (lb/ln-mi)	Brine (gal/ln-mi)		Pre-wetted solid salt (lb/ln-mi)		Brine (gal/ln-mi)		
						Light snow	Heavier snow	Light snow	Heavier snow	
Above 32ºF, steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments					1) Monitor pavement temperature closely for drops toward 32ºF and below 2) Treat slick patches if needed with pre-wetted salt at 100 lb/lane-mi or brine 44 gal/ln-mi; plow if needed
Above 32ºF, 32ºF or below is imminent; *ALSO* **20 to 32ºF,** remaining in range	Dry	Apply brine or pre-wetted salt	100	44	Plow as needed; reapply brine or pre-wetted solid salt when needed	100	200	44	88	1) Applications will need to be more frequent at lower temperatures and higher snowfall rates 2) Do not apply brine onto heavy snow accumulation or packed snow 3) After heavier snow periods and during light snow fall, reduce salt rate to 100 lb/lane-mi or 44 gal/ln-mi brine; continue to plow and apply salt as needed
	Wet, slush, or light snow cover	Apply brine or pre-wetted salt	100	44						
10 to 20ºF, remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wetted salt	200		Plow as needed; reapply pre-wetted solid salt when needed	200	250			1) Reduce salt rate to 200 lb/lane-mi after heavier snow periods and during light snow fall; continue to plow and apply salt as needed 2) Liquid calcium chloride may be used for pre-wetting salt at colder temperatures.
Below 10ºF, steady or falling	Dry or light snow cover	Plow as needed			Plow and apply salt/abrasive mix as needed					1) As pavement becomes slick apply salt/abrasive mix to enhance traction. Salt will have limited melting power at this temperatures

Notes: **SALT APPLICATIONS.** (1) Time initial and subsequent salt applications to *prevent* deteriorating conditions or development of packed and bonded snow. (2) ***Anticipate increases in snowfall intensity. Apply higher rate treatments prior to or at the beginning of heavier snowfall periods to prevent development of packed and bonded snow.*** (3) Apply salt ahead of traffic rush periods occurring during storm.
PLOWING. If needed, *plow before salt applications* so that excess snow, slush, or ice is removed and pavement is wet, slushy, or lightly snow covered when treated.

Table 133.5.3.6.2 Continuous Operations Routes

Type 4 Winter Event: Dusting to 1 in. of snow, sleet or other frozen precipitation

PAVEMENT TEMPERATURE RANGE AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	Pavement surface at time of initial operation	Maintenance action	Salt Spread Rates		Maintenance action	Salt Spread Rates		
			Pre-wetted solid salt (lb/ln-mi)	Brine (gal/ln-mi)		Pre-wetted solid salt (lb/ln-mi)	Brine (gal/ln-mi)	
Above 32°F, steady or rising	Dry, wet, slush or light snow cover	None, see comments			None, see comments			1) Monitor pavement temperature closely for drops toward 32°F and below 2) Treat icy patches if needed with pre-wetted solid salt at 100 lb/lane-mi; plow if needed
Above 32°F, 32°F or below is imminent; *ALSO* **15 to 32°F,** remaining in range	Dry	Apply brine or pre-wetted solid salt	100	44	Plow as needed; reapply liquid or solid chemical when needed	100	44	1) Applications will need to be more frequent at lower temperatures and higher snowfall rates 2) It is not advisable to apply a straight brine at the indicated spread rate when the pavement temperature drops below 20°F 3) Do not apply brine onto heavy snow accumulation or packed snow
	Wet, slush, or light snow cover	Apply liquid or solid salt	100	44				
0 to 15°F, remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wetted solid chemical	200		Plow as needed; reapply pre-wetted solid chemical when needed	200		1) Abrasives may be added to the salt to enhance traction at colder temperatures 2) Liquid calcium chloride may be used for pre-wetting solid salt at colder temperatures
Below 0°F, steady or falling	Dry or light snow cover	Plow as needed			Plow and apply salt/abr. mix as needed			1 If pavement becomes slick apply salt/abrasive mix to enhance traction. Salt will have limited melting power in this temperature range. 2) Pre-wet salt/abrasive mix with liquid calcium chloride.

Notes: **SALT APPLICATIONS.** (1) Time initial and subsequent chemical applications to ***prevent*** deteriorating conditions or development of packed and bonded snow. (2) Apply salt ahead of traffic rush periods occurring during storm.
PLOWING. If needed, ***plow before salt applications*** so that excess snow, slush, or ice is removed and pavement is wet, slushy, or lightly snow covered when treated.

Table 133.5.3.6.1 Continuous Operations Routes

Type 5 Winter Event: Frost, Flurries, Freezing Fog, Blowing Snow & Refreeze

PAVEMENT TEMPERATURE RANGE AND TREND	TRAFFIC CONDITION	INITIAL OPERATION			SUBSEQUENT OPERATIONS			COMMENTS
		Maintenance action	Spread rates		Maintenance action	Spread rates		
			Pre-wetted solid salt (lb/ln-mi)	Brine (gal/ln-mi)		Pre-wetted solid salt (lb/ln-mi)	Brine (gal/ln-mi)	
Above 32ºF steady or rising	Any level	None, see comments			None, see comments			1) Monitor pavement temperature closely; begin treatment if starts to fall to 32ºF and below and is at or below dew point
28 to 32ºF, remaining in range or falling to 32ºF or below, *and* equal to or below dew point	Traffic rate less than 100 vehicles per hr	Apply brine or pre-wetted solid salt	25-65	11-28	Reapply pre-wetted solid salt as needed	25-65		1) Monitor pavement closely; if pavement becomes wet or if thin ice forms, reapply salt at higher indicated rate. 2) Do not apply brine on ice so thick that the pavement cannot be seen
	Traffic rate greater than 100 vehicles per hr	Apply brine or pre-wetted solid salt	25-65	11-28	Reapply brine pre-wetted solid salt as needed	25-65	11-28	
20 to 28ºF, remaining in range *and* equal to or below dew point	Any level	Apply brine or pre-wetted solid salt	65-130	28-57	Reapply brine pre-wetted solid salt as needed	65-130	28-57	1) Monitor pavement closely; if thin ice forms, reapply salt at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency 3) It is not advisable to apply a brine at the indicated spread rate when the pavement temperature drops below 20ºF
10 to 20ºF, remaining in range *and* equal to or below dew point	Any level	Apply pre-wetted solid salt	130-200		Reapply pre-wetted solid salt as needed	130-200		1) Monitor pavement closely; if thin ice forms, reapply salt at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency
Below 10ºF, steady or falling	Any level	Apply abrasives			Apply abrasives as needed			1) Monitor pavement closely, salt will have limited melting power in this temperature range. 2) Liquid calcium chloride may be used for pre-wetting salt/abrasive mix at colder temperatures.

Notes: **TIMING.** (1) Conduct initial operation in advance of freezing. Apply brine up to 3 hr in advance. Use longer advance times in this range to effect drying when traffic volume is low. Apply pre-wetted solid salt 1 to 2 hr in advance. (2) In the absence of precipitation, brine at 33 gal/lane-mi has been successful in preventing bridge deck icing when placed up to 4 days before freezing on higher volume roads and 7 days before on lower volume roads.

