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Best Practices for Winter Maintenance Roadway Deicer Applications in the State of Nebraska

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by

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BEST PRACTICES FOR WINTER MAINTENANCE ROADWAY DEICER APPLICATIONS IN THE STATE OF NEBRASKA

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The cost of deicing chemicals is a significant part of the Nebraska Department of Road's winter maintenance budget. The objectives of this research are to review literature to determine current winter maintenance practices, analyze and present information gathered in a survey of winter maintenance professionals across Nebraska, and correlate this information with data obtained via MDSS (Maintenance Decision Support System) software to determine current practices being used in the state of Nebraska. Best practices for winter maintenance deicer applications for rural city and county officials in Nebraska are recommended. An explanation of the development of the survey that winter maintenance crews participated in is provided. Cost estimates for different practices are provided.

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Chapter 1: Introduction

1.1 Background Information

Deicing chemicals are responsible for a significant portion of the Nebraska Department of Road's winter maintenance budget. Currently the U.S spends $2.3 Billion annually to keep its highways clear of snow (Shi, 2009). The use of deicer chemicals increases every year to improve a Level of Service (LOS), and the cost to purchase the chemicals increases yearly. Maintenance Decision Support System (MDSS) helps NDOR winter maintenance officials to be more precise in the selection of chemicals and the application rate for specified weather and pavement conditions. In a previous research sponsored by NDOR, Gerbino-Bevins and Tuan (2011) made recommendations for winter roadway treatments. City and County officials across Nebraska that are not part of the Nebraska Department of Roads made a request of NDOR to provide them with similar recommendations based upon what materials they have readily available. This thesis continues this research and aims to provide recommendations to Rural City and County officials based upon the analysis of a survey that was distributed to City, County, and NDOR officials. This thesis also adds to the data analysis of Maintenance Decision Support System (MDSS) for the years since Gerbino-Bevins's analysis.

1.2 Objectives

This thesis aims to:

- Complete a comprehensive literature review of existing academic literature on winter maintenance practices and deicer applications.
- Analyze and draw conclusions from a survey that was issued to winter maintenance practitioners in the State of Nebraska in regards to what are the best practices for

winter maintenance workers who do not fall under the Nebraska Department of Roads umbrella.

- Analyze and draw conclusions from scenarios that were found within the Maintenance Decision Support System (MDSS) database.
- Summarize conclusions and practices into a table that provides simple, easy-to-use recommendations for winter roadway maintenance workers.

Chapter 2: Literature Survey

Removing ice and snow from pavement is traditionally accomplished by a combination of several ways, such as plowing, natural melting, traffic movement, and chemical treatment. Because the bond between compacted snow and ice and the pavement is strong, removal by plowing alone is not always effective. Chemical treatment helps break the bond by melting into the ice and spreading under the ice layer. Most highway winter maintenance depends on using chemicals and fine granular particles as a primary means for deicing. Recent statistics indicate that approximately 10 million tons of road salt are used in the U.S. each winter. Many different liquid and solid chemicals are also used to treat roadways before and during a snowstorm. This literature search focuses on identifying the best management practices and strategies for winter roadway maintenance to help rural communities in Nebraska.

A wealth of information exists in the literature about the current practices of various state Departments of Transportation and the advances in winter maintenance technologies. Relevant information is summarized herein regarding the different practices in the field and different treatment chemicals currently being used by the Nebraska Department of Roads.

2.1 Winter Maintenance Practices

Depending on the road weather circumstances, resources available, and local rules of practice, Departments of Transportation use a combination of different methods ranging from anti-icing, deicing, sanding, plowing, and snow-fencing. Winter maintenance strategies that utilize liquid deicers include anti-icing, pre-wetting, slurry and deicing (Shi, Fay, Gallaway, Volkening, Peterson, Pan, Creighton, Lawlor, Mumma, Liu, and Nguyen 2009). Winter maintenance strategies also utilize a variety of different types of deicers. Nebraska road officials commonly use Road Salt, Salt Brine, Sand/Gravel, Apex

Meltdown (Magnesium Chloride), Calcium Chloride, Ice Slicer, and Geomelt C (beet juice). Other types of deicers such as formates and acetates are not readily available in Nebraska. Chemical deicers are also typically not used when roadway temperatures are below 12°F (Blackburn, Amsler, Baurer 2004; Staples, Gamradt, Stein, Shi 2004).

