Synthesis of Material Application Methodologies for Winter Operations

Washington State University



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SYNTHESIS OF MATERIAL APPLICATION METHODOLOGIES FOR WINTER OPERATIONS

FINAL REPORT

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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 – MgCl₂, and calcium chloride – CaCl₂), 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.

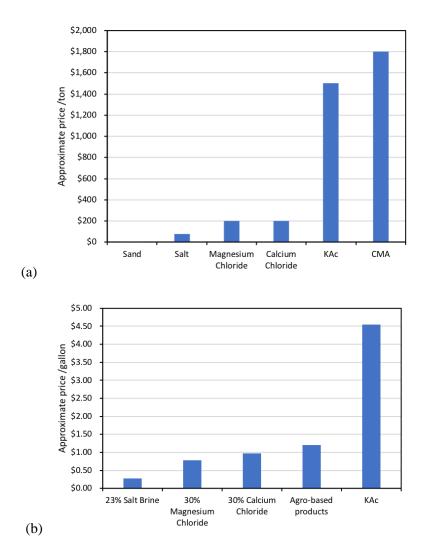
Understanding road weather is important for successful winter material application. Weather forecasting services can provide forecasts through using road-based information (TAC 2013). Precipitation can take many forms during winter storms, such as snow, frost, freezing rain, black ice, and sleet (MnDOT 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).





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⁺, Mg²⁺, Ca²⁺) 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, MgCl₂ 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, MgCl₂, and CaCl₂, 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 1/2" 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 3/8" 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 %") 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 CaCl₂ and MgCl₂ 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). MgCl₂ and CaCl₂ are common alternatives in liquid form for anti-icing or pre-wetting to NaCl. However, both CaCl₂ and MgCl₂ 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). MgCl₂ and CaCl₂ 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%, MgCl₂ and CaCl₂ 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, MgCl₂ and CaCl₂ 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 CaCl₂ and MgCl₂ 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. MgCl₂ and CaCl₂ remain effective down to -10° F and -20° F, respectively, while only down to 15°F for NaCl (Ketcham et al. 1996). Liquid MgCl₂ 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, MgCl₂ is more corrosive to automobile components than NaCl under humid environments (Xi and Xie 2002). Liquid NaCl, MgCl₂ or CaCl₂ 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 MgCl₂ 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 agrobased 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.

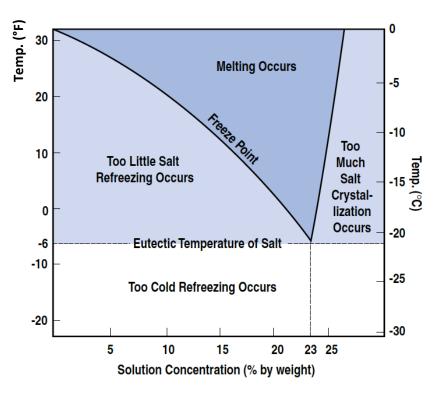


Figure 2: Phase diagram for the salt-water system (Salt Institute 2016)

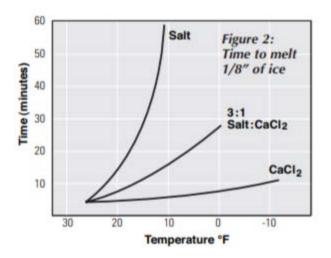


Figure 3: Time to melt 1/8" of ice (Wisconsin TIC 2005)

Table 1: Practical or effective working temperatures of	of chloride- and acetate-based materials
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Lowest practical working temperature (°F)	Reference	Lowest practical working temperature (°F)	Reference
NaCl: Average 16°F, Most Common 15°F		MgCl ₂ : Avera	ge 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. Prewetting solid deicers with liquid chemicals can be used for either anti-icing or deicing strategies. Prewetting 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 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 CaCl₂ and MgCl₂, as expected, outperformed dry salt in most test cases, with CaCl₂ outperforming MgCl₂ (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 cleanup 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. Prewetted 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 Jeng 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 antiicing, 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, CaCl₂, MgCl₂, 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.

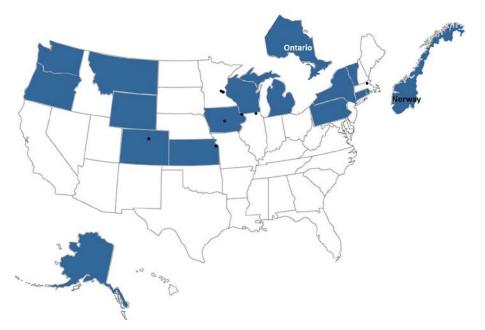


Figure 10: Map of Interviewee locations

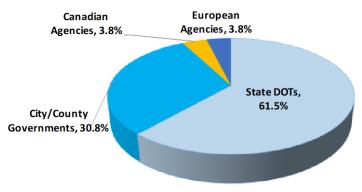


Figure 11: Distribution of Agency Category

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).

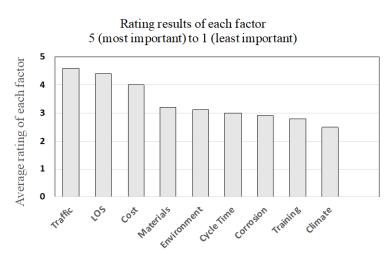


Figure 12: Ranking of factors according to agency's priorities when managing equipment, material application methodologies and material usage for snow and ice control

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.

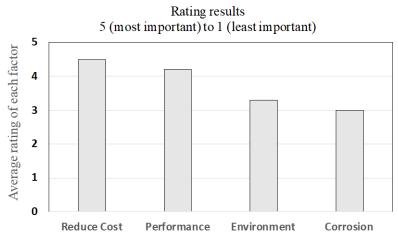


Figure 13: Ranking of goals according to agency's priorities when managing equipment, material application methodologies and material usage for snow and ice control

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 MgCl₂, CaCl₂, and/or organic-based chemicals during some winter events (e.g., solid NaCl prewet with MgCl₂, or solid NaCl prewet with a brine composed of 90% salt brine and 10% CaCl₂ 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 MgCl₂, CaCl₂, 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
 - <u>Application Rates of Pre-Wet Salt</u>: 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 (CaCl₂, MgCl₂, 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
 - <u>Salt-Additive Rate to Abrasives:</u> 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
 - <u>Automated Application Rate Spreaders:</u> 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). MgCl₂ and CaCl₂ 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% CaCl₂ or 30% MgCl₂ 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, MgCl₂ at 0.55 - 1/gallon, CaCl₂ 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 to heavy snow application rates ranged from 100 to 250 pounds per lane mile depending on pavement surface and temperature 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 CaCl₂ 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

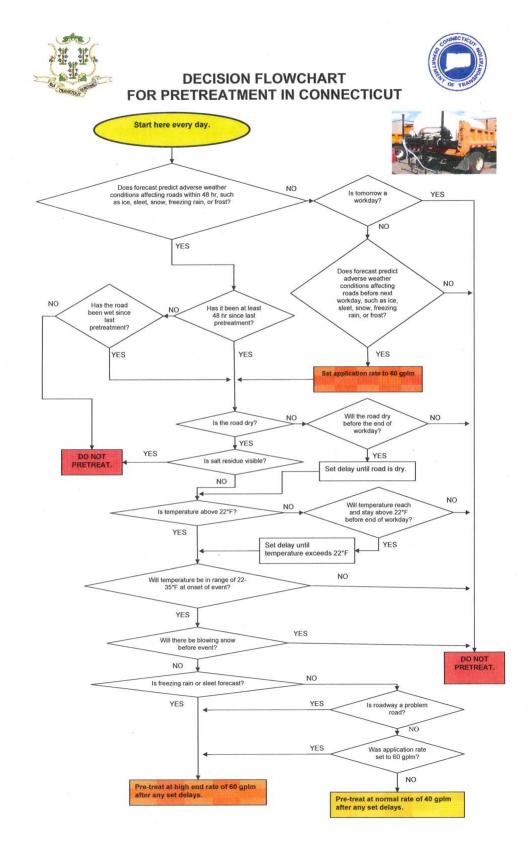
Colorado DOT (1 page)

Pavemer	nt	Weather	Pound	s Per 2-La	ne Mile	
Temp		Conditions	100% Salt	50/50	Stock-pile	Actions & Recommendations
	٨	Snow	150-300	N/R	N/R	Plow & Treat HAZARDS Only!
Above 30°	f	Frz Rain	150-300	N/R	N/R	Apply As Needed
ADOVE 30	F	Snow	200-400	N/R	N/R	Plow & Apply As Needed
	•	Frz Rain	200-400	N/R	N/R	Apply As Needed
	•	Snow	200-400	N/R	N/R	Plow & Apply As Needed
25° to 30°	Т	Frz Rain	200-400	N/R	N/R	Apply As Needed
25 10 30	f	Snow	300-500	N/R	N/R	Plow & Apply As Needed
	· ·	Frz Rain	300-500	500-750	N/R	Apply As Needed
	←	Frz Rain	300-500	500-750	N/R	Apply As Needed
20° to 25°	F	Snow	300-500	N/R	N/R	Plow & Apply As Needed
	×.	Frz Rain	400-500	500-750	N/R	Apply As Needed
	*	Snow	300-500	N/R	N/R	Plow & Apply As Needed
15° to 20°	f	Frz Rain	400-500	500-750	N/R	Apply As Needed
	≯	Snow	400-500	500-750	500-750	Plow & Apply As Needed
Below 18	5°	Snow	N/R	N/R	500-750	Plow & Treat HAZARDS Only!
	ROS	T: 15°F & Rising: T	reat by ANTI-IC	ING (Brine @	20-40G/LM) or	15°F &Falling: 100% SALT (150#/LM)

1	-		-	s Per 2-La		Rate Recommendation Chart
Pavemer	nt	Weather	Pound			Actions & Decommondations
Temp		Conditions	RG8 Salt	R ^{G8} Sand	Clearl ane	Actions & Recommendations
	*	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
Above 30°	т	Frz Rain	N/R	N/R	N/R	Use Salt/Brine
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
5	*	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
25° to 30°	T	Frz Rain	N/R	N/R	N/R	Use Salt/Brine
20 10 50	J	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
	· ·	Frz Rain	N/R	N/R	N/R	Use Salt/Brine
	1	Frz Rain	N/R	N/R	N/R	Use Salt/Brine
20° to 25°	f	Snow	N/R	N/R	N/R	Plow, use Salt with Brine
	× .	Frz Rain	300-350	350-500	N/R	Use Salt/Brine
61		Snow	200-350	N/R	100-250	Plow, use Salt or Sand with Brine
15° to 20°	Ť	Frz Rain	300-350	350-500	200-300	Use Salt/Brine
	4	Snow	300-350	350-500	300-500	Plow, use Salt or Sand with Brine
Below 15	5°	Snow	350-500	350-500	300-500	Plow & treat HAZARDS only
FROST: 1	5°F & I	Rising: Treat by AN	TI-ICING (BRIN	E@20-40G/LM) or 15°F &Falli	ing: RG8 SALT@100#/LM or RG8 SAND@200#/LM

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 OP	ERATIONS			ONGOING (PERATION	NS	
			Spread Rate (Per Lane M			Spread Rat (Per Lane M	e Range	
PAVEMENT TEMPERATURE RANGE AND TREND Above 32 F	Initial Surface Conditions	Suggested Actions	Pre-wet* Solid Salt	Dry Salt	Suggested Actions NONE	Pre-wet* Solid Salt	Dry Salt	COMMENTS
Above 32 F Steady or Rising	Dry, wet, slush or light snow cover	NONE See comments			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

Illinois DOT (page 2 of 5)

November 15, 1999

Table 1

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

	INITIAL OP	ERATIONS			ONGOING O	PERATION	S	
			Spread Rat (Per Lane I			Spread Rat (Per Lane I		
<u>PAVEMENT</u> <u>TEMPERATURE</u> 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	6.1		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

Illinois DOT (page 3 of 5)

November 15, 1999

Table 1

Moderate or Heavy Snow Storm

	INITIAL O	PERATIONS			ONGOING 0	PERATIO	NS	
			Spread Rate (Per Lane M			Spread Ra (Per Lane		
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 0	PERATIONS			ONGOING	OPERATI	ONS	
			Spread Rat (Per Lane)			Spread Ra (Per Lane		
<u>PAVEMENT</u> <u>TEMPERATURE</u> 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 Ibs.	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 OP	ERATIONS			ONGOING O	PERATION	S	
			Spread Rate (Per Lane M			Spread Rate (Per Lane M		
<u>PAVEMENT</u> <u>TEMPERATURE</u> <u>FORECAST</u> 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	A11	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

Iowa DOT (1 page)

Roadway Su	Prewetted Salt @	32-30	29-27	26-24	23-21	20-18	17-15
Pounds	Heavy Frost Mist Light Snow	50	75	95	120	140	170
of Salt	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' wid	e lane (a	ssume 3-			
Roadway Sur	face Temp - Fahrenheit	32-30	29-27	26-24	23-21	20-18	17-15
Pounds	Heavy Frost Mist Light Snow	75	115	145	180	210	255
of Salt	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