BLACK ICE

Surface Temp. Range (° F)	Surface Condition	Initial Maintenance Action	Dry Rock Salt Lbs./lm.	Pre-Wetted Rock Salt Lbs./lm	Follow Up Action	Follow Up Rock Salt Lbs./lm	Follow Up Pre- Wetted Rock Salt Lbs./lm	Comments
Above 32	Dry or Damp	Apply pre-wetted rock salt or direct liquids to prevent formation.		115	None, see comments.			Monitor pavement temperature closely; begin treatment if pavement temperature starts to fall toward 32 and it is at or below the dew point.
23 to 32	Frost or Black Ice	Apply pre-wetted rock salt or direct liquid; use dry salt if pre-wetted not available.	275	225	Re-apply pre-wetted rock salt as needed.	115	90	1) Monitor pavement temperatures closely; if pavement becomes wet or if thin ice forms re-apply chemicals. 2) Do not apply direct liquids on ice so thick that the pavement cannot be seen. 3) Heavier follow up application(s) may be necessary.
15 to 23	Frost or Black Ice	Apply pre-wetted rock salt; use dry rock salt if pre-wetted not available.	360	275	Re-apply pre-wetted or dry rock salt as needed	115	90	1) Monitor pavement temperature closely; if pavement becomes wet or if thin ice forms re-apply chemicals. 2) Do not apply direct liquids on ice so thick that the pavement can not be seen. 3) Heavier follow up applications(s) may be necessary.
Below 15	Frost or Black Ice	Apply abrasives			Apply abrasives			1) Refer to Snow and Ice Guidelines Section 5.4406, paragraph B. for abrasive application rates.

Notes: 1) Black ice or frost is normally a spot condition – these application rates would be applied to areas susceptible to the formation of black ice or areas where black ice has developed. Watch for freezing surface temperatures below dew point with sources of vapor, clear night skies and light winds. 2) Refer to direct liquid chemical application guide lines (Appendix C Page C – 10) if anti-icing liquids are used.

FREEZING RAIN

Surface Temp. Range (° F)	Surface Condition	Initial Maintenance Action	Dry Rock Salt Lbs./lm.	Pre-Wetted Rock Salt Lbs./lm	Follow Up Action	Follow Up Rock Salt Lbs./lm	Follow Up Pre- Wetted Rock Salt Lbs./lm	Comments
Above 32	Wet or Slushy	Apply pre-wetted or dry rock salt, plow if plowable.	115	90	Monitor precipitation and temperature.			1) Monitor pavement closely and anticipate drops toward 32° F and below. 2) Adjust application rates as surface conditions and precipitation intensities change.
Above 32, but dropping to 32 or below soon	Wet or Slushy	Apply pre-wetted or dry rock salt, plow if plowable.	180	115	Re-apply pre-wetted or dry rock salt as needed.	180	115	1) Monitor pavement temperatures and precipitation closely. 2) Treat icy patches and colder areas with higher applications. 3) Increase applications if precipitation intensity increase or surface shows signs of icing.
23 to 32	Wet or Slushy	Apply pre-wetted or dry rock salt, plow if plowable.	275	225	Re-apply pre-wetted or dry rock salt as needed.	275	225	1) Monitor pavement temperatures and precipitation closely and adjust application rates as surface conditions and precipitation intensities change. 2) Treat icy patches and colder areas with higher applications. 3) Increase applications if precipitation intensity increase or surface shows signs of icing.
23 to 32	Icy	Apply pre-wetted or dry rock salt.	360	320	Re-apply pre-wetted or dry rock salt as needed.	360	320	1) Use Application Rate for "wet and slushy" when icing condition is removed. 2) Increase application rate if precipitation intensity increases or if pavement shows signs of re-freezing.
15 to 23	Wet or Slushy	Apply pre-wetted or dry rock salt, plow if plowable.	360	275	Re-apply pre-wetted or dry rock salt as needed.	360	275	1) Monitor pavement temperatures and precipitation closely and adjust application rates as surface conditions and precipitation intensities change. 2) Treat icy patches and colder areas with higher applications. 3) Increase applications if precipitation intensity increase or surface shows signs of icing.
15 to 23	Icy	Apply pre-wetted or dry rock salt.	450	360	Re-apply pre-wetted or dry rock salt as needed.	450	360	1) Use Application Rate for "wet and slushy" when icing condition is removed. 2) Increase application rate if precipitation intensity increases or if pavement shows signs of re-freezing.
Below 15	Dry, wet or icy	Apply abrasives			Re-apply abrasives			Refer to Snow and Ice Guidelines Section 5.440 (B) for application rates.

Notes: 1) Freezing Rain requires a timely and aggressive response to prevent ice formation; application rates should be increased if not effective or cycle times are increased due to difficult driving.

SLEET

Surface Temp. Range (° F)	Surface Condition	Initial Maintenance Action	Dry Rock Salt Lbs./lm.	Pre-Wetted Rock Salt Lbs./lm	Follow Up Action	Follow Up Rock Salt Lbs./lm	Follow Up Pre- Wetted Rock Salt Lbs./lm	Comments
Above 32	Dry	Patrol and spot treat as needed. See comments.			Patrol and spot treat as needed. See comments.			1) Monitor pavement temperatures closely and anticipate drops toward 32 F and below. 2) Treat icy patches with pre-wetted rock salt at 115 lbs./lm.
Above 32	Snow, slush, or wet.	Apply pre-wetted or dry rock salt, plow if plowable.	115	90	Re-apply pre-wetted or dry rock salt as needed.	115	90	1) Monitor pavement temperatures closely and anticipate drops toward 32F. 2) Treat icy patches and colder areas with higher applications. 3) Increase rates if precipitation intensity increases.
Above 32, but dropping to 32 or below soon.	Snow, slush, or wet.	Apply pre-wetted or dry rock salt, plow if plowable.	180	115	Re-apply pre-wetted or dry rock salt as needed.	180	115	1) Monitor pavement temperatures and precipitation closely. 2) Treat icy patches and colder areas with higher application rates. 3) Increase application rates if precipitation intensity increases.
23 to 32	Snow, slush, or wet.	Apply pre-wetted or dry rock salt, plow if plowable.	225	180	Re-apply pre-wetted or dry rock salt as needed.	225	180	1) Monitor pavement temperatures and precipitation closely. 2) Treat icy patches and colder areas with higher application rates. 3) Increase application rates if precipitation intensity increases.
15 to 23	Snow, slush, or wet.	Apply pre-wetted or dry rock salt, plow if plowable.	275	225	Re-apply pre-wetted or dry rock salt as needed.	275	225	1) Monitor pavement temperatures and precipitation closely. 2) Treat icy patches and colder areas with higher application rates. 3) Increase application rates if precipitation intensity increases.
Below 15	Any condition.	Apply abrasives.			Re-apply abrasives.			1) Refer to Snow and Ice Guidelines Section 5.4406 (B) for abrasive application rates.

Notes: 1) Sleet that creates accumulating ice will require more aggressive treatment.