2.2 Maintenance Decision Support System (MDSS)

MDSS (Maintenance Decision Support System) is a computer program that uses location-specific road weather forecasts, route data, traffic levels, maintenance materials and practices, reports of weather and road conditions, and previous maintenance actions to make recommendations for future maintenance actions (NDOR Maintenance Manual, 2010).

According to Pisano, Huft, and Stern (2005), early in the late 1990's the FHWA (Federal Highway Administration) began development of the Road Weather Management Program, but at that time there was no link correlating weather forecasting to maintenance decisions used by winter maintenance operators. The MDSS project was collaboration between a diverse stakeholder group consisting of State Departments of Transportation (DOT) maintenance practitioners, five national laboratories, and the academic and private sector communities. By the end of 2005, FHWA had sponsored seven MDSS stakeholder meetings with interest and attendance continuing to climb with each. From 2000-2005, 37 states (Figure 1) participated in the stakeholder meetings (Pisano et al. 2005)

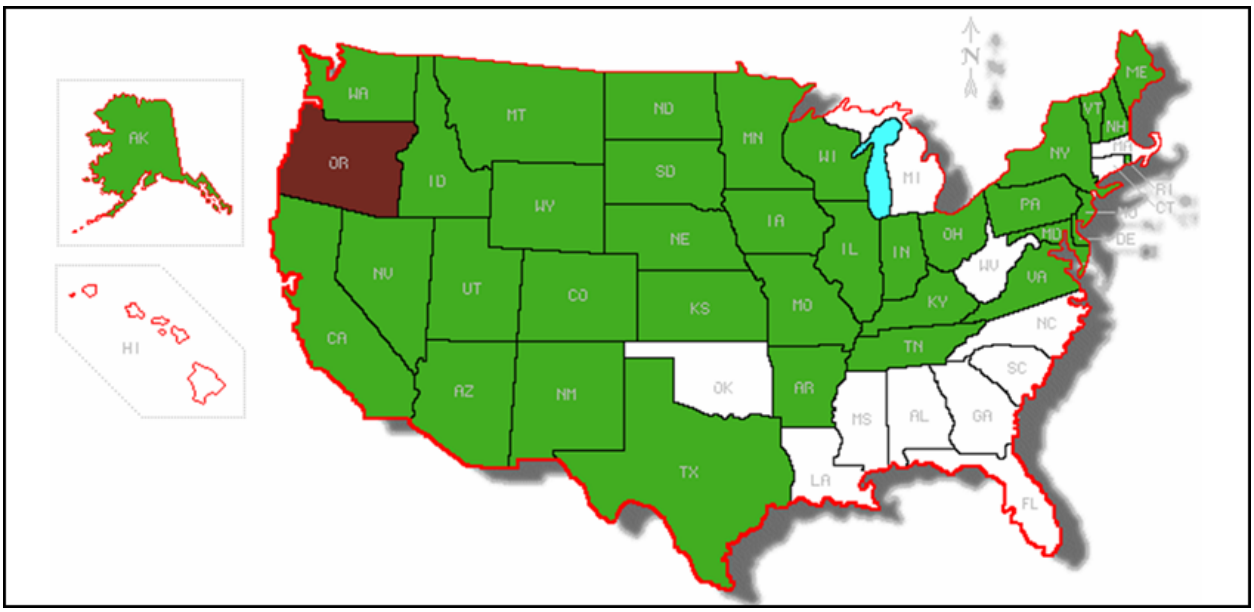

Figure 1: States That Participated In MDSS Development (Pisano, Huft, Stern. 2005)

Recommendations from MDSS are intended to aid maintenance workers in choosing the most effective practice to achieve a desired Level of Service (LOS). The different LOS and their target time to regain bare pavement are defined in Table 1 (NDOR Maintenance Manual, 2010).

Table 1: Level of Service (LOS) Definitions in NDOR Maintenance Manual

Level of Service	Guideline	Target
Route Designation	Traffic Level (ADT)	Regain time (hours)
Super Commuter	>50,000	4 (bare pavement)
Urban Commuter	20,000-50,000	6 (bare pavement)
Rural Commuter	7,000-20,000	8 (bare lane)
Primary	2,500-7,000	12 (bare lane)
Secondary	1,000-2,500	24 (bare lane)
Low Volume	< 1,000	48 (bare lane)

It should be noted that these LOS standards are only applicable to Nebraska. On a national scale, level of service varies considerably with terrain. The terrain in Nebraska is largely flat. Nixon (2007) cites Interstate I-80 as an example of a road that runs through flat terrain in Nebraska and Iowa, yet mountainous in California. Therefore, it is necessary to consider the responsibilities of the road users of the highway system to develop a national LOS system.