Road Road Surface Imperature Product Rate at Time of Initial Product Rate at Time of Action Product Rate Brine Sait Sait Maintenance Maintenance Brine Froduct Rate Sait Product Rate Brine Comments Above 32 ⁶ r, Range Dry, wet, Sub or light Action Brine None, Sait when None, Sait when Sait Maintenance Brine Brine mile, Above 32 ⁶ r, Sait when Sait Montor rad temps closely for would 32 ⁶ and below. Above 32 ⁶ r, Steady or rising Dry, wet, sismunient Apply brine or sow cover 45 125-200 Plow as a sub or light 2.0 on closed ber sow accumulation or packed sait when 1.155-200 at lower temps and higher sow at lower temps and higher sow at low or close blow 3.6 Above 32 ⁶ r Dry, wet, brine range Apply sait from temp and temp crose blow 3.6 1.155-200 at lower temp and spite sow at low or close blow 3.6 Above 32 ⁶ r Dry, wet, simminent Apply sait from second temps fait a 2.5 2.0 on close blow 3.6 4. one road temps fait a 2.5 Above 32 ⁶ r Dry, wet, simminent Apply sait from second temps fait a 2.5 2.0 on explore blow 3.5 4. one road temps fait a 2.5 Above 31 ⁶ r, simminent Dry, wet, simminent Apply sait from second temps fait a 2.5			Initial Operation	tion		Subseq	Subsequent operations	SU	
Road Surface Product Rate Product Rate at Time of Initial Maintenance Action Brine Brine Brine Brine Salt Maintenance Brine Brine Salt Maintenance Brine Salt Pounds Dry, wet, Isush or light None, Slush or light None, Slush or light See comments Salt None, Salt when Salt when Iane mile Jane mile									
at Time of Initial Maintenance Action Brine Gallons Sait Annemile Maintenance Action Brine Gallons Sait Pounds Operation Action Gallons Pounds Action Gallons Pounds Dry, wet, slush or light None, see comments None, see comments None, see comments Apply brine or sati when 45 125-200 Pounds 125-200 Vet, slush Apply brine or prewetted salt 45 125-200 Polw as salt when 125-200 Wet, slush Apply salt 125-200 Polw as salt when 125-200 125-200 Vet, slush Apply salt 125-200 Readed, reapply 125-200 125-200 Vet, slush Apply salt 125-200 Readed, reapply 125-200 125-200 Vet, slush Apply salt 125-200 Readed, reapply pre- salt when 125-200 125-200 Vet, slush Apply salt 125-200 Readed, reapply pre- salt when 125-200 125-200 Vet, slush Apply Apply salt 125-200 Readed, reapply pre- salt when 125-200 Dry, wet, Pow as needed, reapply pre- slus	Road	Road Surface		Produ	ct Rate		Produc	ct Rate	
Initial Action Gallons Pounds Operation Action Gallons Pounds Dry, wet, None, Jane mile Anne mile Jane mile Bry, wet, None, None, See comments See comments slush or light see comments see comments See comments Anne mile Dry Apply brine or 45 125-200 Plow as 125-200 Vet, slush Apply salt 45 125-200 Plow as 125-200 Vet, slush Apply salt 125-200 Plow as 125-200 Vet, slush Apply salt 125-200 Reded, reapply 125-200 Silk Net, slush Apply salt 125-200 Reded, reapply Silk Net, slush None, reded Reapply pre-	Temperature	at Time of	Maintenance	Brine	Salt	Maintenance	Brine	Salt	Comments
Operation /lane mile /lane mile /lane mile /lane mile /lane mile /lane mile Dry, wet, slush or light snow cover None, see comments None, see comments None, see comments None, see comments None, see comments None, see comments Dry Apply brine or prewetted salt 45 125-200 Plow as salt when 125-200 Wet, slush Apply salt 125-200 needed, reapply salt when 125-200 Vet, slush Apply salt 125-200 needed, salt when 125-200 Or light Prevetted salt 200 wetted salt 200 Dry, wet, snow cover Plow as wetted salt 200 Dry or light Plow as wetted salt 200 Dry or light Plow as meeded 200 Snow cover Plow as meeded meeded	Range	Initial	Action	Gallons	Pounds	Action	Gallons	Pounds	
Dry, wet, slush or light see commentsNone, see commentsDryApply brine or snow cover45125-200Plow as see commentsDryApply salt45125-200Plow as salt when125-200Wet, slushApply salt125-200Plow as salt when125-200Wet, slushApply salt125-200Plow as salt when125-200Wet, slushApply salt125-200Plow as salt when125-200Wet, slushApply salt125-200Plow as salt when125-200Dry, wet,Apply salt125-200Plow as salt when125-200Dry, wet,Apply salt125-200Plow as seded,125-200Dry, wet,Apply salt200Plow as wetted salt200Dry or lightPlow as neededPlow as needed,200Dry or lightPlow as neededPlow as neededPlow as needed200Dry or lightPlow as neededPlow as neededPlow as neededPlow as neededDry or lightPlow as neededPlow as neededPlow as neededPlow as neededPlow as neededPlow as neededDry or lightPlow as neededPlow		Operation		/lane mile	/lane mile		/lane mile	/lane mile	
Dry, wet, slush or light snow cover None, see comments Dry Apply brine or prewetted salt 45 125-200 Plow as salt when 125-200 Vet, slush Apply salt 45 125-200 Plow as salt when 125-200 Vet, slush Apply salt 125-200 Plow as salt when 125-200 Vet, slush Apply salt 125-200 Reapply Vet, slush Apply salt 125-200 Now cover Apply salt 125-200 Dry, wet, Plow as needed, 125-200 Dry or light Plow as Plow as needed, Suow cover Plow as Plow as needed, Dry or light Plow as Plow as Dry or light									1. Monitor road temps closely for drops
slush or light snow cover see comments see comments Dry Apply brine or prewetted salt 45 125-200 Plow as asit when 125-200 Wet, slush Apply salt 125-200 Plow as asit when 125-200 125-200 Wet, slush Apply salt 125-200 Plow as asit when 125-200 Wet, slush Apply salt 125-200 Plow as needed, when needed 125-200 Dry, wet, Apply 125-200 Plow as needed, when needed 125-200 Dry or light Prewetted salt 200 wetted salt Dry or light Plow as now cover Plow as needed, when needed 200 Dry or light Plow as now cover Plow as needed, when needed 200	Above 32 ^o F,	Dry, wet,	None,			None,			toward 32 [°] F and below.
snow cover Apply brine or prewetted salt 45 125-200 Plow as needed, reapply 125-200 Vet, slush Apply salt 45 125-200 Plow as 125-200 Vet, slush Apply salt 125-200 Plow as 125-200 Vet, slush Apply salt 125-200 Plow as Vet, slush Apply salt 125-200 125-200 Vet, slush Apply salt 125-200 Plow as Dry, wet, Apply 200 Reapty pre- Suow cover Plow as Plow as needed, 200 Dry or light Plow as Plow as Plow as	steady or rising	slush or light	see comments			see comments			2. Treat icy patches with salt, if needed, at
DryApply brine or prewetted salt45125-200Plow as125-200Wet, slushprewetted saltaslt when salt whenneeded, reapply125-200Wet, slushApply salt125-200needed125-200Wet, slushApply salt125-200needed125-200Wet, slushApply salt125-200needed125-200Wet, slushApply salt125-200needed125-200Or lightReaply re-Needed125-200125-200Dry, wet,Apply200Reapply pre-200Dry or lightPlow asNeeted salt200Dry or lightPlow asNeeted200Snow coverNeededPlow asPlow asDry or lightPlow asPlow asDry or		snow cover							150 lbs/lane mile; plow if needed.
DryApply brine or prewetted salt45125-200Plow as salt when125-200Wet, slushApply salt									1. Applications will need to be more frequent
prevetted salt needed, reapply salt when salt when needed needed, reapply Wet, slush Apply salt 125-200 Net, slush Apply salt 125-200 Or light Plow as needed, 125-200 Dry, wet, Apply 200 Reapply pre- wetted salt Dry or light Plow as 200 Dry or light Plow as Plow as Dry or light Plow as needed	Above 32 ⁰ F,	Dry	Apply brine or	45	125-200	Plow as		125-200	at lower temps and higher snowfall rates
Wet, slush Apply salt aslt when Wet, slush Apply salt 125-200 or light needed 125-200 snow cover Plow as needed, 125-200 Dry, wet, Apply 200 Reapply pre- slush or light prewetted salt 200 Reapply pre- Dry or light Plow as wetted salt 200 Dry or light Plow as needed plow as	32 ⁰ F or below		prewetted salt			needed, reapply			2. Do not apply salt brine when the
Wet, slush Apply salt 125-200 or light 125-200 snow cover 125-200 Dry, wet, Apply salt Dry, wet, Apply salt slush or light Plow as needed, Dry or light Plow as	is imminent					salt when			pavement temp drops below 20 ⁰ F.
Wet, slush Apply salt 125-200 125-200 or light integration or light integration or light integration or light Dry, wet, Apply 200 Reapply pre- 200 slush or light prewetted salt 200 Reapply pre- 200 Dry or light prewetted salt when needed, 200 200 Dry or light plow as needed 200 seapply pre- 200 Dry or light plow as needed needed 200 200 Dry or light plow as needed needed 200 200	ALSO					needed			3. Do not direct apply salt brine onto heavy
or light snow cover Dry, wet, Bry, wet, Slush or light snow cover bry or light Plow as bry or light Plow as needed Plow as needed Plow as needed Plow as needed	20 to 32 ⁰ F	Wet, slush	Apply salt		125-200			125-200	snow accumulation or packed snow.
snow cover Dry, wet, slush or light snow cover Dry or light Plow as needed, 200 Reaphy pre- wetted salt when needed Plow as needed needed	remaining in range	or light							4. Once road temps fall to 25°F, prewet salt
Dry, wet, slush or light Apply prevetted salt 200 Reapply pre- 200 Slush or light prevetted salt when needed 200 Dry or light Plow as Plow as Plow as Dry or light needed needed		snow cover							with CaCl.
Dry, wet, Apply 200 Reapply pre- 200 slush or light prewetted salt 200 wetted salt 200 snow cover when needed meeded Plow as Plow as Dry or light Plow as needed needed needed						Plow as needed,			
slush or light prewetted salt wetted salt snow cover by the needed when needed bry or light plow as needed needed needed needed needed needed	15 to 20 ⁰ F	Dry, wet,	Apply		200	Reapply pre-		200	
snow cover when needed when needed bry or light plow as plow as needed needed needed	remaining in range	slush or light	prewetted salt			wetted salt			
Dry or light Plow as Plow as snow cover needed		snow cover				when needed			
Dry or light Plow as Plow as snow cover needed needed									1. It is not recommended that salt be applied
snow cover needed needed	Below 15 ⁰ F,	Dry or light	Plow as			Plow as			in this temperature range. If an application is
Cacl. 2. Abrasives can be applied to e traction.	steady or falling	snow cover	needed			needed			warranted, the salt must be prewetted with
2. Abrasives can be applied to e traction.									CaCl.
traction.									2. Abrasives can be applied to enhance
_									traction.

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.

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Kentucky Snow and Ice Treatment Recommendations Light Snow Storm With Periods of Moderate to Heavy Snow
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		Initial Operation	tion		Subseq	Subsequent operations	ns	
						Produ	Product rate	
Road	Road Surface		Produ	Product Rate		Light Snow	Heavy Snow	
Temperature	at Time of	Maintenance	Brine	Salt	Maintenance	Salt	Salt	Comments
Range	Initial	Action	Gallons	Pounds	Action	Pounds	Pounds	
	Operation		/lane mile	/lane mile		/lane mile	/lane mile	
								 Monitor road temps closely for drops
Above 32 ⁰ F,	Dry, wet,	None,			None,			toward 32 [°] F and below.
steady or rising	slush or light	see comments			see comments			Treat icy patches with salt, if needed, at
	S NOW COVER							150 lbs/lane mile; plow if needed.
								1. Applications will need to be more frequent
Above 32 ⁰ F,	Dry	Apply brine or	45	125-200	Plow as			at lower temps and higher snowfall rates
32 ⁰ F or below		prewetted salt			needed, reapply			Do not apply sait brine when the
is imminent					salt when	200	250	pavement temp drops below 20 [°] F.
ALSO					needed			After heavy snow periods and during light
25 to 32 ⁰ F	Wet, slush	Apply salt		125-200				snowfall, reduce salt rates to 200 lb/lane mile
remaining in range	or light							continue to plow and apply salt as needed.
	S NOW COVER							Once road temps fall to 25^oF, prevet
								salt with Ca Cl.
					Plow as needed,			 Reduce salt rate to 250 lb/lane mile after
15 to 25 ⁰ F	Dry, wet,	Apply		250	Reapply pre-	250	300	heavier snow periods and during light
remaining in range	slush or light	prewetted salt			wetted salt			snowfall. Continue to plow and apply salt as
	s now cover				when needed			needed.
								 It is not recommended that salt be applied
Below 15°F,	Dry or light	Plow as			Plow as			in this temperature range. If an application is
steady or falling	S NOW COVER	needed			needed			warranted, the salt must be prewetted with
								CaCl.
								Abrasives can be applied to enhance
								traction.
NOTES:	NOTES: Salt Applications (1)	1) Time initial and	subsequent:	alt application	is to prevent deter	iorating cond	tions or deve	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. 7 ļ 2

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

NULES: Salt Applications (1) lime 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.

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ucky Snow and Ice Treatment Recommendations.	Freezing Rain Storm
Kentuck	

	Initial (Initial Operation	Subsequen	Subsequent operations	
Road					Comments
Temperature	Maintenance	Salt Application Rate	Maintenance	Salt Application Rate	
Range	Action	(lb/lane mile)	Action	(lb/lane mile)	
Above 32 ⁰ F,	None,		None,		 Monitor pavement temperature closely for drops toward 32^{°F} and below.
steady or rising	see comments		see comments		Treat icy patches if needed with prewetted salt at 150 lbs/lane mile.
Above 32 [°] F,	Apply	180-200	Reapply prewetted	180-200	Monitor pavement temperature and
32 [°] F or below is imminent	prewetted salt*		salt as needed		precipitation closely.
					1. Monitor pavement temperature and
20 to 32 ⁰ F	Apply	200-250	Reapply prewetted	200-250	precipitation closely
remaining in range	prewetted salt*		salt as needed		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.
					1. Monitor precipitation closely.
15 to 20 ⁰ F	Apply	250-400	Reapply prewetted	250-400	2. Increase application rate toward higher
remaining in range	prewetted salt*		salt as needed		rate if intensity of freezing rain increases.
					3. Decrease application rate toward lower
					rate if intensity of freezing rain decreases.
					It is recommended that salt NOT be applied
Below 15 ⁰ F,	Apply abrasives			Apply abrasives	in this temperature range. However, if an
steady or falling				as needed	application is warranted, the salt must be
					prewetted with CaCl.
Matter Calt And Institute (1) T	a bare bare a second				

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. $\mbox{*}$ Once road temps drop to $25^{0} F$ or below, prewet salt with CaCl.