LIGHT SNOW
(Less than ½"/hour; visibility > ½ mile)

Surface Temp. Range (° F)	Surface Condition	Initial Maintenance Action	Dry Rock Salt Lbs./lm.	Pre-Wetted Rock Salt Lbs./lm	Follow Up Action	Follow Up Rock Salt Lbs./lm	Follow Up Pre- Wetted Rock Salt Lbs./lm	Comments
Above 32	Wet, slush or light snow covered.	Patrol and spot treat as needed. See comments.			Patrol and spot treat as needed. See comments.			1) Monitor pavement temperature for drops toward 32 F. 2) Blast isolated icy patches with salt, treat slushy areas beginning to freeze with 180 dry/160 pre-wet, lbs./lm and plow as needed
Above 32, but dropping to 32 or below soon.	Dry	Apply pre-wetted rock salt or direct liquids. Patrol and spot treat as needed. See comments.		160	Patrol and spot treat as needed. See comments.			1) Monitor pavement temperature and precipitation and select appropriate follow up as conditions change.
Above 32, but dropping to 32 or below soon.	Wet, slush, or light snow covered.	Apply pre-wetted or dry rock salt, plow as needed.	180	160	Plow and re-apply pre-wetted or dry rock salt as needed.	115	100	1) Application will need to be more frequent at lower temperature and higher snowfall rates. 2) Adjust application rates as surface conditions and precipitation intensities change.
23 to 32	Dry	Apply pre-wetted rock salt or direct liquids.		160	See comments.			1) Monitor pavement temperature and precipitation and use select appropriate follow up as conditions change.
23 to 32	Wet, slush or light snow covered.	Apply pre-wetted or dry rock salt, plow as needed.	200	160	Plow and re-apply pre-wetted or dry rock salt as needed.	115	100	1) Application will need to be more frequent at lower temperature and higher snowfall rates. 2) Adjust application rates as surface conditions and precipitation intensities change.
15 to 23	Wet, slush or light snow covered.	Apply pre-wetted rock salt, plow as needed.	250	200	Plow and re-apply pre-wetted rock salt as needed.	180	160	1) If sufficient moisture is present, dry rock salt can be applied. Dry pavement at these temperatures is better left untreated if snow does not track to surface.
Below 15	Dry or light snow covered. Wet and Snow/ice/slush	Plow as needed. If previous salt applications made, plow and apply pre-wetted rock salt as needed.		200	Plow as needed. If previous salt applications made, plow and re-apply pre-wetted rock salt as needed.		160	1) Abrasives can be applied to enhance traction, a heavy salt mix will create glazing. Refer to Snow & Ice Guidelines Section 5.4406 (B) for abrasive application rates. Apply rock salt in anticipation of rising temperatures. 2) If salt had been applied prior, continue with pre-wet salt as needed.

Notes: 1) Rush Period Traffic on high volume highways may require more aggressive initial treatments. 2) Use weather information to anticipate changes in storm intensity, precipitation type, and surface temperatures; Use appropriate guideline for heavier intensity or precipitation type change. 3) Rates may need to be increased if cycle times are longer than normal. 4) In the event of hard pack or icing development, adjust application rates as needed. 5) For pre-storm anti-icing operations, refer to direct liquid chemical application guides lines. Consider use of follow-up application rates for initial maintenance action if pre-storm liquid anti-icing is effective.

MODERATE OR HEAVY SNOW

(Moderate: ½ "/– 1"/hour; visibility ¼ to ½ mile) (Heavy: More than 1"/hour; visibility < ¼ mile)

Surface Temp. Range (° F)	Surface Condition	Initial Maintenance Action	Dry Rock Salt Lbs./lm.	Pre-Wetted Rock Salt Lbs./lm	Follow Up Action	Follow Up Rock Salt Lbs./lm	Follow Up Pre- Wetted Rock Salt Lbs./lm	Comments
Above 32	Wet, slush or light snow covered.	Patrol and spot treat as needed. See comments.			Patrol and spot treat as needed. See comments.			1) Monitor pavement temperature for drops toward 32 F. 2) Blast isolated icy patches with salt, treat slushy areas beginning to freeze with 180 dry/160 pre-wet, lbs./lm and plow as needed.
Above 32, but dropping to 32 or below soon.	Dry	Apply pre-wetted rock salt or direct liquids. Patrol and spot treat as needed. See comments.		160	Patrol and spot treat as needed. See comments.			1) Monitor pavement temperature and precipitation and select appropriate follow up as conditions change.
Above 32, but dropping to 32 or below soon.	Wet, slush, or light snow covered.	Apply pre-wetted or dry rock salt, plow as needed.	180	160	Plow and re-apply pre-wetted or dry rock salt as needed. Slushy Conditions	180 115	160 100	1) If normal cycle times can not be maintained, the application rates can be increased to 220 dry/180 pre-wet, lbs./lm to accommodate longer cycles.
23 to 32	Dry	Apply pre-wetted rock salt or direct liquids.		160	See comments.			1) Monitor pavement temperature and precipitation and use select appropriate follow up as conditions change.
23 to 32	Wet, slush or light snow covered.	Apply pre-wetted or dry rock salt, plow as needed.	200	160	Plow and re-apply pre-wetted or dry rock salt as needed. Slushy Conditions	200 115	160 100	1) If normal cycle times can not be maintained, the application rates can be increased to 250dry/200 pre-wet, lbs./lm to accommodate longer cycles. 2) See notes below.
15 to 23	Wet, slush or light snow covered.	Apply pre-wetted rock salt, plow as needed.	250	200	Plow and re-apply pre-wetted rock salt as needed. Slushy Conditions	250 200	200 100	1) If normal cycle times can not be maintained, the application rates can be increased to 325 dry/250 pre-wet, lbs./lm to accommodate longer cycles. 2) See notes below.
Below 15	Dry or light snow covered. Wet and Snow/ice/slush	Plow as needed. If previous salt applications made, plow and apply pre-wetted rock salt as needed.		200	Plow as needed. If previous salt applications made, plow and re-apply pre-wetted rock salt as needed.		160	1) Abrasives can be applied to enhance traction, a heavy salt mix will create glazing. Refer to Snow & Ice Guidelines Section 5.4406 (B) for abrasive application rates. Apply rock salt in anticipation of rising temperatures. 2) If salt had been applied prior, continue with pre-wet salt as needed.

Notes: 1) Rush Period Traffic on high volume highways may require more aggressive initial treatments. 2) Use weather information to anticipate changes in storm intensity, precipitation type, and surface temperatures; Use appropriate guideline for heavier intensity or precipitation type change. 3) Rates may need to be increased if cycle times are longer than normal. 4) In the event of hard pack or icing development, adjust application rates as needed. 5) For pre-storm anti-icing operations, refer to direct liquid chemical application guides lines. Consider use of follow-up application rates for initial maintenance action if pre-storm liquid anti-icing is effective.