Information recorded in MDSS is taken from a variety of sources and can be compared to verify reliability. Temperatures are taken from weather stations or even infrared sensors that are equipped on trucks (Smith, 1998). The trucks positioning is tracked via GPS (Global Positioning System).

According to Shi (2009), a recent cost benefit-study reveals that the tangible benefits of MDSS significantly outweigh its costs. Also, there have been many intangible benefits since MDSS's implementation such as improved documentation of actual maintenance activities, reduced response and clearance time, reduced labor and equipment costs, reduced corrosion, and environmental impacts (Shi, 2009). Analyses of several scenarios from MDSS are found in Chapter 4.

2.3 Anti-icing

Anti-icing is a method that applies chemicals to the roadway prior to a winter storm event. The objective of anti-icing is to prevent the formation of bonded snow and ice to a pavement surface (Roosevelt 1997; NDOR Maintenance manual, 2010). This improves the road surface condition after plowing (Shi, Akin, Pan, Fay, Liu, and Yang 2009), by creating a layer of briny slush that separates the roadway and the ice or snow (Perkins, Mwakalonge, Jasek, Carson, Obeng-Boampong, Pesti 2011). Anti-icing practices can lead to decreased applications of chemical and abrasives, decreased maintenance costs, and lower accident rates. Colorado Department of Transportation maintenance personnel have found magnesium chloride and magnesium chloride/agriculture-based blends to be more effective, less toxic, and less corrosive (Shi et al. 2009). Texas research also cites magnesium chloride as a popular anti-icing chemical (Perkins et al. 2011). Anti-icing can become ineffective under temperatures lower than 20°F, strong winds, and heavy snowfall or freezing rain conditions. In windy conditions, anti-icing can actually cause blowing snow to adhere to the pavement, and rainy conditions can wash the liquid chemical away (Shi et al. 2009). Liquid deicers are best suited for providing longer residual effect than solid deicers as traffic would disperse dry materials.

Shi, Akin ,Huang, Zhang, Jungwirth, Fang, Muthumani, and Yi (2013) recommended guidelines on using anti-icing based on lab testing and field testing. The pavement temperature and humidity are the two important factors in decision making. They reported that salt brine (at 30 gal/lane-mile) should not be replaced at low pavement temperatures (15°F) with high humidity, and that Calcium Chloride products (at 30 gal/lane-mile) would reduce the pavement friction coefficient at these conditions.

2.4 Pre-wetting

Pre-wetting solids (road salts, other solid chemicals, sands and gravels) improves the adhesion to pavement surface, thus reduces the amount of materials wasted when applied to roadways. This will improve performance and reduce the total amount of chemicals used. Shi and O'Keefe (2005) showed in a field study in Michigan that 96 percent of the pre-wetted salt was retained on the road surface as opposed to 70 percent of the dry salt due to bounce and scatter. Some evidence suggests that pre-wetting accelerates the process of melting ice and snow as well as lowering the effective temperature of the salt (Shi et al. 2013; Luker, Rokash, and Leggert 2004). Effective temperature ranges of sodium chloride are increased by pre-wetting with $MgCl_2$ and $CaCl_2$. Pre-wetting reduces the amount of abrasives required by 50 percent in cold temperatures (Fay, Akin, Wang, Shi, and Williams 2010). As a result, pre-wetting also reduces labor costs, the spring cleanup costs, and the amount of chemicals released into the environment. It was reported by NDOR winter maintenance via Transportation Improvement Programs (TIPS) that pre-wetting with Apex Meltdown should be limited to 3-6 gal/ton to reduce leaching. Other liquid chemicals such as salt brine can be applied to a stock pile at a much higher rate 12-15 gal/ton. If using Geomelt (a beet juice additive), an 80/20 of a liquid deicer to Geomelt mixture is a good practice. The beet juice is sticky and could clog spreaders at higher ratios. This ratio is recommended for all pre-wetting and deicing applications. Further reducing Geomelt in the mix would not reduce the cost of the chemical significantly when used for pre-wetting.

2.5 Deicing

While anti-icing is proactive, deicing is a reactive operation in which a deicer is applied to the top of an accumulation of snow, ice, or frost that is already bonded to the pavement surface. To be effective, the deicer must be able to cut through packed snow and ice in order to break the bond such that the loosened snow/ice can be removed by plowing or displaced by traffic (Shi, 2009).