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

tally based o	n your expe	rience.		
		Gallons/La	ane Mile	
Condition	CaCl _z	MgCl ₂	Salt Brine	Other Products
1. Regularly scheduled applications	15 - 25	15 - 25	20 - 40	Follow manufacturers'
2. Prior to frost or black ice event	15 – 25	15 – 25	20 - 40	recommendations.
3. Prior to light or moderate snow	15 - 25	15 - 25	20 – 50	

Anti-icing Application Rate Guidelines These guidelines are a starting point. Reduce or increase rates incremen-An Har Ka

Deicing Application Rate Guidelines	24' of pavement (typical two-lane road)	alues, but rather the low end of a range to be selected and adj	the iter is a state of a subscription of the state of the
Deicing Applic	24' of pavemen	d values, but rather	to its local and its

These rates	s are not fix	74 or pavenient (typical two-rails today) These rates are not fixed values, but rather the low end of a range to be selected and adjusted twan anoncy according to its local conditions and experience	c+ or pavement (typical two-tails today ues, but rather the low end of a range t s local conditions and experience	rend of a rang	e to be selecte	ed and adjusted
in An						
				Lbs/ two	Lbs/ two-lane mile	
Pavement Temn (°F)	Weather	Maintenance	Salt Prowottod/	Salt Promottod/	Dry Salt*	Winter Sand
and Trend	Collation		Pretreated	Pretreated		(covice) lub
(t)			With Salt	With Other		
			Brine	Blends		
>30°†	Snow	Plow, treat	80	70	100*	Not
		intersections only	(40/lane mile)			recommended
	Frz. rain	y 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	- 200*	Not recommended
	Frz. rain	Apply chemical	150 - 200	130 180	180 - 240*	Not recommended
Z5 - 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 - 22° 🕇	Snow	Plow & apply chemical	200 - 280	175-250		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
12 - 20° 🕇	Snow or Frz. rain	Plow & apply chemical	240-320	210 – 280	300 400*	500 for frz. rain
0 to 15° 11	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 r	not recomme	*Dry salt is not recommended. It is likely to blow off the road before it melts ice	to blow off the r	oad before it n	nelts ice.	

**A blend of 6 – 8 gal/ton MgCl₂ or CaCl₂ added to NaCl can melt ice as low as -10°.

5						
			Application	Rate Reco	Application Rate Recommendation Chart	Chart
	Pavement	Weather	Pounds F	Pounds Per Two (2) Lane Mile	Lane Mile	Actions & Annlication
	Temp	Conditions	100% Salt	50% Salt	Stock Pile	Recommendation
		Snow	150-300	Not Recommended	Not Recommended	Plow, Treat Hazards ONLY
	Above 30° 1	Freezing Rain	150-300	Not Recommended	10N Hecommended	Apply As Needed
	→	Snow	200-400	Not Recommended	Not	Plow & Apply As Needed
		Freezing Rain	200-400	Not Recommended	Not Not	Apply As Needed
		Snow	200-400	Not Recommended	Not Recommended	Plow & Apply As Needed
eyj	25° to 30° 1	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
	+	Snow/ Frz Rain	300-500	500-750	Not Recommended	Plow & Apply As Needed
	20° to 25°	Snow	300-500	Not Recommended	Not Recommended	Plow & Apply As Needed
	•	Freezing Rain	400-500	200-750	Not Recommended	Apply As Needed
	+	Snow	300-500	Not Recommended	Not Recommended	Plow & Apply As Needed
	15° to 20°	Freezing Rain	400-500	200-750	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	200-750	Plow, Treat Hazards w/ Stockpile
	FROST: 15"	8. RISING: TREAT	BY ANTI-ICIN	G (Brine 20-4	0 G/LM) or 15"	FROST: 15" & RISING: TREAT BY ANTI-ICING (Brine 20-40 GAM) or 15" & FALLING: 100% SALT @ 150 #AAM
	WIND CONDITI	IONS: PLOW, TREA	VT (TROUBLE S	POTS ONLY!)	WITH 50/50 @;	WIND CONDITIONS: PLOW, TREAT (TROUBLE SPOTS ONLY!) WITH 50,50 @ 300#/LM OR STOCKPILE @ 200-400 #/LM
	IF EVEN	T/SHIFT TEMPERA	ATHRES WILL	BICE LICE CAL	IT INCTEAD OF	IL EVENT/CULIET TEMBERATI IBES MULL R/CE TICE CALT INCITEAD OF CAMD (8, visor varies as formore fail)

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Anoka County Minnesota:

Table 133.5.3.6.5 Continuous Operations Routes

Salt spread rates tion Salt spread rates tion Pre-wetted Brine solid salt gal/In-mi) mi) ee 100 44 pply 200 87 solid salt 200 87 pply 250 87 solid salt 250 87 lation 250 87	PAVEMENT		INITIAL OPERATION	ATION		SUBSEQUE	SUBSEQUENT OPERATIONS	SNO	COMMENTS
MD TREND surface at initial action operation Pre- solid salt (Ib/In-mi) Bine (Ib/In-mi) action (Ib/In-mi) Pre-wetted (Ib/In-mi) Bine (Ib/In-mi) action Pre-wetted solid salt Bine (Ib/In-mi) F Dy, wet, sush or cover Dy, wet, ight snow None, see (Ib/In-mi) None, see (Ib/In-mi) None, see (Ib/In-mi) Solid salt (gal/In- im) F, 32°F or cover Dy Apply brine or salt 100 44 Plow 100 44 F, 32°F or cover Dry Apply brine or salt 100 44 Plow 100 44 remaining or light pre-wetted solid 150-200 65-87 Plow 200 87 In range Dry Apply brine or sold salt 35 needed 36 36 37 In range Dry Apply brine or sold salt 150-200 65-87 Plow 200 87 In range Dry Apply brine or sold salt 35 Plow 250 7 In range Solid salt Drow cover Solid salt <td< th=""><th>TEMPERATURE</th><th>Pavement</th><th>Maintenance</th><th>Salt sprea</th><th>d rates</th><th>Maintenance</th><th>Salt sprea</th><th>nd rates</th><th></th></td<>	TEMPERATURE	Pavement	Maintenance	Salt sprea	d rates	Maintenance	Salt sprea	nd rates	
time of operation time of billol (b/ln-mi) wetted (b/ln-mi) (gal/ln- mi) solid salt (b/ln-mi) solid salt (b/ln-mi) solid salt (b/ln-mi) (gal/ln- mi) F Dy, wet, slush or cover None, see subs or cover None, see comments None, see comments see comments see comments see comments see comments see comments see comments see cover see comments see cover see cover see cover se see cover see cover	RANGE AND TREND	surface at	action	Pre-	Brine	action	Pre-wetted	Brine	
Operation Solid sail III) IIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIIII IIIIIIII IIIIIIIIIII IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII		time of		wetted	(gal/In-		solid salt	(gal/ln-	
F Dry, wet, sush or cover None, see sush or salt None, see comments F, 32°F or cover Dry Apply brine or salt 100 44 Plow 100 44 F, 32°F or cover Dry Apply brine or salt 100 44 Plow 100 44 minent; Salt Apply brine or snow cover 100 44 Plow 44 remaining or light Plow and reapply 200 87 87 nrange Dry Apply brine or salt 150-200 65-87 Plow 200 87 in range Salt Apply brine or salt 150-200 65-87 Plow 200 87 in range Salt Apply brine or salt 150-200 65-87 Plow 250 87 in range Salt Plow 250 Plow 250 7 in range Salt Plow 250		operation		(lb/ln-mi)	Î		(1111-111/01)	Î	
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g in range pre-wetted solid accumulation accumulation salt and reapply wet, slush, Apply brine or 150-200 65-87 brine or solid salt or light pre-wetted solid solid salt as needed as needed as needed as needed as the snow cover salt inght snow wetted solid salt cover and reapply brine or solid salt of talling show cover and reapply brine or solid salt ar needed as	20 to 30°F		Apply brine or	150-200		Plow		87	1) If the desired plowing/treatment frequency
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or light pre-wetted solid as needed snow cover saft 250 PF, remaining Dry, wet, Apply pre- sush, or wetted solid salt 200 ilight snow and reapply and reapply cover as needed as needed PF, Dry or light Plow as needed ofF, Dry or light Plow as needed		ľs,	Apply brine or	150-200		brine or solid salt			operational cycles
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Dry or light Plow as needed 250 250 snow cover accumulation as beeded 250 accumulation as 250 accumulation		cover				brine or solid salt			operational cycles
Dry or light Plow as needed Plow 250 I accumulation as 250 I needed						as needed			Liquid calcium chloride may be used for pre-
Dry or light Plow as needed Plow 250 snow cover accumulation as 250 needed									wetting salt at colder temperatures
snow cover accumulation as needed	Below 10°F,		Plow as needed			Plow	250		 As pavement becomes slick apply salt/abrasive
	steady or falling					accumulation as			mix to enhance traction. Salt will have limited
						needed			melting power in this temperature range.

Type 1 Winter Event: More than 12 in. of snow in 24 hours OR more than $^3\!4$ in. of ice

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.

Missouri DOT (page 1 of 5)

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RE Pavement Maintenance Saft spread rates Saft spread rates END surface at action Pre- Brine Saft spread rates Surface at initial action Pre- Brine Saft spread rates Dry, wet, see Dry, wet, see solid saft (gal/In-mi) (Ib/In-mi) mi) Operation None, see comments fib/In-mi) None, see solid saft (gal/In-mi) mi) Dry, wet, such one ments Ib/In-mi) None, see comments fib/In-mi) mi) Over Dry, wet, comments Ib/In-mi) None, see comments fib/In-mi) Nore, see solid saft none, see comments fib/In-mi) mi) Over Dry pre-wetted solid 100 44 accommutation Net, slush, Apply brine or 150-200 65-87 Plow 200 87 Net, slush, wet, abply brine or 150-200 65-87 Plow 200 87 Net, slush, wet, abply brine or 150-200 65-87	PAVEMENT		INITIAL OPERATION	ATION		SUBSFOUE	SUBSECUENT OPERATIONS	SNOL	COMMENTS
E AND TREND Taventer Description Description <thdescription< th=""> <thdescription< th=""> <t< td=""><td>TEMPEDATIDE</td><td>Devemont</td><td>Maintonanco</td><td>Calt enros</td><td>d rates</td><td>Maintonanco</td><td>Colt enro</td><td>ad rates</td><td></td></t<></thdescription<></thdescription<>	TEMPEDATIDE	Devemont	Maintonanco	Calt enros	d rates	Maintonanco	Colt enro	ad rates	
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or light pre-wetted solid as needed as needed anow cover salt Dry, wet, Apply pre- bry, wet, Apply pre- bry, wet, Apply pre- light snow wetted solid salt and reapply brine or solid salt as needed brine or solid salt as needed bry or light Plow as needed accumulation as snow cover anow cover anow and reacting and rea		sh,	Apply brine or	150-200	65-87	brine or solid salt			operational cycles
snow cover salt 250 Dry, wet, Apply pre- slush, or 200 Plow Slush, or wetted solid salt and reapply slush, or wetted solid salt and reapply light snow snow cover brine or solid salt Dry or light Plow as needed Plow Dry or light Plow as needed Plow			pre-wetted solid			as needed			Do not apply brine onto heavy snow
Dry, wet, Apply pre- slush, or wetted solid salt light snow cover cover Dry or light Plow as needed as needed as needed accumulation as needed as needed accumulation as 250 how 250 h			salt						accumulation or packed snow
slush, or wetted solid salt accumulation light snow brine or solid salt and reapply brine or solid salt as needed as needed as needed accumulation as 250 how cover needed accumulation as heeded		Dry, wet,	Apply pre-	200		Plow	250		 If the desired plowing/treatment frequency
light snow and reapply cover brine or solid salt brine or solid salt as needed Dry or light Plow as needed snow cover accumulation as needed		slush, or	wetted solid salt			accumulation			cannot be maintained, the spread rate can be
cover brine or solid salt Dry or light Plow as needed Snow cover accumulation as needed		light snow				and reapply			increased to 500 lb/lane-mi to accommodate longer
Dry or light Plow as needed 250 snow cover accumulation as needed needed 250		cover				brine or solid salt			operational cycles
Dry or light Plow as needed Plow 250 snow cover accumulation as needed needed						as needed			Liquid calcium chloride may be used for pre-
Dry or light Plow as needed Plow 250 snow cover accumulation as needed									wetting salt at colder temperatures
snow cover accumulation as needed	Below 10°F,	Dry or light	Plow as needed			Plow	250		 As pavement becomes slick apply salt/abrasive
	steady or falling	snow cover				accumulation as			mix to enhance traction. Salt will have limited
						needed			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.

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Table 133.5.3.6.3 Continuous Operations Routes

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PAVEMENI		INITIAL OPERATION	VIION		SUB	SEQUEN	SUBSEQUENT OPERATIONS	TIONS		COMMENTS
TEMPERATURE	Pavement	Maintenance	Salt spread rates	rates	Maintenance		Salt spread rates	ad rates		
KANGE AND TREND	surface at time of initial	action	Pre- wetted solid salt	Brine (gal/In- mi)	action	Pre-wet s (Ib/li	Pre-wetted solid salt (Ib/In-mi)	Br (gal/	Brine (gal/In-mi)	
	operation		(im-nl/dl)			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					 Monitor pavement temperature closely for drops toward 32°F and below Treat slick patches if needed with pre- wetted salt at 100 lb/lane-mi or brine 44 qal/ln-mi: plow if needed
Above 32°F, 32°F or below is imminent; M. SO	Dry	Apply brine or pre-wetted salt	100	44	Plow as needed; reapply brine or pre-wetted	100	200	44	8	 Applications will need to be more frequent at lower temperatures and higher snowfall rates Do not apply brine onto heavy snow
20 to 32°F, remaining in range	Wet, slush, or light snow cover	Apply brine or pre-wetted salt	100	44	when needed					accumutation of packed show 3) After heavier snow process and during light snow fall, reduce saft rate to 100 lb/lane-mi or 44 gal/ln-mi brine; continue to plow and apply saft as needed
10 to 20⁰F, 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			 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 10°F, steady or falling	Dry or light snow cover	Plow as needed			Plow and apply salt/abrasive mix as needed					 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. How before 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.