Oregon Department of Transportation Deicer Application Guidelines[i]

Anti-Icing (Before the Storm)			
Pavement Temperature at the time of application	Snow	Freezing Fog/Black Ice	Freezing Rain/Sleet
Over 30	15-30 (L)	15-30 (L) or 100-200 (S)	100-200 (S)
26 to 30	20-40 (L)	20-30 (L) or 100-200 (S)	100-200 (S)
21 to 25	30-50 (L)	20-40 (L) or 100-200 (S)	200-300 (S)
15 to 20	40-60 (L)	30-40 (L) or 200-300 (S)	200-400 (S)
Below 15	Not Recommended	Not Recommended	Not Recommended

Deicing (During the Storm)				
Pavement Temperature at the time of application	Light Snow (1" per hour or less)	Moderate - Heavy Snow (More than 1" per hour)	Freezing Fog/Black Ice	Freezing Rain/Sleet
Over 30	15-30 (L) or 100-200 (S)	200-300 (S)	15-30 (L) or 100-200 (S)	200-300 (S)
26 to 30	20-40 (L) or 100-200 (S)	200-300 (S)	20-40 (L) or 100-200 (S)	200-300 (S)
21 to 25	20-40 (L) or 100-200 (S)	200-400 (S)	30-50 (L) or 100-200 (S)	200-400 (S)
15 to 20	40-60 (L) or 200-300 (S)	200-500 (S)	40-60 (L) or 200-300 (S)	200-500 (S)
Below 15	PA	PA	AA	AA

After Storm (Precipitation has Stopped)			
Pavement Temperature at the time of application	Compacted/Bonded Snow	Freezing Fog/Black Ice	Freezing Rain/Sleet
Over 30	200-300 (S)	15-30 (L) or 200-300 (S)	200-300 (S)
26 to 30	200-300 (S)	20-30 (L) or 200-300 (S)	200-300 (S)
21 to 25	200-400 (S)	30-40 (L) or 200-400 (S)	200-400 (S)
15 to 20	200-500 (S)	30-50 (L) or 200-400 (S)	200-400 (S)
Below 15	PA or AA	AA	AA

(L) = Liquid Mag ($MgCl_2$) gallons per lane mile **(S)** = Solid Salt (NaCl) pounds per lane mile

PA = Plow and apply pre-wetted abrasives as needed **AA** = Apply pre-wetted abrasives as needed

Page **1** of **2**

Oregon DOT Deicer Application Guidelines (page 2 of 2)

Practical Tips/Best Management Practices

1. **These are typical application rate ranges, and can be adjusted based on pavement/weather variables and to meet operational objectives.**
2. **Generally choose a lower application rate when the pavement temperature trend is rising or steady, and a higher application rate when the temperature trend is falling.**
3. **Melting or "burning" all snow or ice from the pavement is not recommended – apply just enough to loosen the bond between the ice/compacted snow so that it can be effectively plowed off.**
4. **Time applications to prevent conditions from deteriorating and avoid the development of packed and bonded snow.**
5. **Plow as much snow and ice as possible (initial or re-application) before applying any deicing chemical. Target depth should be 2 inches or less.**
6. **Cycle times should allow time for product to work prior to plowing and re-application. Higher application rates can be used to accommodate longer cycle times by countering dilution of deicer caused by melting and/or precipitation.**
7. **All solids must be pre-wetted with liquid mag ($MgCl_2$) at a rate of 10-20 gallons/ton in order maximize effectiveness.**
8. **The application of liquid deicer is not recommended when snow/ice is too thick to see pavement or if the pavement is wet.**

ODOT Maintenance & Operations Branch – 2017

[i] The following references were used to establish the deicer application rates:

1. *Establishing Effective Salt and Anti-Icing Application Rates*, Clear Roads Research Program, 2014.
2. *Snow and Ice Control: Guidelines for Materials and Methods (Report 526),* National Cooperative Highway Research Program, 2004.
3. *Manual of Practice for an Effective Anti-Icing Program,* Federal Highway Administration, 1996.

Ohio DOT Material Application Guidelines (1 page)

Ohio Department of Transportation

Materials Application Guidelines

Conditions			Equipment	Pre-Treat	Light Snowfall*				Heavy Snowfall** w/Plowing				Freezing Rain			
Pavement Temperature Range, and Trend	Pavement surface at time of operation	Recommended Maintenance Action	Recommended Snow Removal Equipment	*** 23 % Solution of Salt Brine 23% (gal/mile)	Solid (#/mile)		*** ## Prewet solid (#/mile)	Comment #	Solid (#/mile)		*** ## Prewet solid (#/mile)	Comment #	Solid (#/mile)		*** ## Prewet solid (#/mile)	Comment #
Above 32°F Steady or rising	Dry, wet, slush, or light snow cover	Monitor Road and Weather Conditions	Front Plow Wing Plow Underbody Plow	20 - 40				1 2				1 2				
Above 32°F Below is imminent	Dry	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre-wetting Tanks	20 - 40			50 to 100				50 to 100	3				
	Wet, slush, or light snow cover	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader		50 to 100		50 to 100		200 to 300		100 to 200	3	300 to 400		200 to 300	
25°F to 32°F Remaining in range	Dry	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre-wetting Tanks	20 - 40			50 to 100				100 to 200	3				
	Wet, slush, or light snow cover	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader		100 to 200		50 to 100	5	300 to 400		300 to 400	3, 5	300 to 400		300 to 400	5
20°F to 25°F Remaining in range	Dry	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre-wetting Tanks	20 - 40			100 to 200									
	Wet, slush, or light snow cover	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader		200 to 300		100 to 200	5, 6	Max 400		Max 400	5, 6	Max 400		Max 400	5, 6
15°F to 20°F Remaining in range	Dry	Monitor Conditions						4				4				4
	Wet, slush, or light snow cover	Apply solid materials	Salt Spreader		300 to 400		300 to 400	5, 6	Max 400		Max 400	5, 6	Max 400		Max 400	5, 6
Below 15°F Steady of falling	Dry	Monitor Conditions						4				4				4
	Wet, slush, or light snow cover	Plow as needed Apply salt with calcium chloride	Front Plow Wing Plow Underbody Plow				200 to 300	5			Max 400	5	Max 400		Max 400	5

* less than 2 inch per hour ** 2 inch or more per hour
8 to 10 GALLONS of salt brine per TON is recommended for Pre-wet solid

1) Monitor temperatures and road pavement conditions for cold or icy spots. Treat problem areas as needed.
2) Treat icy spots at 100#/mile or 20 gal/mile, plow as needed.
3) Do not apply liquid to heavy snow accumulation or packed snow.
4) Do not apply chemicals and maintain dry pavement during windy conditions
5) A mixture of salt and abrasives is recommended or acceptable at these temperatures.
6) Calcium Chloride may be used in temperatures less than 25 degrees F

*** SEE ATTACHED FOR OTHER LIQUID ANTI/DE-ICER APPLICATION RATES

Maintenance Administration 10-8-2008

Table 1. Weather event: *LIGHT SNOW*
Using a 32% concentration of ***Calcium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM… plow if needed
32ºF, or below is imminent;	Dry	Apply liquid	15-35	Plow as needed; reapply liquid Chemical when needed	15-35	*Application rates will depend on dilution potential
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover		20-40		20-40	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover		30-65		30-65	* Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R	Plow as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 2. Weather event: *LIGHT SNOW STORM WITH PERIOD (S) OF MODERATE OR HEAVY SNOW*