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PAVEMENT		INITIAL OPERATION	ATION		SUBSEQUENT OPERATIONS	NT OPERAT	TIONS	COMMENTS
TEMPERATURE	Pavement	Maintenance Salt Spread Rates	Salt Sprea	d Rates	Maintenance	Salt Spread Rates	ad Rates	
RANGE AND	surface at	action	Pre-	Brine	action	Pre-	Brine	
TREND	time of initial		wetted solid salt	(gal/ln- mi)		wetted solid salt	(gal/In- mi)	
	operation		(Ib/In-mi)			(Ib/In-mi)		
Above 32°F, steady or rising	Dry, wet, shish or	None, see			None, see			1) Monitor pavement temperature closely for drops toward 320E and helow
	light snow							2) Treat icy patches if needed with pre-
	cover							wetted solid salt at 100 lb/lane-mi; plow if needed
Above 32°F,	Dry	Apply brine or	100	44	Plow as	100	44	1) Applications will need to be more
32°F or below is		pre-wetted			needed; reapply			frequent at lower temperatures and higher
imminent;		solid salt			liquid or solid			snowfall rates
					chemical when			It is not advisable to apply a straight
ALSO	Wet, slush,	Wet, slush, Apply liquid or	100	44	needed			brine at the indicated spread rate when the
15 to 32°F,	or light	solid salt						pavement temperature drops below 20°F
remaining in range	snow							Do not apply brine onto heavy snow
	cover							accumulation or packed snow
0 to 15°F,	Dry, wet,	Apply pre-	200		Plow as	200		1) Abrasives may be added to the salt to
remaining in range	slush, or	wetted solid			needed; reapply			enhance traction at colder temperatures
	light snow	chemical			pre-wetted solid			2) Liquid calcium chloride may be used for
	cover				chemical when			pre-wetting solid salt at colder
					needed			temperatures
Below 0°F,	Dry or light Plow as	Plow as			Plow and apply			1 If pavement becomes slick apply
steady or falling	snow	needed			salt/abr. mix as			salt/abrasive mix to enhance traction. Salt
	cover				needed			will have limited melting power in this
								temperature range.
								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.

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Table 133.5.3.6.1 Continuous Operations Routes

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

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

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.

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

BLACK ICE

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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. Notes:

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Durace remp. Burrace		Rock	Rock	Follow Up Action	гоцоw Up Rock	Follow Up Pre- Wetted	Comments
Condition	on Maintenance Action	Salt Lbs./Im.	Salt Lbs./Im		Salt Lbs./Im	Rock Salt Lbs./Im	
Wet or	Apply pre-wetted			Monitor precipitation and			1) Monitor pavement closely and anticipate
Slushy	or dry rock salt, plow if plowable.	115	06	temperature.			drops toward 52° F and below. 2) Adjust application rates as surface conditions and precipitation intensities change.
Wet or	Apply pre-wetted			Re-apply pre-wetted or dry			1) Monitor pavement temperatures and
Slushy	or dry rock salt,	180	115	rock salt as needed.	180	115	precipitation closely. 2) Treat icy patches and
	plow if plowable.						colder areas with higher applications. 3) Increase applications if precipitation intensity increase or surface shows states of some
Wet or	Applv pre-wetted			Re-apply pre-wetted or dry			1) Monitor pavement temperatures and
Slushv	or dry rock salt.	275	225	rock salt as needed.	275	225	precipitation closely and adjust application
	plow if plowable.						rates as surface conditions and precipitation intensities observed [3] Trust intensities and
	•						colder areas with higher applications. 3)
							Increase applications if precipitation intensity
							increase or surface shows signs of icing.
Icy	Apply pre-wetted			Re-apply pre-wetted or dry			1) Use Application Kate for "wet and slushy"
	or dry rock salt.	360	320	rock salt as needed.	360	320	when iting condition is removed. 2) increase application rate if precipitation intensity
							increases or if pavement shows signs of re-
							freezing.
Wet or	Apply pre-wetted			Re-apply pre-wetted or dry			1) Monitor pavement temperatures and
Slushv	or dry rock salt	360	275	rock salt as needed.	360	275	precipitation closely and adjust application
	alour if alourable						rates as surface conditions and precipitation
	prow II prowaoto.						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.
Icy	Apply pre-wetted			Re-apply pre-wetted or dry			 Use Application Rate for "wet and slushy"
•	or dry rock salt	450	360	rock salt as needed	450	360	when icing condition is removed. 2) Increase
							application rate if precipitation intensity
							increases or if pavement shows signs of re-
							freezing.
Dry, wet or	or Apply abrasives			Re-apply abrasives			Refer to Snow and Ice Guidelines Section
irv							5.440 (B) for application rates.

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.

Notes:

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DnMaintenanceSait Lbs./hmSait Lbs./hmKeek Sait Lbs./hmPatrol and spotLbs./hmLbs./hmLbs./hmLbs./hmLbs./hmPatrol and spotFatrol and spotPatrol and spotReaded. See comments.See comments.See comments.Patrol and spotRe-apply pre-wetted or dry115Apply pre-wetted11590Re-apply pre-wetted or dry11590Apply pre-wetted180115pow if plowable.11590115Apply pre-wetted180115rock salt as needed.18011590Apply pre-wetted180115rock salt as needed.18011590Apply pre-wetted180115rock salt as needed.18011590Apply pre-wetted180115rock salt as needed.225180115Plow if plowable.225180rock salt as needed.275225225Plow if plowable.255rock salt as needed.275225180Apply pre-wetted275225rock salt as needed.275225Plow if plowable.255plow if plowable.275225225Apply abrasives.Apply abrasives.Apply abrasives.Apply abrasives.275225	Surface Temp.		Initial	Dry Rock	Pre-Wetted Rock	Pre-Wetted Follow Up Action	Follow Up Rock	Follow Up Pre- Wetted	Comments
2 Dry Patrol and spot Ibs./Im. Ibs./Im. Ibs./Im. Ibs./Im. 2 Dry Patrol and spot hs./m. Ibs./Im. Ibs./Im. Ibs./Im. 2 Dry Patrol and spot reat as needed. Featrol and spot reat as 2 Snow, Apply pre-wetted 115 90 rock salt as needed. 90 2 Snow, Apply pre-wetted 115 90 rock salt as needed. 115 90 2 but Snow, Apply pre-wetted 115 90 rock salt as needed. 115 90 2. but Snow, Apply pre-wetted 180 115 rock salt as needed. 180 115 2. but Snow, Apply pre-wetted 180 115 rock salt as needed. 180 115 3. but Snow, Apply pre-wetted 180 115 rock salt as needed. 180 115 oon wet. plow if plowable. 225 180 115 115 oon wet. plow if plowable. 225 180 125 shush, or or dry rock salt rock salt as needed. 275 225 wet. plow if plo	Range (° F)	Condition	Maintenance	Salt	Salt		Salt	Rock Salt	
2 Dry Patrol and spot treat as Patrol and spot treat as 2 Snow, Apply pre-wetted, 115 90 2 Snow, Apply pre-wetted, 115 90 needed. See comments. 2 Snow, Apply pre-wetted, 115 90 needed. See comments. 90 2 Snow, Apply pre-wetted, 115 90 nock salt as needed. 115 90 2. but Snow, Apply pre-wetted 180 115 90 115 2. but Snow, Apply pre-wetted 180 115 nock salt as needed. 116 115 0.0.n. wet. plow if plowable. 180 115 nock salt as needed. 115 115 0.n. wet. plow if plowable. 180 115 nock salt as needed. 125 180 115 0.n. Met. plow if plowable. 225 180 125 180 115 0.n. Snow, Apply pre-wetted 275 225 180 125 180 125 0.n.			Action	Lbs./lm.	Lbs./Im		Lbs./Im	Lbs./Im	
2Interest as needed. See comments.Interest as needed.Interest as needed. <thi< td=""><td>Above 32</td><td>Dry</td><td>Patrol and spot</td><td></td><td></td><td>Patrol and spot treat as</td><td></td><td></td><td>1) Monitor pavement temperatures closely and</td></thi<>	Above 32	Dry	Patrol and spot			Patrol and spot treat as			1) Monitor pavement temperatures closely and
2Snow, slush, or wet.See comments.>>>>2Snow, wet.Apply pre-wetted plow if plowable.11590Re-apply pre-wetted or dry rock salt as needed.115902. but st 0.32 or st 0.0n.Snow, wet.Apply pre-wetted plow if plowable.180115902. but st 0.32 or st 0.32 or wet.Snow, plow if plowable.18011590Re-apply pre-wetted or dry rock salt as needed.1803. but st 0.32 or st 0.30.Apply pre-wetted plow if plowable.180115901155Any or wet.Apply pre-wetted plow if plowable.2251801805AnyApply abrasives.235235235235600.Apply abrasives.275225225225			treat as needed.			needed. See comments.			anticipate drops toward 32 F and below. 2)
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wet.plow if plowable.plow if plowable.2, butSnow,Apply pre-wettedRe-apply pre-wetted or dry1152, butSnow,Apply pre-wetted180115115on.wet.plow if plowable.180115rock salt as needed.180on.wet.Apply pre-wetted225180rock salt as needed.180shush, oror dry rock salt.225180rock salt as needed.225180shush, oror dry rock salt.275225180rock salt as needed.275225shush, oror dry rock salt.275225rock salt as needed.275225shush, orplow if plowable.275225rock salt as needed.275225shush, orplow if plowable.Paply pre-wetted or dry275225225shush, orplow if plowable.Paply abrasives.Paply abrasives.Paply abrasives.Paply abrasives.		slush, or	or dry rock salt,	115	06	rock salt as needed.	115	<u> 00</u>	anticipate drops toward 32F. 2) Treat icy
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on. wet. plow if plowable. on Snow, Apply pre-wetted Re-apply pre-wetted or dry Snow, Apply pre-wetted 225 slush, or or dry rock salt, 225 wet. plow if plowable. 225 Snow, Apply pre-wetted 225 slush, or or dry rock salt, 275 slush, or or dry rock salt, 275 wet. plow if plowable. 275 slush, or or dry rock salt, 275 slush, or plow if plowable. 275 shush, or plow if plowable. 275 Any Apply abrasives. Re-apply abrasives.	dronning to 32 or	shish or	or dry rock salt	180	115	rock salt as needed	180	115	precipitation closely. 2) Treat icy patches and
DOL. Wet. PHOW IL PLOW ADLE. Sinow, Apply pre-wetted Re-apply pre-wetted or dry Sinsh, or or dry rock salt, 225 wet. Plow if plowable. Sinow, Apply pre-wetted Sinsh, or or dry rock salt, vet. Plow if plowable. Sinsh, or or dry rock salt, vet. plow if plowable. Sinsh, or or dry rock salt, vet. plow if plowable. Any Apply abrasives.	to be an end of the second								colder areas with higher application rates. 3)
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slush, or or dry rock salt, wet. 225 180 rock salt as needed. 225 180 wet. plow if plowable. 215 180 Re-apply pre-wetted or dry 275 225 Snow, Apply pre-wetted 275 225 rock salt as needed. 275 225 slush, or or dry rock salt, plow if plowable. 275 225 rock salt as needed. 275 225 5 Any Apply abrasives. Re-apply abrasives. Re-apply abrasives. 205 225	23 to 32	Snow,	Apply pre-wetted			Re-apply pre-wetted or dry			 Monitor pavement temperatures and
wet. plow if plowable. Snow, Apply pre-wetted Snow, Apply abrasives. Snow, Apply abrasives.		shish or	or dry rock salt	200	180	rock salt as needed	205	180	precipitation closely. 2) Treat icy patches and
wct. prow it prow ut prow dotted Re-apply pre-wetted or dry 275 Snow, Apply pre-wetted 275 225 slush, or or dry rock salt, prow if plowable. 275 225 wet. plow if plowable. 275 225 5 Any Apply abrasives. Re-apply abrasives.		areate	alour if alourable		2				colder areas with higher application rates. 3)
Snow, Apply pre-wetted Re-apply pre-wetted or dry 275 slush, or or dry rock salt, 275 225 rock salt as needed. wet. plow if plowable. 275 225 225 5 Any Apply abrasives. Re-apply abrasives. 225		MCL.	prow II prowaute.						Increase application rates if precipitation
Snow, Apply pre-wetted Re-apply pre-wetted or dry 275 225 slush, or or dry rock salt, 275 225 rock salt as needed. wet. plow if plowable. 275 225 225 5 Any Apply abrasives. Re-apply abrasives. 225									intensity increases.
slush, or or dry rock salt, 275 225 rock salt as needed. 275 225 wet. plow if plowable. 275 225 Re-apply abrasives. 275 225 Any Apply abrasives. Re-apply abrasives. Re-apply abrasives. 275 225	15 to 23	Snow,	Apply pre-wetted			Re-apply pre-wetted or dry			1) Monitor pavement temperatures and
wet. plow if plowable. Any Apply abrasives. Re-apply abrasives.		slush. or	or dry rock salt.	275	225	rock salt as needed.	275	225	precipitation closely. 2) Treat icy patches and
wet. plow 11 plow 2016. Any Apply abrasives. Re-apply abrasives. Condition.		+	alamit alamia						colder areas with higher application rates. 3)
Any Apply abrasives. Re-apply abrasives.		MCI.	plow II plowable.						Increase application rates if precipitation
Any Apply abrasives. Re-apply abrasives. condition.									intensity increases.
tition.	Below 15	Any	Apply abrasives.			Re-apply abrasives.			1) Refer to Snow and Ice Guidelines Section
		condition.							5.4406 (B) for abrasive application rates.

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

New York DOT (page 3 of 5)

SLEET

April, 2006 (Revised January 2012)

C – 6

LIGHT SNOW	s than $\frac{1}{2}$ "/hour, visibility > $\frac{1}{2}$ mile)
Г	(Less than

Surface Temp.	Surface	Initial	Dry	Pre-Wetted	Follow Up Action	Follow Up	Follow Up	Comments
Range (° F)	Condition	Maintenance	Kock Salt	Kock Salt	•	Kock Salt	Pre- Wetted Rock Salt	
)		Action	Lbs./Im.	Lbs./Im		Lbs./lm	Lbs./lm	
Above 32	Wet, slush or light snow	Patrol and spot treat as needed.			Patrol and spot treat as needed. See comments.			 Monitor pavement temperature for drops toward 32 F. 2) Blast isolated icy patches with salt, treat slushy areas beginning to freeze with
	covered.	See comments.						180 dry/160 pre-wet, lbs./Im and plow as needed
Above 32, but dropping to 32 or	Dry	Apply pre-wetted rock salt or direct		160	Patrol and spot treat as needed. See comments.			 Monitor pavement temperature and precipitation and select appropriate follow up
below soon.		liquids. Patrol						as conditions change.
		and spot treat as needed. See						
		comments.						
Above 32, but	Wet, slush, or	Apply pre-wetted			Plow and re-apply pre-			1) Application will need to be more frequent at
dropping to 32 or	light snow	or dry rock salt,	180	160	wetted or dry rock salt as	115	100	lower temperature and higher snowfall rates. 2) Adiust application rates as surface
below soon.	covered.	plow as needed.			needed.			conditions and precipitation intensities change.
23 to 32	Dry	Apply pre-wetted			See comments.			1) Monitor pavement temperature and
		rock salt or direct		160				precipitation and use select appropriate romow
		liquids.						up as condutons change.
23 to 32	Wet, slush or	Apply pre-wetted			Plow and re-apply pre-			1) Application will need to be more frequent at
	light snow	or dry rock salt,	200	160	wetted or dry rock salt as	115	100	lower temperature and higher snowfall rates.
	covered.	plow as needed.			needed.			 Adjust application rates as surface conditions and precipitation intensities change.
15 to 23	Wet, slush or	Apply pre-wetted			Plow and re-apply pre-			1) If sufficient moisture is present, dry rock
	light snow	rock salt, plow as	250	200	wetted rock salt as needed.	180	160	salt can be applied. Dry pavement at these
	covered.	needed.						temperatures is petter left uniteated if snow does not track to surface.
Below 15	Dry or light	Plow as needed.			Plow as needed.			1) Abrasives can be applied to enhance
	snow covered.							uacuon, a neavy sair mix will create glazing. Refer to Snow & Ice Guidelines Section
		If previous salt			If previous salt applications			5.4406 (B) for abrasive application rates.
	Wet and	applications			made, plow and re-apply			Apply rock salt in anticipation of nsing
	Snow/ice/slush	made, plow and		200	pre-wetted rock salt as		160	temperatures.
		apply pre-wetted			needed.			z) It sait hat been applied prior, commue with pre-wet sait as needed.
		needed						
]					
Notes: 1) Kush P	eriod Tratfic on m	igh volume highways	may requi	re more aggi	gressive initial treatments. 2) Us	Ise weather info	ormation to anti	1) Kush Period I rathe on high volume highways may require more aggressive initial treatments. 2) Use weather information to anticipate changes in storm intensity,

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 guide anti-icing is effective. C - 7 April, 2006 (Revised November 2014) Supersedes January 2012 revision

New York DOT (page 4 of 5)

Kock Kock Kock Salt Salt Salt Lbs./Im.
160
160
2
160
160
160
200
200

MODERATE OR HEAVY SNOW

New York DOT (page 5 of 5)

April, 2006 (Revised January 2012)

	Anti-Icing	Anti-Icing (Before the Storm)	
<u>Pavement</u> 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

Oregon Department of Transportation Deicer Application Guidelines¹

		Deicing (During the Storm)		
Pavement Temperature	Light Snow (1" per hour	Moderate - Heavy Snow (More		factor Data /Class
at the time of application	or less)	than 1" per hour)	Freezing Fog/ black ice	Freezing Kain/Sieet
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
	Afte	After Storm (Precipitation has Stopped)	pped)	
Townships of the second s				

	After Storm (I	After Storm (Precipitation has Stopped)	
<u>Pavement</u> 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

Page 1 of 2

AA = Apply pre-wetted abrasives as needed (S) = Solid Salt (NaCl) pounds per lane mile

PA = Plow and apply pre-wetted abrasives as needed (L) = Liquid Mag (MgCl2) gallons per lane mile

Oregon DOT Deicer Application Guidelines (page 1 of 2)

- These are typical application rate ranges, and can be adjusted based on pavement/weather variables and to meet operational objectives. ÷
- 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. <u>ה</u>
- 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. ÷.
- Time applications to prevent conditions from deteriorating and avoid the development of packed and bonded snow. 4
- 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. <u>ە</u>
- 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. . ف
- All solids must be pre-wetted with liquid mag (MgCl2) at a rate of 10-20 gallons/ton in order maximize effectiveness. 2.
- The application of liquid deicer is not recommended when snow/ice is too thick to see pavement or if the pavement is wet. ø.



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Page 2 of 2

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

Establishing Effective Salt and Anti-Icing Application Rates, Clear Roads Research Program, 2014.

Snow and Ice Control: Guidelines for Materials and Methods (Report 526), National Cooperative Highway Research Program, 2004. 5

^{3.} Manual of Practice for an Effective Anti-Icing Program, Federal Highway Administration, 1996.

		Ohio	Ohio Department of Transportation	tment	of T	ran	s b	or	atio	L C					
			Materia	Materials Application Guidelines	ation G	Suide	line	S							
0	Conditions		Equipment	Pre-Treat	Light \$	Light Snowfall*	*	Hea	Heavy Snowfall** ^{w/Plowing}	vfall** g		Freezing Rain	ng Ra	in	
Pavement Temperature Rance, and Trend	Pavement surface at time of operation	Recommended Maintenance Action	Recommended Snow : Removal Equipment	 23% Solution of Salt Brine 23% (cal/mile)	Solid (#/mile)	Prewet solid (#/mile)	≣ crĕ≢	Solid (#/mile)		Prewet ##	Comment #		Prewet solid (#/mile)	16	# tnemmo
Above 32°F Steady or rising	Dry, wet, slush, or light snow cover		Front Plow Wing Plow Underbody Plow	20 - 40			2 1					4			
Above 32°F	лı	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre- wetting Tanks	20 - 40		5 2 2 2				855	e				
Below is imminent	Wet, slush, or light snow cover	App ly liquid or prewetted solid	Anti-Iding System or Salt Spreader		50 to 100	10 to 20		200 300 to		100 200 to	300 400		200 to 300		
25°F to 32°F	ы	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre- wetting Tanks	20 - 40		50 100 100			4	100 to 200	3				
Remaining in range	Wet, slush, or light snow cover	Apply liquid or prewetted solid	Anti-Iding System or Salt Spreader		100 to 200	50 100	2 P	300 to 400		300 to 400	3, 5 to 400		300 to 400		5
20°F to 25°F	Dry	Apply liquid or prewetted solid	Anti-Icing System or Salt Spreader and Pre- wetting Tanks	20 - 40		100 to 200									
Remaining in range	Wet, slush, or light snow cover	App ly liquid or prewetted solid	Anti-Iding System or Salt Spreader		200 to 300	100 to 200	έγ	6 Max 400		5 Max 400	5, 6 Max 400	00	Max 400		5, 6
	Dry	Monitor Conditions					4				4			~	4
15°F to 20°F. Remaining in range	Wet, slush, or light snow cover	Apply solid materials	Salt Spreader		300 to 400	300 to 400	ŝ	6 Max 400		5 Max 400	5, 6 Max 400	00	Max 400		5, 6
	Dry	Monitor Conditions					4				4			~	4
Below 15°F Steady of falling	Wet, slush, or light snow cover	P low as needed Apply salt with cal clum chloride	Front Plow Wing Plow Underbody Plow			200 300	°°		_	Max 400	5 Max 400	0	Max 400		ŝ
					* 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	ch per hour ONS of salt	brine per	TON is rev	** 2 inch or more per hour FON is recommended for Pre	our Pre-wet sol	P				
 Monitor temperatures and road pavement conditions for cold or ky spots. Treat problem areas as needed. Treat ky spots at 100# mile or 20 gal/mile, piow as needed. Do not apply liquid b heavy smow accumulation or packed and/or conditions Do not apply licture to maintain dry pavement during windy conditions A mixture of sait and abrasives is recommended or accgrabile at these temperatures. A mixture of sait and abrasives is recommended or accgrabile at these temperatures. Calcium Chloride may be used in temperatures less than 25 degrees F 	Ind road pavement. Imile or 20 gal/mile eavy snow accumu i and maintain dory vrasives is recommu- ie used in temperat	conditions for cold or icy, a, plow as needed. Jiation or packed snow. pavement during windy co nended or acceptable at th tures less than 25 degrees	spots. Treat problem area inditions see temperatures. 5 F	as as needed.		80 1	EATTA	CHED FOI	*** SEE ATTACHED FOR OTHER LIQUID ANTIVE-ICER APPLICATION RATES	IID ANT/DE	-ICER AP	PLICATION	RATES		

Ohio DOT Material Application Guidelines (1 page)

Maintenance Administration 10-8-2008

		T Usin	Table 1. We g a 32% com	Table 1. Weather event: <u>LIGHT SNOW</u> Using a 32% concentration of <u>Calcium Chloride</u>	<u>HT SNOW</u> um Chloriu	le
	INI	INITIAL OPERATION	N	SUBSEQUENT OPERATIONS	RATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid CaCl2	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid CaCl2	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		15-35		15-35	1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 - 1 -
ALSO 20 to 32°F, Remaining in range	Wet, slush, or light snow cover	Apply liquid	20-40	Flow as needed, reapply liquid Chemical when needed	20-40	Application rates will depend on dilution potential
15 to 20°F, Remaining in range	Dry, wet, slush, or light snow cover		30-65		30-65	* 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
HEMICAL APPI event deteriorating	LICATIONS: The conditions or dev	ese application rate velopment of packe	es are starting po	ints. Local experience sho now. Monitor temperature	ould refine these e and humidity t	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control of CHEMICAL RATES: The recommended snot on how these conditions are expected to change	e applying any ici ES: The recomme ions are expected i	e control chemical, inded snow and ice to change over the	, the surface sho control materia time period (wi	PLOWING: Defore applying any ice control chemical, the surface should be cleared of as much show and ice as possible CHEMICAL RATES : The recommended snow and ice control material application rates depend on atmospheric and pave on how these conditions are expected to change over the time period (window) between the current treatment and the next of	snow and ice as on atmospheric it treatment and t	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.
OLID DEICER: S	See Sodium Chlor	SOLID DEICER: See Sodium Chloride for application recommendations.	recommendatio	ns.		

		160	100 0/7C B ST			1
	INI	INITIAL OPERATION	N	SUBSEQUENT OPERATIONS	RATIONS	COMMENTS
PAVEMENT TEMPERATURE	Pavement surface at time	Maintenance	Chemical spread rate (gal/ln-mi)		Chemical spread rate (gal/h-mi)	
RANGE, AND TREND	of Initial operation	Action	Liquid CaCl2	Maintenance Action	Liquid CaCl2	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		15-35		15-35	*Do not apply liquid chemical onto heavy snow
ALSO 20 to 32°F, Remaining in range	Wet, slush, or light snow cover	Apply liquid	20-40	Plow as needed; reapply liquid Chemical when needed	20-40	accumuation or packed show * Application rates will depend on dilution potential
15 to 20°F, Remaining in range	Dry, wet, slush, or light snow cover		30-70		30-70	$\ensuremath{^{\ast}}$ 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
IEMICAL APPL	ICATIONS: The conditions or dev	ese application rate velopment of pack	es are starting po ed and bonded s	vints. Local experience sho now. Monitor temperature	wild refine these e and humidity t	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	e applying any ice	e control chemical,	, the surface sho	chemical, the surface should be cleared of as much snow and ice as possible	snow and ice as	possible
HEMICAL RATE how these conditi	S: The recomme ons are expected	inded snow and ice to change over the	e control materiz	il application rates depend ndow) between the current	on atmospheric t treatment and 1	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	see Sodium Chlor	ride for application	1 recommendation	.SD(

Washington State DOT (page 2 of 18)