Using a 32% concentration of ***Calcium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM… plow if needed
32ºF, or below is imminent;	Dry	Apply liquid	15-35	Plow as needed; reapply liquid Chemical when needed	15-35	*Do not apply liquid chemical onto heavy snow accumulation or packed snow * Application rates will depend on dilution potential
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover		20-40		20-40	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover		30-70		30-70	* Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R	Plow as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 3. Weather event: ***MODERATE OR HEAVY SNOW STORM***

Using a 32% concentration of *Calcium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM plow if needed
32ºF, or below is imminent;	Dry	Apply pre-wet solid NaCl	N/R	Plow accumulation and reapply pre-wet solid chemical as needed	N/R	* If sufficient moisture is present, solid chemical without pre-wetting can be applied * Do not apply liquid chemical onto heavy snow accumulation or packed snow
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover		N/R		N/R	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover		N/R		N/R	
Below 15ºF, Steady or falling	Dry or light snow cover	Plow accumulation as needed	N/R	Plow accumulation as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 4. Weather event: *FROST OR BLACK ICE*

Using a 32% concentration of *Calcium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	TRAFFIC CONDITION	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
		Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $CaCl_2$	N/R=Not Recommended
32°F, Steady or rising	Any level	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely; begin treatment if temperature starts to fall to 32°F or below and is at or below dew point
28 to 32°F, Remaining in range or falling 32°F or below, *and* equal to or below dew point	Traffic rate less than 100 vehicles per hour	Apply liquid chemical	10-25	Reapply liquid chemical as needed	10-25	* Application rates will depend on dilution potential
	Traffic rate greater than 100 vehicles per hour		20-35		20-35	
15 to 28°F, Remaining in range, *and* equal to or below dew point	Any level		20-40		25-40	* Application rates will depend on dilution potential
Below 15°F, Steady or falling	Any level	Apply abrasives	N/R	Apply abrasives as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 5. Weather event: ***FREEZING RAINSTORM***

Using a 30% concentration of *Magnesium Chloride*

Using a 32% Calcium *Chloride*

Using a 25% concentration of *CMA*

CHEMICAL APPLICATIONS: It is possible to use these chemicals during this event but is not recommended. However, these products can be used through a pre-wet system to increase solid / abrasive efficacy. The application rate for liquids alone would be cost prohibitive and the potential for dilution is high. It is recommended to use a solid chemical application or abrasives.

Using Solid *Sodium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	N/R=Not Recommended
Above 32ºF, Steady or rising	None, see comments	N/R	None, see comments	N/R	* Monitor pavement temperature closely *Treat icy patches if needed with pre-wetted solid chemical at 100--150 lb/lane-mi
32ºF, or below is imminent	Apply solid chemical	100-200	Reapply solid chemical as needed	100-200	*Monitor pavement temperature and precipitation closely * Application rates will depend on dilution potential
20 to 32ºF, Remaining in range		200-300		200-300	
15 to 20ºF, Remaining in range		250-400		250-400	
Below 15ºF, Steady or falling	Apply abrasives	N/R	Apply abrasives as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 6. Weather event: *SLEET STORM*

Using a 32% concentration of ***Calcium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Liquid $CaCl_2$	Maintenance Action	Liquid $CaCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	None, see comments	N/R	None, see comments	N/R	Go to Sodium Chloride Chart
32ºF, or below is imminent	Apply solid NaCl	N/R	Plow accumulation and reapply pre-wet solid chemical as needed	N/R	
28 to 32ºF, Remaining in range					
15 to 28ºF, Remaining in range					
Below 15ºF, Steady or falling	Plow as needed	N/R	Plow as needed	N/R	

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 1. Weather event: ***LIGHT SNOW***

Using a 30% concentration of ***Magnesium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM… plow if needed
32ºF, or below is imminent;	Dry	Apply liquid	15-35	Plow as needed; reapply liquid chemical when needed	15-35	*Application rates will depend on dilution potential
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover		20-40		20-40	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover		45-65		45-65	* Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R	Plow as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 2. Weather event: *LIGHT SNOW STORM WITH PERIOD (S) OF MODERATE OR HEAVY SNOW*

Using a 30% concentration of *Magnesium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	N/R=Not Recommended
Above 32°F, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM… plow if needed
32°F, or below is imminent;	Dry	Apply liquid	15-35	Plow as needed; reapply liquid chemical when needed	15-35	
ALSO **20 to 32°F,** Remaining in range	Wet, slush, or light snow cover		20-40		20-40	*Application rates will depend on dilution potential
15 to 20°F, Remaining in range	Dry, wet, slush, or light snow cover		45-70		45-70	* Application rates will depend on dilution potential
Below 15°F, Steady or falling	Dry or light snow cover	Plow as needed	N/R	Plow as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 3. Weather event: *MODERATE OR HEAVY SNOW STORM*

Using a 30% concentration of *Magnesium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION			SUBSEQUENT OPERATIONS		COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 15-35 GPLM plow if needed
32ºF, or below is imminent;	Dry	Apply pre-wet solid NaCl	N/R	Plow accumulation and reapply pre-wet solid chemical as needed	N/R	* If sufficient moisture is present, solid chemical without pre-wetting can be applied * Do not apply liquid chemical onto heavy snow accumulation or packed snow
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover		N/R		N/R	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover		N/R		N/R	
Below 15ºF, Steady or falling	Dry or light snow cover	Plow accumulation as needed	N/R	Plow accumulation as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

SOLID DEICER: See Sodium Chloride for application recommendations.

Table 4. Weather event: *FROST OR BLACK ICE*

Using a 30% concentration of *Magnesium Chloride*

PAVEMENT TEMPERATURE RANGE, TREND	TRAFFIC CONDITION	INITIAL OPERATION: Maintenance Action	INITIAL OPERATION: Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	SUBSEQUENT OPERATIONS: Maintenance Action	SUBSEQUENT OPERATIONS: Chemical spread rate (gal/ln-mi) Liquid $MgCl_2$	COMMENTS: N/R=Not Recommended
32°F, Steady or rising	Any level	None, see comments	N/R	None, see comments	N/R	*Monitor pavement temperature closely; begin treatment if temperature starts to fall to 32°F or below and is at or below dew point
28 to 32°F, Remaining in range or falling 32°F or below, *and* equal to or below dew point	Traffic rate less than 100 vehicles per hour	Apply liquid chemical	15-35	Reapply liquid chemical as needed	15-30	* Application rates will depend on dilution potential
	Traffic rate greater than 100 vehicles per hour		20-35		20-35	
15 to 28°F, Remaining in range, *and* equal to or below dew point	Any level		25-40		25-40	* Application rates will depend on dilution potential
Below 15°F, Steady or falling		Apply abrasives as needed	N/R	Apply abrasives as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 5. Weather event: *FREEZING RAINSTORM*

Using a 30% concentration of *Magnesium Chloride*

Using a 32% concentration of *Calcium Chloride*

Using a 25% concentration of *CMA*

CHEMICAL APPLICATIONS: It is possible to use these chemicals during this event but is not recommended. However, these products can be used through a pre-wet system to increase solid / abrasive efficacy. The application rate for liquids alone would be cost prohibitive and the potential for dilution is high. It is recommended to use a solid chemical application or abrasives.