ATTON SUBSEQUENT OPERATIONS ATTON Chemical spread rate chemical spread rate (gal/In-mi) Liquid Liquid CaCl2 N/R N/R None, see comments N/R N/R	Intral OPERATION SUBSEQUENT OPERATIONS Pavement Favement Superad rate surface at time Maintenance Specad rate of Action Chemical Spread rate of Action Spread rate Spread rate of Action Chemical Spread rate of Action Spread rate Spread rate Dry, wet, stush, None, see N/R N/R Dry, wet, stush, or None, see N/R N/R Dry, wet, stush, or N/R N/R N/R Dry Met, stush, or N/R N/R Dry Wet, stush, or Solid NaCl N/R Dry, wet, stush, or Solid NaCl N/R N/R Dry or ligh			Usin	ıg a 32% con	Using a 32% concentration of <i>Calcium Chloride</i>	um Chlori	te
Pavement surface at time of Initial operationChemical spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate spread rate spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate spread rate (gal/h-mi) Liquid CaCl2Chemical spread rate spread rate (gal/h-mi) Liquid (gal/h-mi) Liquid (gal/h-mi) Liquid (gal/h-mi) Liquid (gal/h-mi) (ga	PAYENEXT RAVENCY ENTRATICRE ADD TREND ADD TREND ADD TREND Pertation ADD TREND Present ADD TREND P		INI	TIAL OPERATIO	N	SUBSEQUENT OPE	RATIONS	COMMENTS
Dry, wet, stush, couterNone, see conmentsN/RNone, see commentsN/RDryDryN/RN/RN/RN/RN/RDryDryMet, slush, or ight snowM/RN/RN/RDry, wet, slush, or light snowM/RPlow accumulation and coverN/RN/RDry, wet, slush, or light snowN/RPlow accumulation and coverN/RDry or light snowN/RN/RN/RDry or light snowN/RN/RN/R	Above 32°F. Dry, wet, stash, cover None, see cover N/R *Monitor parement temperature closely *Treat icy patches if needed with chemical at 15.35 GPL M plow if needed 32°F. Dry without pre-weth 15.35 GPL M plow if needed 32°F. Dry *Treat icy patches if needed 32°F. N/R *Test icy patches if needed 32°F. N/R *Test stypetches if needed 32°F. N/R N/R *Test stypetches if needed 415/0 Wet, stush, cover N/R * Test sufficient moisture is present, solid chemical at needed 15 to 20°F. Dry, wet, stush, cover N/R * Test sufficient moisture is present, solid chemical	PAVEMENT EMPERATURE RANGE, AND TREND	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid CaCl2	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid CaCl2	N/R=Not Recommended
DryDryN/RN/RWet, slush, or light snowApply pre-wetN/RN/RWet, slush, or light snowApply pre-wetN/RN/RDry, wet, slush, or light snowN/RN/RN/RDry, wet, slush, or light snowN/RN/RN/RDry, wet, slush, or light snowN/RN/RN/RDry or light snow coverPlowN/RN/RDry or light snow neededN/RPlow accumulation as neededN/R	329F, or below is imminent:Dry or below is imminent:N/RN/RIf sufficient moisture is present, solid chemical without pre-wetting can be applied apply pre-wet solid N/RN/RIf sufficient moisture is present, solid chemical and sepold chemical onto heavy snow without pre-wetting can be applied accountation or 32°F, inght snowN/RN/RIf sufficient moisture is present, solid chemical and N/R20 to 32°F, emaining in range coverDry, wet, slush, or light snow or light snowN/RPlow accumulation and themical as needed N/RN/RN/R* Do not apply liquid chemical onto heavy snow accumulation or packed snow15 to 20°F, emaining in range coverDry wet, slush, or light snow or superN/RPlow accumulation as accumulation as N/RN/R* It is not recommended that chemicals be applied in this temperature range accumulation as and or chemical as neededN/R* It is not recommended that chemicals be applied in this temperature rangeBelow 15°F, Steady or falling snow coverDry or light accumulation as neededN/RPlow accumulation as this temperature range accumulation as needed* It is not recommended that chemicals be applied in this temperature rangeBelow 15°F, snow coverDry or light accumulation as neededN/RPlow accumulation as this temperature rangeBelow 15°F, snow coverDry or light accumulation as now coverN/RPlow accumulation as this temperature rangeBelow 15°F, snow coverDry or light accumulation as now coverN/RPlow accumulati	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
Wet, slush, or light snow Apply pre-wet solid NaCl reapply pre-wet N/R row accumuation and reapply pre-wet solid N/R Dry, wet, slush, or light snow N/R reapply pre-wet solid N/R Dry, wet, slush, or light snow N/R Plow N/R Dry or light snow Plow N/R N/R	ALSOWet, slnsh, or ight snowApply pre-wet solid NaClreapply pre-wet solid reapply pre-wet solid maining in range*. Do not apply liquid chemical onto heavy snow accumulation or packed snow20 to 32°F, entaining in rangeDry, wet, slnsh, or light snowN.R*. Do not apply liquid chemical onto heavy snow reapply pre-wet solid N.R*. Do not apply liquid chemical onto heavy snow15 to 20°F, entaining in rangeDry, wet, slnsh, or light snow coverN.RN.R*. If is not recommended that chemicals be applied in this temperature range mededBelow 15°F, snow coverDry or light accumulation as now coverN.RN.R*. If is not recommended that chemicals be applied in this temperature rangeBelow 15°F, snow coverDry or light accumulation as neededN.R*. If is not recommended that chemicals be applied in this temperature rangeBelow 15°F, snow coverDry or light accumulation as neededN.R*. If is not recommended that chemicals be applied in this temperature rangeBelow 15°F, snow coverDry or light accumulation as neededN.RPlow accumulation as this temperature rangeBelow 15°F, snow coverDry or light accumulation as neededN.RPlow accumulation as this temperature rangeBelow 15°F, snow coverDry or light accumulation as accumulation as neededN.RPlow accumulation as the temperature rangeBelow 15°F, snow coverDry or light accumulation as accumulation as accumulation as accumulation as accumulation as accumulation as <td>32°F, or below is imminent;</td> <td>Dry</td> <td></td> <td>N/R</td> <td></td> <td>N/R</td> <td>* If sufficient moisture is present, solid chemical without pre-wetting can be applied</td>	32°F, or below is imminent;	Dry		N/R		N/R	* If sufficient moisture is present, solid chemical without pre-wetting can be applied
Dry, wet, stush, or light snow N/R Dry or light Plow Dry or light Plow needed N/R	IS to 20°F, emaining in range Dry, wet, slush, or light snow N/R N/R N/R Below 15°F, Steady or falling Dry or light snow cover Plow N/R * It is not recommended that chemicals be applied in this temperature range Below 15°F, Steady or falling Dry or light snow cover Plow N/R Plow accumulation as needed N/R * It is not recommended that chemicals be applied in this temperature range Steady or falling now cover Plow N/R Plow accumulation as N/R * Abrasives can be applied to enhance traction Steady or falling snow cover needed N/R * Abrasives can be applied to enhance traction EMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to went deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.	ALSO 20 to 32°F, emaining in range	Wet, slush, or light snow cover	Apply pre-wet solid NaCl	N/R	Plow accumutation and reapply pre-wet solid chemical as needed	N/R	* Do not apply liquid chemical onto heavy snow accumulation or packed snow
Dry or light Plow Accumulation as N/R Plow accumulation as N/R needed N/R	Below 15°F, Steady or falling Dry or light accumulation as Plow NR Plow accumulation as NR * It is not recommended that chemicals be applied in this temperature range * applied in this temperature range Steady or falling anow cover needed NR * It is not recommended that chemicals be applied in this temperature range EMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to vent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.	15 to 20°F, emaining in range	Dry, wet, slush, or light snow cover		N/R		N/R	
	EMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to vent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.	Below 15°F, 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
PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible		TEMICAL RATE these condition	S: The recomme ons are expected t	nded snow and ice to change over the	control materia time period (wi	l application rates depend ndow) between the current	on atmospheric it treatment and t	and pavement conditions at the time of treatment an he next anticipated treatment.
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 on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	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	ee Sodium Chlor	ide for application	recommendatio	nns.		

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		Tabl	e 4. Weathel ng a 32% con	Table 4. Weather event: <u>FROST OR BLACK ICE</u> Using a 32% concentration of <u>Calcium Chloride</u>	<u>r OR BLACH</u> Icium Chlor	<u>ide</u>
		INTTAL 0	NITIAL OPERATION	SUBSEQUENT OPERATIONS	PERATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	TRAFFIC CONDITION	Maintenance Action	Chemical spread rate (gal/h-mi) Liquid CaCl2	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid CaCl2	N/R=Not Recommended
32ºF , Steady or rising	Any level	None, see comments	N/R	None, see comments	NR	*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	Traffic rate less than 100 vehicles per hour		10-25		10-25	
or tailing 22-r or below, and equal to or below dew point	Traffic rate greater than 100 vehicles per hour	Apply liquid chemical	20-35	Reapply liquid	20-35	. Аррисаной такех with depend on dututon рокениан
15 to 28°F, Remaining in range, <i>and</i> equal to or below dew point	Any level		20-40	chemical as needed	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	NR	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction
CHEMICAL APPI prevent deteriorating	LICATIONS: Thes g conditions or deve	e application ra elopment of pac	tes are starting po ked and bonded s	ints. Local experience now. Monitor tempera	should refine thes ature and humidity	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Befor	e applying any ice c	control chemical	l, the surface shou	PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible	ich snow and ice a	; possible
CHEMICAL RAT on how these condit	ES: The recommen- ions are expected to	ded snow and io change over th	e control materia e time period (wi	l application rates dep ndow) between the cur	end on atmospheri rrent treatment and	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.

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		Table ^{Usi}	 Weather of ng a 30% conce Using a Using a 	(ther event: <u>FREEZING R</u> 6 concentration of <u>Magnesium</u> Using a 32% Calcium C <i>hloride</i> ng a 25% concentration of <u>C</u>	Table 5. Weather event: <pre>FREEZING RAINSTORM</pre> Using a 30% concentration of Magnesium ChlorideUsing a 32% Calcium ChlorideUsing a 25% concentration of CMA
CHEMICAL APPLICATIONS: It is	PLICATIONS.	. It is possib	le to use these o	chemicals du	possible to use these chemicals during this event but is not recommended. However, these products of increase solid / observer, ofference, The analization rate for limite along mould be need modulitients.
can be used unrough a pre-wet system to and the potential for dilution is high. It	n a pre-wet sys or dilution is hig	gh. It is reco	ase sond / aora mmended to us	sive emcacy se a solid che	can be used intrough a pre-wet system to increase song / abrasive enreacy. The application rate for injugs arone would be cost promotive and the potential for dilution is high. It is recommended to use a solid chemical application or abrasives.
			Using Solid		Sodium Chloride
	INITIAL OPERATION	ERATION	SUBSEQUENT OPERATIONS	DPERATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	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
32°F , or below is imminent	Apply solid	100-200	Reapply solid	100-200	*Monitor pavement temperature and precipitation closely
20 to 32°F, Remaining in range	chemical	200-300	chenucal as needed	200-300	* Application rates will depend on dilution potential
15 to 20°F, Remaining in range		250-400		250-400	
Below 15°F, 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 APPLI prevent deteriorating c	CATIONS: These onditions or devel	e application ra lopment of paci	tes are starting poi ked and bonded sn	ints. Local expe tow. Monitor to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	applying any ice co	ontrol chemica	1, the surface shou	ld be cleared of	chemical, the surface should be cleared of as much snow and ice as possible
CHEMICAL RATES on how these condition	 The recommend ns are expected to 	led snow and it change over th	ce control material le time period (win	l application rat idow) between	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.
					Page 6-7

The problem of the prob	This a 32% concentration of Calcium Choice ATMATY COMENTS THARTATION CITATION COMENTS TAPERATION CITATION COMENTS TAPERATION CITATION COMENTS TAPERATION CITATION COMENTS Contraction COMENTS COMENTS ADMONTS CITATION COMENTS Contraction COMENTS COMENTS Contraction Contraction COMENTS Contraction Contraction Contraction Contrestrip Contraction	Using a 32% FAVEMENT FAVEMENT Using a 32% FAVEMENT SUBSE FAVEMENT MILLAD PERATION SUBSE RANGE, AND TREND Maintenance Liquid CaCl2 Maintenance Above 32°F, Above 32°F, Above 32°F, Steady or rising None, see NR None 32°F, or below is imminent Maintenance MR None None 32°F, or below is None, see NR None None 32°F, or below is NacIl NR NR None 32°F, or below is NaCIl NR NR None 28 to 32°F, Steady or falling NaR NR Plow as Steady or falling N/R N/R Plow as Steady or falling N/R N/R Plow as Below 15°F, Steady or falling Plow as needed N/R Plow as Below 15°F, Steady or falling Plow as needed N/R Plow as Commining in range N/R Plow as Plow as Steady or falling Interconductions or development of packed and bond Plow as COWING: Before applying any ice control chemical, t		
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Above 3.3°F.None, seeNRNone, seeSteady or risingcommentsNRcommentssteady or risingcommentsPlowor 960witminimentPlow38 rot 28	Above 3.97. Steady or ritinize None, see comments N/R None, see comments N/R starting imming 15 to 357. Steady or falling Apply solid NGCI N/R Plow a and resply mad resply in any present of the steady or falling Plow to Sodium Chloride Chart Steady or falling in range M/SCI N/R Plow as needed N/R Remaining in range in range Plow as needed N/R Plow as needed N/R Below 15 T, Steady or falling Plow as needed N/R Plow as needed N/R Remaining in range in range Plow as needed N/R Plow as needed N/R Remaining in range over 15 to 15 These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to wer deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing. OWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible OWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible OWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible OWING: Before applying on the time pericod (w	Above 32°F, Steady or rising None, see comments NR None commonset 32°F, or below is imminent 32°F, steady or below is imminent NR Plo 28 to 38°F, Remaining in range Apply solid N/R accumant and re been 28 to 28°F, Remaining in range N/R N/R pre-we need 15 to 28°F, Steady or falling Plow as needed N/R Plow as below 15°F, EMICAL APPLICATIONS: These application rates are startin went deteriorating conditions or development of packed and bonc O// The surfacc OWING: Before applying any ice control chemical, the surfacc O// The second of and bonc If MICAL RATES: The recommended snow and ice control ma how these conditions are expected to change over the time period If Mice control ma If Mice control ma		N/R=Not Recommended
32F. Apply solid Remaining in range Apply solid NR accumulation NR Control control of a commutation NR Control of a commutation Control of a control of control of a control of a c	37.F. immediation immediation 38 to 33°F. Below 15°F. 36 to 35°F. Naction 15 to 35°F. Below 15°F. Plow as needed Plow and reaction chemical as below 15°F. Plow as needed Dow and the chemical as needed N/R. N/R Plow accumulation chemical as needed N/R. N/R Co to Sodium Chloride Chart Seady or failing Below 15°F. Seady or failing Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Seady or failing Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 15°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 16°F. Plow as needed N/R Plow as needed N/R Remaining in range Below 16°F. Plow as needed N/R Plow as neede	32Ft, or below is imminent 32Ft, or below is imminent Apply solid Pile 28 to 32°F, Remaining in range Apply solid N/R accum and re pre-we below 15°F, Remaining in range NaCl N/R pre-we below 15°F, Below 15°F, Steady or failing Plow as needed N/R Plow as below 15°F, Below 15°F, Steady or failing Plow as needed N/R Plow as below as needed OWING: Before applying any ice control chemical, the surface OWING: Before applying any ice control chemical, the surface the MICAL RATES: The recommended snow and ice control ma how these conditions are expected to change over the time period		
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EMICAL APPLICATIONS : These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>vent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing. OWING : Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible EMICAL RATES : The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	EMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to vent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing. WING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible EMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	EMICAL APPLICATIONS: These application rates are startiu vent deteriorating conditions or development of packed and bond OWING: Before applying any ice control chemical, the surface EMICAL RATES: The recommended snow and ice control ma how these conditions are expected to change over the time period		
OWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible EMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	OWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible EMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	OWING: Before applying any ice control chemical, the surface EMICAL RATES : The recommended snow and ice control ma how these conditions are expected to change over the time period	ng points. Local experience ded snow. Monitor temper	e should refine these recommendations. Time chemical applications to rature and humidity to determine application timing.
IEMICAL RATES : The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	EMICAL RATES : The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	IEMICAL RATES: The recommended snow and ice control ma how these conditions are expected to change over the time period	e should be cleared of as m	nch snow and ice as possible
			aterial application rates der d (window) between the cu	pend on atmospheric and pavement conditions at the time of treatment and arrent treatment and the next anticipated treatment.