Using Solid *Sodium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	N/R=Not Recommended
Above 32ºF, Steady or rising	None, see comments	N/R	None, see comments	N/R	* Monitor pavement temperature closely *Treat icy patches if needed with pre-wetted solid chemical at 100--150 lb/lane-mi
32ºF, or below is imminent	Apply solid chemical	100-200	Reapply solid chemical as needed	100-200	*Monitor pavement temperature and precipitation closely * Application rates will depend on dilution potential
20 to 32ºF, Remaining in range		200-300		200-300	
15 to 20ºF, Remaining in range		250-400		250-400	
Below 15ºF, Steady or falling	Apply abrasives	N/R	Apply abrasives as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 6. Weather event: *SLEET STORM*

Using a 30% concentration of ***Magnesium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Liquid $MgCl_2$	Maintenance Action	Liquid $MgCl_2$	N/R=Not Recommended
Above 32°F, Steady or rising	None, see comments	N/R	None, see comments	N/R	Go to Sodium Chloride Chart
32°F, or below is imminent	Apply solid NaCl	N/R	Plow accumulation and reapply pre-wet solid chemical as needed	N/R	
28 to 32°F, Remaining in range					
15 to 28°F, Remaining in range					
Below 15°F, Steady or falling	Plow as needed	N/R	Plow as needed	N/R	

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 1. Weather event: ***LIGHT SNOW***

Using a 23% concentration of ***Sodium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	Pavement surface at time of Initial operation	Maintenance action	Chemical spread rate (gal/ln-mi or lb/ln-mi)		Maintenance action	Chemical spread rate (gal/ln-mi or lb/ln-mi)		N/R=Not Recommended
			Liquid NaCl	Solid or pre-wet solid (lb)		Liquid NaCl	Solid or pre-wet solid (lb)	
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R		None, see comments	N/R		*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 100 lb/lane-mi; plow if needed
32ºF, or below is imminent;	Dry	Apply liquid or pre-wet solid chemical	40-50	75-125	Plow as needed; reapply liquid or solid chemical when needed	40-50	75-125	*Application rates will depend on dilution potential
ALSO **20 to 32ºF**, Remaining in range	Wet, slush, or light snow cover	Apply liquid or solid chemical	40-90	100-210		40-90	100-210	
15 to 20ºF, Remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wet solid chemical	N/R	200-240	Plow as needed; reapply pre-wet solid chemical when needed	N/R	200-240	*If sufficient moisture is present, solid chemical without pre-wetting can be applied *Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R		Plow as needed	N/R		* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 2. Weather event: *LIGHT SNOW STORM WITH PERIOD (S) OF MODERATE OR HEAVY SNOW*

Using a 23% concentration of *Sodium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS					COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi or lb/ln-mi)		Maintenance Action	Chemical spread rate (gal/ln-mi or lb/ln-mi)				N/R=Not Recommended
			Liquid NaCl	Solid or pre-wet Solid		Liquid NaCl		Solid or pre-wet solid		
						Light snow	Heavier snow	Light snow	Heavier snow	
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R		None, see comments	N/R				*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 40-65 GPLM; plow if needed
32ºF, or below is imminent;	Dry	Apply liquid or pre-wet solid chemical	40-65	75-150	Plow as needed; reapply liquid or solid chemical when needed	40-50	50-65	75-125	150-200	*Do not apply liquid chemical onto heavy snow accumulation or packed snow * Application rates will depend on dilution potential
ALSO **25 to 32ºF,** Remaining in range	Wet, slush, or light snow cover	Apply liquid or solid chemical	65-90	175-200		65-80	80-90	175-185	190-200	
15 to 25ºF, Remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wet solid chemical	N/R	200-230	Plow as needed; reapply pre-wet solid chemical when needed	N/R		200-230	200-250	* If sufficient moisture is present, solid chemical without pre-wetting can be applied * Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R		Plow as needed	N/R				* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 3. Weather event: *MODERATE OR HEAVY SNOW STORM*

Using a 23% concentration of ***Sodium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION				SUBSEQUENT OPERATIONS			COMMENTS
	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi or lb/ln-mi): Liquid NaCl	Chemical spread rate (gal/ln-mi or lb/ln-mi): Solid or pre-wet Solid	Maintenance Action	Chemical spread rate (gal/ln-mi or lb/ln-mi): Liquid NaCl	Chemical spread rate (gal/ln-mi or lb/ln-mi): Solid or pre-wet solid	N/R=Not Recommended
Above 32ºF, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R		None, see comments	N/R		*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 40-65 GPLM; plow if needed
32ºF, or below is imminent;	Dry	Apply liquid or pre-wet solid chemical	40-65	75-150	Plow accumulation and reapply liquid or pre-wet solid chemical as needed	50-65	150-200	*Do not apply liquid chemical onto heavy snow accumulation or packed snow * Application rates will depend on dilution potential
ALSO **25 to 32ºF**, Remaining in range	Wet, slush, or light snow cover	Apply solid chemical	N/R	175-200	Plow accumulation and reapply pre-wet solid chemical as needed	80-90	190-200	*Do not apply liquid chemical onto heavy snow accumulation or packed snow * Application rates will depend on dilution potential
15 to 25ºF, Remaining in range	Dry, wet, slush, or light snow cover	Apply pre-wet solid chemical	N/R	200-230	Plow as needed; reapply pre-wet solid chemical when needed	N/R	200-250	* If sufficient moisture is present, solid chemical without pre-wetting can be applied * Application rates will depend on dilution potential
Below 15ºF, Steady or falling	Dry or light snow cover	Plow as needed	N/R		Plow as needed	N/R		* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 4. Weather event: ***FROST OR BLACK ICE***

Using a 23% concentration of ***Sodium Chloride***

PAVEMENT TEMPERATURE RANGE, TREND	TRAFFIC CONDITION	INITIAL OPERATION			SUBSEQUENT OPERATIONS			COMMENTS
		Maintenance Action	Chemical spread rate (gal/ln-mi or Lb/ln-mi)		Maintenance Action	Chemical spread rate (gal/ln-mi or lb/ln-mi)		N/R=Not Recommended
			Liquid **NaCl**	Solid or pre-wet solid		Liquid **NaCl**	Solid or pre-wet solid	
32ºF, Steady or rising	Any level	None, see comments	N/R		None, see comments	N/R		*Monitor pavement temperature closely; begin treatment if temperature starts to fall to 32ºF or below and is at or below dew point
28 to 32ºF, Remaining in range or falling 32ºF or below, *and* equal to or below dew point	Traffic rate less than 100 vehicles per h	Apply liquid or pre-wet solid chemical	45-60	100-130	Reapply liquid or pre-wet solid chemical when needed	45-60	100-130	* Application rates will depend on dilution potential
	Traffic rate greater than 100 vehicles per h		45-75	100-130		45-75	100-130	
20 to 28ºF, Remaining in range, *and* equal to or below dew point	Any level		65-80	165-200		65-80	165-200	* Application rates will depend on dilution potential
15 to 20ºF, Remaining in range, *and* equal to or below dew point		Apply pre-wet solid chemical	N/R	175-225	Reapply pre-wet solid chemical when needed	N/R	175-225	
Below 15ºF, Steady or falling		Apply abrasives	N/R		Apply abrasives as needed	N/R		* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 5. Weather event: ***FREEZING RAINSTORM***

Using a 30% concentration of *Magnesium Chloride*

Using a 32% concentration of *Calcium Chloride*

Using a 25% concentration of *CMA*

CHEMICAL APPLICATIONS: It is possible to use these chemicals during this event but is not recommended. However, these products can be used through a pre-wet system to increase solid / abrasive efficacy. The application rate for liquids alone would be cost prohibitive and the potential for dilution is high. It is recommended to use a solid chemical application or abrasives.

Using Solid *Sodium Chloride*

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	N/R=Not Recommended
Above 32ºF, Steady or rising	None, see comments	N/R	None, see comments	N/R	* Monitor pavement temperature closely *Treat icy patches if needed with pre-wetted solid chemical at 100--150 lb/lane-mi
32ºF, or below is imminent	Apply solid chemical	100-200	Reapply solid chemical as needed	100-200	*Monitor pavement temperature and precipitation closely * Application rates will depend on dilution potential
20 to 32ºF, Remaining in range		200-300		200-300	
15 to 20ºF, Remaining in range		250-400		250-400	
Below 15ºF, Steady or falling	Apply abrasives	N/R	Apply abrasives as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

Table 6. Weather event: ***SLEET STORM***

Using a 23% concentration of ***Sodium Chloride***

PAVEMENT TEMPERATURE RANGE, AND TREND	INITIAL OPERATION		SUBSEQUENT OPERATIONS		COMMENTS
	Maintenance Action	Chemical spread rate, lb/lane-mi NaCl	Maintenance Action	Chemical spread rate, lb/lane-mi NaCl	N/R=Not Recommended
Above 32ºF, Steady or rising	None, see comments	N/R	None, see comments	N/R	* Monitor pavement temperature closely *Treat icy patches if needed with pre-wetted solid chemical at 100-150 lb/lane-mi
32ºF, or below is imminent	Apply solid chemical	125	Plow accumulation and reapply pre-wet solid chemical as needed	125	*Monitor pavement temperature and precipitation closely * Application rates will depend on dilution potential
28 to 32ºF, Remaining in range		125-325		125-325	
15 to 28ºF, Remaining in range		250-400		250-400	
Below 15ºF, Steady or falling	Plow as needed	N/R	Plow as needed	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction

CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to *prevent* deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.

PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible

CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.

APPENDIX C: PLOW CONFIGURATION

- *Front End Plows:* The front-end snow plow is one of the most common types of snow plow used for winter maintenance operations. The plow is mounted onto the front of a truck and is controlled by hydraulics for position and angle (Ketcham et al. 1996). In terms of size, wider plows (e.g., 14 ft in width) have become more popular because they can better clear the entire lane and push snow further away from the roadway, thus reducing the need for a second pass and improving plowing efficiency (FHWA 2012).
- *Side-Wing or Wing Plows:* The front-end plow can be integrated with one or two wing plows to cover more area and push snow further away from the side of the roadway. These types of plows, especially those of dual wings, have become increasingly popular in recent years (Conger 2005). Dual wing plows, consisting of a 12-ft wing on both sides of a maintenance truck in addition to the front plow, are much more versatile and can clear two full highway lanes or up to 24ft of roadway in one pass (Dorsey 2013). It should be noted that this type of plows also requires trucks with much higher horsepower, due to the increase in snow load being moved (Conger 2005).
- *Underbody Plows:* An underbody plow, in which the plow is installed under the truck body, has the advantage of better visibility of the road surface for the operator. In addition, underbody plows are considered to be the more effective than front plows because of the downward forces on the plow blade, which gives better results in terms of the completeness of snow removal (Nixon and Potter 1997). Because it can better clean the excess snow and ice, the amount of deicers needed can therefore be reduced.
- *Tow Plow:* Tow plows are used in conjunction with a front-end plow. A truck with a front-end plow pulls the tow plow behind and controls its position. The tow plow offers versatility for winter maintenance operations when clearing snow and ice from a multi-lane roadway. Tow plows enable one operator to clear widths of up to 25ft at high speeds (FHWA 2012). A tow plow can be used to reduce the number of passes needed to remove snow and ice from a roadway or reduce the number of plows needed on a road segment, which leads to lower costs associated with fuel savings, and reduced operator and vehicle hours.
- *Tandem or Close Echelon Plowing:* Tandem plowing or close echelon plowing is a method to operate multiple plow trucks staggered across a highway segment. It is a way of removing snow from all lanes in one direction of a multi-lane highway with one pass so that the impact on traffic can minimized (Rizzo and Moran 2013).
- *V-plow:* Front mounted V-plows can effectively handle deeper accumulations of snow and lift snow over windrows on both sides of the lane (TAC 2013).
- *Icebreaker:* Icebreaker is a steel drum with spikes that attaches to the front of a maintenance truck. The icebreaker breaks up the ice to allow a snow plow to remove excess snow and ice from the pavement. It can also provide a rough surface for better traction. The icebreaker is an alternative method for other techniques of breaking up and removing ice from roadways, such as scraping the ice with serrated grader blades and underbelly plows (Friedman 2013).

APPENDIX D: SOLID SPREADER CONFIGURATION

- *Hopper spreader*: The standard method for spreading solids is horizontal spinner with hopper (Rubin et al. 2010). Generally, hopper spreaders are self-contained units consisting of a steel V-box body, discharge/feed conveyer, spinner disc, power drive, and other necessary components. The application rate of the material can be controlled by adjusting the discharge conveyer and the gate opening on the body (TAC 2013). In practice, if a certain area is particularly close to a wetland or other area with environmental concerns, material application must be minimized in this location (Thompson and Thompson 2014). In this case, a very precise small amount of solid materials can be deployed by the hopper spreader, often in concert with liquids. Recently, the new hopper design with rear-discharge or slide-in units has become popular. Specifically, it was reported that some rear-discharge spreaders can adjust the spread pattern, such as widths and symmetry, to suit different road conditions (TAC 2013).
- *Tailgate spreader*: Compared with conventional hopper spreaders which are less versatile for other operations during the off-season, tailgate spreaders can provide multi-purpose that could be used year-round. Tailgate spreaders are filled with applied materials by raising the body, which are considered a simple and dependable unit (TAC 2013). There are several limitations, though, from dump boxes not dumping sufficient material into the hoper, inconsistent delivery, and restricted views by the operator in seeing material placement (Venner Consulting and Brinckerhoff 2004; TAC 2013).
- *Side-discharge spreader*: Another important category of solid chemical spreader that has advantage in some conditions is side-discharge spreader ahead of drive wheels. This type of application was reported can provide improved traction under the drive wheels of the spreader vehicle (TAC 2013).
- *Dual dump spreader*: Dual dump spreaders were developed specifically to address limitations of tailgate spreaders. They function as regular rear dumping bodies when not being used to apply winter maintenance materials, and can be raised and moved to the front of trucks to allow material application ahead of drive wheels, improving traction for the truck and allowing the operator to monitor application placement (TAC 2013). However, this reduces the truck’s stability and care is required by operator to ensure a precise application rate (Venner Consulting and Brinckerhoff 2004).
- *Multipurpose spreader*: Multipurpose spreaders incorporate most benefits of other spreaders (Venner Consulting and Brinckerhoff 2004). A longitudinal conveyor is usually used to transport materials to the front of a large dump box. Additionally, the material can also be transported to the left or right side of the body by a lateral conveyor (TAC 2013).