		L	able 1. We	Table 1. Weather event: <u>LIGHT SNOW</u>	HONS LE	
		Using	a 30% conce	Using a 30% concentration of <i>Magnesium Chloride</i>	sium Chlo	ide
	INI	INITIAL OPERATION	N	SUBSEQUENT OPERATIONS	RATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid MgCl ₂	Maintenance Action	Chemical spread rate (gal/h-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
32⁰F, or below is innninent;	Dry		15-35		15-35	
ALSO 20 to 32ºF, Remaining in range	Wet, slush, or light snow cover	Apply liquid	20-40	Plow as needed; reapply liquid chemical when needed	20-40	Application rates will depend on dilution potennal
15 to 20°F, Remaining in range	Dry, wet, slush, or light snow cover		45-65		45-65	* 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 APPI prevent deteriorating	JCATIONS: The conditions or dev	ese application rate velopment of packe	es are starting po ed and bonded s	ints. Local experience sho now. Monitor temperature	uld refine these and humidity to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before	e applying any ice	control chemical,	the surface shot	PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible	now and ice as]	ossible
CHEMICAL RATI on how these conditi	ES: The recomme ions are expected i	inded snow and ice to change over the	control materia time period (wi	l application rates depend ndow) between the current	on atmospheric treatment and t	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	See Sodium Chlor		application recommendations.	ns.		

Tal	ble 2. Weathe	r event: <u>LIGH</u>	T SNOW ST	JRM WITH PERIOD	(S) OF MO	Table 2. Weather event: <u>LIGHT SNOW STORM WITH PERIOD (S) OF MODERATE OR HEAVY SNOW</u>
		Using	a 30% conce	Using a 30% concentration of <u>Magnesium Chloride</u>	sium Chlo	ide
	INI	INITIAL OPERATION	N	SUBSEQUENT OPERATIONS	RATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/h-mi) Liquid MgCl2	Maintenance Action	Chemical spread rate (gal/h-mi) Liquid MgCl2	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		15-35		15-35	
ALSO 20 to 32°F, Remaining in range	Wet, slush, or light snow cover	Apply liquid	20-40	Plow as needed; reapply liquid	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	cuenucal when needed	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 APPL prevent deteriorating	ICATIONS: The conditions or dev	ese application rate velopment of packe	es are starting po ed and bonded s	ints. Local experience sho now. Monitor temperature	uld refine these and humidity to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	e applying any ice	control chemical,	the surface shou	chemical, the surface should be cleared of as much snow and ice as possible	mow and ice as I	ossible
CHEMICAL RATE on how these conditi	ES: The recomme ons are expected i	nded snow and ice to change over the	e control materia time period (wi	I application rates depend ndow) between the current	on atmospheric t treatment and t	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.	See Sodium Chlor	ide for application	n recommendatio	.str		

	Ta	Table 3. Weath	ier event: /	Weather event: MODERATE OR HEAVY SNOW STORM	HEAVY SN	OW STORM
		Using a	1 30% conce	Using a 30% concentration of <u>Magnesium Chloride</u>	sium Chloi	ide
	INI	INITIAL OPERATION	N	SUBSEQUENT OPERATIONS	RATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Pavement surface at time of Initial operation	Maintenance Action	Chemical spread rate (gal/ln-mi) Liquid MgCl2	Maintenance Action	Chemical spread rate (gal/h-mi) Liquid MgCl2	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		N/R		N/R	 If sufficient moisture is present, solid chemical without pre-wetting can be applied
ALSO 20 to 32°F, Remaining in range	Wet, slush, or light snow cover	Apply pre-wet solid NaCl	N/R	Plow accumulation and reapply pre-wet solid chemical as needed	N/R	* Do not apply liquid chemical onto heavy snow accumulation or packed snow
15 to 20⁰F, Remaining in range	Dry, wet, slush, or light snow cover		N/R		N/R	
Below 15°F, 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 APPL	ICATIONS: The conditions or dev	se application rate: elopment of packe	s are starting po d and bonded sı	ints. Local experience sho now. Monitor temperature	ould refine these and humidity to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before	applying any ice	control chemical, t	the surface shou	PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible	snow and ice as I	ossible
CHEMICAL RATE on how these conditio	S: The recommer ons are expected t	nded snow and ice o change over the	control material time period (wir	application rates depend idow) between the current	on atmospheric t treatment and t	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	ee Sodium Chlori	de for application	recommendatio	DS.		

		Table	e 4. Weatho	Table 4. Weather event: <u>FROST OR BLACK ICE</u>	T OR BLAC	KICE
		Using	a 30% conc	Using a 30% concentration of <i>Magnesium Chloride</i>	mesium Ch	loride
		INITIAL OPERATION	PERATION	SUBSEQUENT OPERATIONS	PERATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, TREND	TRAFFIC CONDITION	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid MgCl2	Maintenance Action	Chemical spread rate (gal/In-mi) Liquid MgCl2	N/R=Not Recommended
32⁰F, Steady or nising	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	Traffic rate less than 100 vehicles per hour		15-35		15-30	,
or failing 3.2. F or below, and equal to or below dew point	Traffic rate greater than 100 vehicles per hour	Apply liquid chemical	20-35	Reapply liquid	20-35	* Applucation fates will depend on dutition potential
15 to 28°F. Remaining in range, and equal to or below dew point	Any level		25-40	chemical as needed	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 APPI prevent deteriorating	LICATIONS: Thes conditions or deve	e application rat lopment of pack	es are starting p ced and bonded	oints. Local experienc snow. Monitor tempe	ce should refine the rature and humidit	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	e applying any ice c		, the surface sho	chemical, the surface should be cleared of as much snow and ice as possible	nuch snow and ice	as possible
CHEMICAL RATI on how these conditi	ES: The recommentions are expected to	ded snow and ic change over th	e control materi e time period (w	al application rates de indow) between the cr	pend on atmospher urrent treatment ar	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.

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		Table Usi U	5. Weather (ng a 30% conce sing a 32% con Using a 2:	event: <u>FR</u> entration of <u>A</u> centration of 5% concent	able 5. Weather event: <u>FREEZING RAINSTORM</u> Using a 30% concentration of <u>Magnesium Chloride</u> Using a 32% concentration of <u>Calcium Chloride</u> Using a 25% concentration of <u>CMA</u>
CHEMICAL API can be used throug and the potential fo	PLICATIONS the a pre-wet system of the dilution is high	. It is possibl tem to increa gh. It is record	le to use these o ase solid / abra: mmended to us	chemicals du sive efficacy e a solid che	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
	INITIAL OPERATION	ERATION	SUBSEQUENT OPERATIONS	PERATIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	N/R=Not Recommended
Above 32°F, 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
32°F, or below is imminent	Apply solid	100-200	Reapply solid	100-200	*Monitor pavement temperature and precipitation closely
20 to 32°F, Remaining in range	chemical	200-300	cnemical as needed	200-300	* Application rates will depend on dilution potential
15 to 20°F, Remaining in range		250-400		250-400	
Below 15°F, 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 APPLI prevent deteriorating c	CATIONS: These conditions or devel	application ration r	tes are starting poi sed and bonded sn	ints. Local expe low. Monitor to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before a	applying any ice co	ontrol chemical	, the surface shou	ld be cleared of	PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible
CHEMICAL RATE on how these condition	S: The recommend ns are expected to	led snow and ic change over th	e control material e time period (win	application rat idow) between	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: <u>SLEET STORM</u>	Using a 30% concentration of <u>Magnesium Chloride</u>	COMMENTS	N/R=Not Recommended		Go to Sodium Chloride Chart	
er event: <u>SL</u>	ntion of <u>Mag</u>	PERATIONS	Liquid MgCl2	N/R	N/R	NR
ole 6. Weath	30% concentra	SUBSEQUENT OPERATIONS	Maintenance Action	None, see comments	Plow accumulation and reapply pre-wet solid chemical as needed	Plow as needed
Tal	Using a	ERATION	Liquid MgCl ₂	N/R	NR	N/R
		INTIAL OPERATION	Maintenance Action	None, see comments	Apply solid NaCl	Plow as needed
		PAVEMENT	TEMPERATURE RANGE, AND TREND	Above 32°F, Steady or nising	32°F, or below is imminent 28 to 32°F, Remaining in range 15 to 28°F, Remaining in range	Below 15 ⁰ F, Steady or falling

			Table	1. Weath	Table 1. Weather event: <u>LIGHT SNOW</u>	IGHT SI	MON	
			Jsing a 2.	3% concen	Using a 23% concentration of <u>Sodium Chloride</u>	odium C	hloride	
		INITIAL OPER	OPERATION		SUBSEQU	SUBSEQUENT OPERATIONS	SNOID	COMMENTS
PAVEMENT TEMPERATURE	Pavement surface at		Chemical (gal/ln-mi	Chemical spread rate [gal/ln-mi or lb/ln-mi]		Chemical s (gal/In-mi o	Chemical spread rate (gal/In-mi or lb/In-mi)	
RANGE, AND TREND	time of Initial operation	Maintenance action	Liquid NaCl	Solid or pre-wet solid (lb)	Maintenance action	Liquid NaCl	Solid or pre-wet solid (lb)	N/R=Not Recommended
Above 32°F, Steady or rising	Dry, wet, słush, or light snow cover	None, see comments	Ţ	N/R	None, see comments	Ń	N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 100 lb/lane-mi; plow if needed
32°F, or below is inninent;	Dry	Apply liquid or pre-wet solid chemical	40-50	75-125	Plow as needed; reapply liquid	40-50	75-125	1-1-1-1, 1, 1, 1, − 1, − 1, − 1, − 1, −
ALSO 20 to 32ºF, Remaining in range	Wet, shish, or light snow cover	Apply liquid or solid chemical	40-90	100-210	or solid chemical when needed	40-90	100-210	 Application rates will depend on alluton potential
IS to 20⁰F, 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 15°F, Steady or falling	Dry or light snow cover	Plow as needed	ł	N/R	Plow as needed	Ŋ	N/R	* It is not recommended that chemicals be applied in this temperature range * Abrasives can be applied to enhance traction
CHEMICAL APPL prevent deteriorating	ICATIONS: conditions or	These application development of p	rates are st acked and l	tarting points. bonded snow.	Local experienc Monitor tempe	e should refin rature and hu	ne these reco	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	applying any		cal, the sur	face should be	chemical, the surface should be cleared of as much snow and ice as possible	nuch snow an	d ice as possi	ble
CHEMICAL RATE on how these condition	S: The recon ons are expect	nmended snow and ted to change over	l ice contro the time po	l material app eriod (window	dication rates de	pend on atmo urrent treatme	spheric and j ent and the ne	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.