APPENDIX E: EQUIPMENT CALIBRATION

The application rates recommended for a specific snow and ice control methodology must be delivered accurately by a spreader or a distribution system carried by a maintenance truck. These spreaders operate in a very harsh environment (e.g., low temperature, high moisture, and corrosive chemicals), they must be maintained regularly for proper operations. More importantly, the material discharging systems of these trucks are controlled using either manual settings or automatic controller, of which the actual discharging rate is affected by many factors such as material types, vehicle speed, and hydraulic system. As a result, calibration is an essential procedure to measure the pounds of chemicals and sand applied to the roadway at various settings in relation to truck speed. Along with the correct application technique, proper calibration is the greatest first step towards reduced salt use and greater efficiency. A survey conducted by Kimley-Horn (2010) revealed that agencies that calibrated their spreaders realized an 8-14% reduction in salt and grit use. 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 2016). Spreaders must be calibrated individually, as the same models used on two different vehicles can have varying application rates. 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 2016). The Salt Institute's "Snowfighter's Handbook" presents an overview of the steps and calculations employed in granular spreader calibration.

The equipment that controls the spread pattern should also be calibrated to match the recommended application rates and ensure proper placement. Application equipment should be set up so that material is only applied in the travel lane, avoiding scatter or bounce that can lead to material leaving the roadway and impacting the roadside environment (Fay et al. 2013). Records of calibration results and proper calibration will allow for the most efficient use of equipment, and prevent waste or loss of product, potentially reducing impacts to the environment. Proper and frequent equipment calibration is a best management practice in itself, and can lead to cost and material savings. The importance of equipment calibration for winter road maintenance has motivated many agencies to adopt or develop standard procedures for calibrating different types of spreading systems. Transportation Association of Canada (TAC) introduced a training program for equipment calibration (TAC 2013). Equipment should be calibrated separately for all application methods – solid and liquid, and for each product type – sand, salt, salt brine, etc. 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).

The TAC (2013) recommends calibrating equipment:

- At the time it has been acquired or installed,
- Prior to the start of the winter season and points throughout the season, or when material calculations show a discrepancy

APPENDIX F: INTERVIEW QUESTIONS

Phone and in-person interviews were conducted by the research team to determine the use of winter materials by winter maintenance personnel.

Please provide:

- Name:
- Title:
- Agency:
- e-mail:
- Phone:

1. Total lane-miles/km agency responsible for
    a. total number of routes
    b. jurisdiction size (sq. m/ lm)
    c. population
    d. types and numbers of snow and ice control equipment and vehicles
    e. total number of personnel directly involved including contractors
    f. shift schedules
    g. average total snowfall amount
    h. average number of individual winter weather events that require some type of response
    i. typical winter temperature range
    j. general description of topography for the jurisdiction.
    k. any special situations or considerations, such as those specific to your particular operation, (e.g., the individual LOS structure, population density, and environmental regulations).
2. Please rank the following factors in priority order according to your agency's priorities when managing equipment, material application methodologies and material usage for snow and ice control.
    a. Climate conditions and predominant weather patterns
    b. Traffic (mobility of freight and passenger vehicles)
    c. Level of service commitments and route priorities
    d. Cycle times
    e. Material cost
    f. Material availability and stockpile locations
    g. Environmental concerns
    h. Corrosion to fleet, infrastructure, vehicles
    i. Training
    j. Other (describe)

3. Please rank the following goals in priority order according to your agency's priorities when determining equipment, material application methodologies and material usage for snow and ice control.
    a. Performance improvement
    b. Mitigate environmental impacts
    c. Reduce corrosion
    d. Reduce or control costs
    e. Other
4. Please describe your agency's most commonly used methods, equipment and liquid or solid chemicals for anti-icing.
5. Please evaluate the performance (effectiveness, reliability) of methods, equipment and liquid or solid chemicals used in Question 4. Did the usage meet your agency's demand? If not, why?
6. Please describe your agency's most commonly used methods, equipment and liquid or solid chemicals for deicing.
7. Please evaluate the performance (effectiveness, reliability) of methods, equipment and liquid or solid chemicals or equipment used in Question 6. Did the usage meet your agency's demand? If not, why?
8. Please describe your agency's most commonly used methods, equipment and liquid or solid chemicals for pre-wetting (of either solid salt or abrasives).
9. Please evaluate the performance (effectiveness, reliability) of methods, equipment and liquid or solid chemicals used in Question 8. Did the usage meet your agency's demand? If not, why?
10. During the past 10 years, has the methods, equipment and liquid or solid materials your agency using evolved?
    a. Have your agency used new technologies such as RWIS, AVL or MDSS to enhance the performance of winter material applications? If so, do you have data, graphics, or report that you could share?
11. Please briefly describe the cost of applying applications/materials for snow and ice control mentioned before.
    a. Have your agency evaluated the cost-effectiveness or efficiency of different snow/ice control materials or material application methodologies? If so, do you have data or report that you could share?
12. What are the best practices and lessons learned, the remaining knowledge gaps and research needs regarding methods, equipment and liquid or solid chemicals for snow and ice control?
13. Please list the referenced documents you and your agency uses different materials, equipment and methods, such as NCHRP Report 526 and 577.
14. Please indicate if your agency has conducted its own testing of materials.
    a. Have your agency conducted field trials that evaluate the effectiveness of different snow/ice control materials or material application methodologies?
15. Please evaluate the effectiveness and efficiency of guidelines your agency is using.
    a. Have your agency developed/used any tailored material application guidelines for your local or regional road weather scenarios?
16. How does your agency communicate the guideline's successes internally? And with the public?

    a. Briefings/meetings
    b. Regular reports disseminated internally
    c. Posting on internal website
    d. Other
    e. Don’t do anything

    And with the public?

    f. Press release
    g. Posting on agency website
    h. Posting on social media
    i. Other (511 system)
    j. Don’t do anything
17. To whom does your agency report the effectiveness of guideline used for snow and ice control?
18. Over the past 10 years, has your agency developed new or revised existing guidelines for snow and ice control? (If “yes”, please indicate what was changed and when that change occurred.)
19. Has public feedback pressured changes in how your agency defines “success” or how you set performance goals?
20. What other external or internal pressures have influenced changes in guidelines for winter operation?
21. Other information, comments or suggestions you would like to provide

CLEAR ROADS
research for winter highway maintenance

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