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Ta	ble 2. Weath	er event: <u>LI</u> G	HT SN	OW STO	RM WITH PE	RIOD	(S) OF M	10DER 4	TE OR	Table 2. Weather event: LIGHT SNOW STORM WITH PERIOD (S) OF MODERATE OR HEAVY SNOW
		n	sing a 2	3% conc	Using a 23% concentration of <u>Sodium Chloride</u>	Sodiu	m Chlo	ride		
	Π	INITIAL OPERATION	NOII		INS	BSEQUE	SUBSEQUENT OPERATIONS	VIIONS		COMMENTS
PAVEMENT TEMPERATURE	Pavement		Chemica rate (gal lb/h	Chemical spread rate (gal/ln-mi or lb/ln-mi)		Chen	nical spread Ib/l	Chemical spread rate (gal/ln-mi or lb/ln-mi)	n-mi or	
RANGE, AND TREND	time of Initial	Maintenance Action	Liquid NaCl	Solid or pre-wet	Maintenance Action	ΪΪ	Liquid NaCl	Solid or pr solid	Solid or pre-wet solid	N/R=Not Recommended
	operanon			Solid		Light snow	Heavier snow	Light snow	Heavier snow	
Above 32°F, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	N/R	R	None, see comments		4	N/R		*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 40- 65 GPLM; plow if needed
32°F, or below is imminent;	Dry	Apply liquid or pre-wet solid chemical	40-65	75-150	Plow as needed; reapply liquid or solid	40-50	50-65	75-125	150-200	*Do not apply liquid chemical onto heavy snow accumulation or packed snow
ALSO 25 to 32°F, Remaining in range	Wet, slush, or light snow cover	Apply liquid or solid chemical	65-90	175-200	cnenncal wnen needed	65-80	80-90	175-185	190-200	 Application rates will depend on dilution potential
15 to 25°F, 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	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 15°F, Steady or falling	Dry or light snow cover	Plow as needed	N/R	R	Plow as needed		4	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 chem <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing	ICATIONS: TI conditions or de	hese application evelopment of pa	rates are s acked and	tarting poù bonded sn	nts. Local experie ow. Monitor tem	ince shou	ld refine th and humidi	tese reconnity to detern	mendations mine applic	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	applying any ic		cal, the sur	face shoul	chemical, the surface should be cleared of as much snow and ice as possible	s much sn	ow and ice	as possibl	e.	
CHEMICAL RATES: The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	S: The recommon ons are expected	nended snow and to change over	lice contro the time p	ol material eriod (win	application rates dow) between the	depend o	n atmosph(reatment a	eric and par nd the next	vement cor t anticipate	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.
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	Table 3.		event: / 23% cor	<i>MODE</i> Icentrati	Weather event: <i>MODERATE OR HEAVY SNOW STORM</i> Using a 23% concentration of <i>Sodium Chloride</i>	VY SNON hloride	V STORM	
	Ι	INITIAL OPERATION	ION		SUBSEQUE	SUBSEQUENT OPERATIONS	ONS	COMMENTS
PAVEMENT TEMPERATURE	Pavement surface at time		Chemical spread rate (gal/In-mi or Ib/In-mi)	l spread In-mi or mi)		Chemical (gal/ln-mi	Chemical spread rate (gal/In-mi or Ib/In-mi)	
RANGE, AND TREND	of Initial operation	Maintenance Action	Liquid NaCl	Solid or pre-wet Solid	Maintenance Action	Liquid NaCl	Solid or pre-wet solid	N/R=Not Recommended
Above 32°F, Steady or rising	Dry, wet, slush, or light snow cover	None, see comments	NR	~	None, see comments		N/R	*Monitor pavement temperature closely *Treat icy patches if needed with chemical at 40-65 GPLM; plow if needed
32°F, 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
ALSO 25 to 32°F, Remaining in range	Wet, shish, or light snow cover	Apply solid chemical	N/R	175-200	Plow accumulation and reapply pre-wet solid chemical as needed	06-08	190-200	 Application rates will depend on duittion potential
15 to 25%F, 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 LS ⁰ F, Steady or falling	Dry or light snow cover	Plow as needed	N/R	ĸ	Plow as needed	1	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 chem <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.	TIONS: These ap litions or developr	plication rates are ment of packed an	starting po d bonded s	vints. Local now. Mor	l experience should refi uitor temperature and hu	ne these recon unidity to det	nmendations. T	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> 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	lying any ice contr	ol chemical, the s	urface shou	ild be clea	red of as much snow an	d ice as possi	ble	
CHEMICAL RATES: The recommended snov on how these conditions are expected to change	he recommended re expected to cha	snow and ice con inge over the time	rrol materia period (wi	l applicati ndow) bet	v and ice control material application rates depend on atmospheric and pavement conditions at the over the time period (window) between the current treatment and the next anticipated treatment.	ospheric and p ent and the ne	avement condit xt anticipated tr	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.
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		Table 4. ¹ Using a	Weather 23% con	r event:	Table 4. Weather event: <u>FROST OR BLACK ICE</u> Using a 23% concentration of <u>Sodium Chloride</u>	BLACK Chlori	(ICE	
		INITIAL	INITIAL OPERATION	NO	SUBSEQUENT OPERATIONS	IT OPERA	TIONS	COMMENTS
PAVEMENT TEMPERATURE RANGE	TRAFFIC	Maintenance	Chemical spread rate (gal/In-mi or Lb/In-mi)	pread rate -mi or 1-mi)	Maintenance	Chemix rate (ga lb/l	Chemical spread rate (gal/ln-mi or lb/ln-mi)	V.R=Not Recommended
TREND		Action	Liquid NaCl	Solid or pre-wet solid	Action	Liquid NaCl	Solid or pre-wet solid	
32⁰F, Steady or rising	Any level	None, see comments	N/R	Å	None, see comments	Į	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,	Traffic rate less than 100 vehicles per h		45-60	100-130		45-60	100-130	ancientis en bennes tien neder noisenilised 8
ternational at range of falling 32 ^T or below, and equal to or below dew point	Traffic rate greater than 100 vehicles per h	Apply liquid or pre-wet solid	45-75	100-130	Reapply liquid or pre-wet solid chemical when	45-75	100-130	Appuation rates with vepend on writion potential
20 to 28ºF, Remaining in range, and equal to or below dew point		cinetti cat	65-80	165-200	πεεσιεσ	65-80	165-200	* Application rates will depend on dilution potential
IS to 20⁰F, Remaining in range, <i>and</i> equal to or below dew point	Any level	Apply pre-wet solid chemical	N/R	175-225	Reapply pre-wet solid chemical when needed	N/R	175-225	
Below 15°F, Steady or falling		Apply abrasives	N/R	¥	Apply abrasives as needed	I	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 chem prevent deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.	IONS: These applions or developme	lication rates are ent of packed an	starting poi	ints. Local e 10w. Monite	xperience should 1 or temperature and	efine these humidity	e recomment to determine	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deternorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before applying any ice control	ing any ice control	l chemical, the s	urface shou	ld be cleared	chemical, the surface should be cleared of as much snow and ice as possible	and ice as	possible	
CHEMICAL RATES : The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the on how these conditions are expected to change over the time period (window) between the current treatment and the next anticipated treatment.	e recommended sr expected to cham	iow and ice con ge over the time	trol material : period (wir	l application adow) betwe	rates depend on a set the current treat	tmospheric trment and	c and pavem the next ant	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.

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		Table Usi U	5. Weather ing a 30% conce Jsing a 32% con Using a 2	event: <u>FR</u> entration of <u>A</u> icentration of 5% concenti	able 5. Weather event: <u>FREEZING RAINSTORM</u> Using a 30% concentration of <u>Magnesium Chloride</u> Using a 32% concentration of <u>Calcium Chloride</u> Using a 25% concentration of <u>CMA</u>
CHEMICAL AP) can be used throug and the potential fo	PLICATIONS th a pre-wet sys or dilution is hig	: It is possib tem to incre gh. It is reco	le to use these (ase solid / abra mmended to us	chemicals du sive efficacy se a solid che	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.
	INITIAL OPERATION	RATION	USING SOLID SOLID SOLID SOLID SUBSECTIENT OPERATIONS	Olid Sodiu	Using Solid Sodium Chloride FOLENT OPERATIONS CONNENTS
PAVEMENT TEMPERATURE RANGE, AND TREND	Maintenance Action	Chemical spread rate (Ib/In-mi) NaCI	Maintenance Action	Chemical spread rate (lb/ln-mi) NaCl	N/R=Not Recommended
Above 32°F, Steady or nising	None, see comments	N/R	None, see comments	N/R	* Monitor pavement temperature closely *Treat icv patches if needed with pre-wetted solid chemical at 100150 lb/lane-mi
32°F , or below is imminent	Apply solid	100-200	Reapply solid	100-200	*Monitor navement tennerature and orecinitation closely
20 to 32°F, Remaining in range	chemical	200-300	chemical as needed	200-300	* Application rates will depend on dilution potential
15 to 20°F, Remaining in range		250-400		250-400	
Below 15°F, 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 APPLI prevent deteriorating c	CATIONS: These conditions or devel	e application ra lopment of pac	tes are starting po ked and bonded sr	ints. Local expe now. Monitor to	CHEMICAL APPLICATIONS: These application rates are starting points. Local experience should refine these recommendations. Time chemical applications to <i>prevent</i> deteriorating conditions or development of packed and bonded snow. Monitor temperature and humidity to determine application timing.
PLOWING: Before	applying any ice c	control chemics	il, the surface shou	uld be cleared o	PLOWING: Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible
CHEMICAL RATES: The recommended snov on how these conditions are expected to change	S: The recommend ns are expected to	led snow and id change over th	ce control material le time period (wir	l application rat ndow) between	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.
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Using a 23% concentration of Sodium Chloride Utentical SUBSEQUENT OFFRATIONS COMMENTS AATION SUBSEQUENT OPENATIONS COMMENTS Subsequent SUBSEQUENT OPENATIONS CNATIONS Subsequent Maintenance Spread rate, Iblane-mi Maintenance Spread rate, NR=Not Recommended NR None, see N/R * Monitor partement temperature closely Iblane-mi NR=Not Recommended NR None, see N/R * Monitor partement temperature closely Iblane-mi NR=Not Recommended 125 accumulation 125 * Monitor partement temperature and precipitation closely pre-wet solid * Monitor partement temperature and precipitation closely Iblane-mi 250-400 250-400 * Application rates will depend on dilution potential needed * It is not recommended that chemicals be applied in this temperature range NR Plow as needed N/R * It is not recommended that chemicals be applied in this temperature range NR Plow as needed N/R * It is not recommended that chemical so policid to enhance traction	Using a 23% concentration of So TON SUBSEQUENT OPERATIONS TON SUBSEQUENT OPERATIONS Internical Maintenance Interni Action NR None, see NR None, see NR NR I125 Plow accumulation 125 S0-400 needed N/R Plow as needed N/R Plow as needed N/R Plow as needed N/R Nonitor temperation	Using a 23% <u>INITIAL OPERATION</u> SUBSE <u>Chemical</u> Maint intenance spread rate, Maint	lg a 23% conce subsequen	entration of <u>S</u>	dium Chloride
CATION SUBSEQUENT OPERATIONS COMMENTS Chemical spread rate, Maintenance blane-mi MaCI Maintenance spread rate, Maintenance pread NR Chemical spread rate, macine plane-mi Molane-mi	ERATIONSUBSEQUENT OPERATIONSCOMMENTSChemical Spread rate, NaturemanceChemical spread rate, NaturemanceChemical spread rate, NaturemanceChemical spread rate, NaturemanceChemical spread rate, NaturemanceNRMaintemance ActionNone, see NRN/R=Not Recommended N/R=Not Recommended N/R=Not Recommended 125N/R=Not Recommended stateNRNone, see NRN/R* Monitor pavement temperature closely ib/lane-miN/R=Not Recommended ib/lane-mi125Plow125* Monitor pavement temperature and precipitation closely ib/lane-mi125-325 scomulation125-325Plow125-325 scomulation* Monitor pavement temperature and precipitation closely relemical as 250-400125-325Plow125-325 scomulation* Application rates will depend on dilution potential scommendad that chemicals to applied in this temperature range scommended that chemicals to application to to application to the scommended that chemicals to application to to application to to scommended that chemicals to application to to scommended that chemicals to application to scommended that chemical splications to poment of packed and bonded snow. Monitor temperature and humidity to determine application timing.splication rates are starting points. Local experience should refine these recommendations. Time chemical applications to poment of packed and bonded snow. Monitor temperature and humidity to determine application timing.	rION hemical ead rate,	SUBSEQUEN		
Chemical spread rate, blame-mi blame-miChemical spread rate, blame-miChemical spread rate, blame-miChemical spread rate, blame-miChemical blame-miN/RNone, see vone, seeN/R* Merion blame-mi* Merion scommendedN/RNone, see commentsN/R* Merion scommended125Plow accumulation125* Monitor parvement temperature closely thane-mi125Plow accumulation125* Monitor parvement temperature and precipitation closely thane-mi125-325Plow accumulation125* Application rates will depend on dilution potential scommendad that chemical as braver solid125-325Plow as needed N/R* Application rates will depend on dilution potential scommendad that chemicals be applied in this temperature range schemical as blow as neededN/RPlow as neededN/R* It is not recommended that chemicals be applied in this temperature range schemical soN/RPlow as neededN/R* It is not recommended to enhance tractionN/RPlow as neededN/R* Application tractes can be applied to enhance tractionplication rates are starting points. Local experience should refine these recommendedings to freemical application timing.	Chemical spread rate, blame-mit <b< th=""><th></th><th></th><th>COPERATIONS</th><th>COMMENTS</th></b<>			COPERATIONS	COMMENTS
NRNone, see commentsN.R* Monitor parement temperature closely Treat icy patches if needed with pre-wetted solid chemical at 100-150 h/lame-mi 125 PlowPlow* Treat icy patches if needed with pre-wetted solid chemical at 100-150 h/lame-mi 125 accumments 125 125 -325* Monitor parement temperature and precipitation closely chemical as 125 -325 125 -326 125 $250-400$ 125 NRPlow as neededNRPlow as neededNRPlow as neededNRPlow as neededNRNRRenords and bonded snow. Monitor temperature and precipitations. Time chemical applications to the process are starting points. Local experience should refine these recommendations. Time chemical applications to the process are starting points. Local experience should refine these recommendations. Time chemical applications to	NRNone, seeN/R* Monitor pavement temperature closely the comments125Plow comments125125and match and reapply125125-325the second status125-325the second status125-		Maintenance Action	Chemical spread rate, Ib/lane-mi NaCI	N/R=Not Recommended
125 Plow and reapply pre-wet solid 125 125-325 * Monitor pavement temperature and precipitation closely pre-wet solid * Monitor pavement temperature and precipitation closely 125-325 * Application rates will depend on dilution potential 250-400 * To * Solid N/R Plow as needed N/R Plow as needed N/R * Abrasives can be applied to enhance traction nent of packed and bonded snow. Monitor temperature and humidity to determine application timing.	125 Plow and reapily pre-wet solid chemical as 125 125-325 and reapily pre-wet solid chemical as *Monitor pavement temperature and precipitation closely *Application rates will depend on ditution potential 250-400 250-400 **It is not recommended that chemicals be applied in this temperature range N/R Plow as needed * It is not recommended that chemicals be applied in this temperature range N/R Plow as needed * Abrasives can be applied to enhance traction nent of packed and bonded snow. Monitor temperature and humidity to determine application timing. Time chemical applications to intended the chemical applications to intended.		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
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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 Vbox 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).
- 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 <u>RWIS, AVL or MDSS</u> 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 <u>cost-effectiveness or efficiency</u> 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 <u>effectiveness</u> 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 <u>tailored</u> 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



research for winter highway maintenance

Lead state: Minnesota Department of Transportation Research Services 395 John Ireland Blvd. St. Paul, MN 55155