Deicing is traditionally done with solid chemicals. However, direct liquid application (DLA) applies liquids directly to the roadway. DLA optimizes the material usage by reducing the application rates and scatter-bounce loss of material and minimizes the post-storm cleanup. Amsler (2006) has summarized the advantages of liquid chemicals: liquids tend to stay on the roadway better than solids; liquids reduce the bouncing and scattering of applied salt and sand; liquids have instant melting action compared to solids, and can be used on paved surface or to treat solid chemicals prior to application to speed melting action. However, liquid chemicals cannot be used to effectively treat thick ice or snow pack, and are limited to pavement temperature typically above 20°F. Liquid deicers will become diluted (and may refreeze) more quickly than solid salt during heavy snow and ice storms.

When deicing, the pavement temperature is the controlling item in the treatment of highways during winter storms (Smith, 2009). Generally speaking Road Salt is effective down to roadway temperatures of 10°F. Below this either the quantity of Road Salt increases greatly or another deicer chemical with a lower eutectic temperature needs to be used. Sands and Gravels are also commonly below 12°F for traction benefits (Akin, Huang, Shi, Veneziano D, Williams D, 2013)

2.6 Types of Deicers

The most commonly used chemical deicers are sodium chloride (NaCl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), and potassium acetate (KCH_3CO_2, abbreviated as KAc) (Shi et al. 2013).

2.6.1 Sodium Chloride

Road salts (NaCl) are the most common chemicals used for winter road maintenance applications. They are inexpensive and abundant. Brines can be produced locally and are readily available. Typical application rates for anti-icing range from 20 to 50 gallons per lane mile. Sodium

chloride (NaCl) has a eutectic temperature of -6°F (-21°C) at 23% concentration. Its effective temperature is 16°F (-9°C), but is relied upon down to 10°F. Corrosion inhibitors can be added to reduce the caustic effects on vehicles and infrastructure (Shi et al. 2013). Chemical chloride blends can be very effective. Blending salt brine with different deicers can be very advantageous and cost effective. Blending 10-15% agro-based products in or 10% $CaCl_2$ can provide a significant increase in the residual of salt on high volume roads when anti-icing and lower the effective working temperature of brine when pre-wetting at the spinner.

2.6.2 Calcium Chloride

Field studies have shown $CaCl_2$ to be more effective than NaCl, owing to its ability to attract moisture and stay on the road (Shi et al. 2013). However, research also indicates that, because of its ability to attract moisture, calcium chloride can cause slippery conditions at high humidity (Gerbino-Bevins and Tuan 2011). Calcium chloride has a eutectic temperature of -60°F (-51°C) at 30% concentration. Its effective temperature is -26°F (-32°C) (Shi et al. 2013).

2.6.3 Magnesium Chloride

Magnesium chloride brines perform better at lower temperatures. Magnesium chloride has a eutectic temperature of -27°F (-33°C) at 22% concentration. Its effective temperature is also -26°F (-32°C). (Shi et al. 2013)

2.6.4 Beet Juice/Ag-based/Geo-melt 55

Geo-melt 55 is an organic beet-juiced based concentrate that winter maintenance crew can blend with salt brine to increase ice melting performance. The “sticky-ness” of the Geomelt causes the brine to adhere to the road and leave a longer lasting residue upon the road (Shi et al. 2013). In a field study comparing roadway applications of deicers, Gerbino-Bevins and Tuan (2011) note that it appeared

that direct sunlight enhanced the performance of beet juice by absorbing solar radiation. While using higher concentrations of beet juice will increase deicing performance, it is recommended not to use more than 20% beet-juice in a mixture to avoid clogging spreaders. Pre-wetting rock salt or abrasives can have the same effect and cause salt and sand to adhere to the road better (Shi et al. 2013).

2.6.5 Sand/Gravel Abrasives

Abrasives such as sand and gravel do not really qualify as deicer as they do not lower the freezing point of a liquid at all. Sand and gravel is used for traction purposes by bonding to the roadway when freezing occurs. Sand and Gravel is also used when temperatures are so low that deicer chemicals are rendered ineffective. However, if applied to early or if the roadway temperature does not freeze, sand and gravel can actually reduce the traction. There can also be a high cleanup cost from the application of sand and gravel.

The environmental impacts of sand and gravel are also not necessarily intuitive. Staples, Gamradt, Stein, and Shi (2004) claim that the environmental impacts of sand generally outweigh the negative impacts of chlorides. They found that particles that were less than 2mm become problematic because they block the movement of oxygen in streambed gravels and thus endanger aquatic life.

2.6.6 Ice Slicer

Ice Slicer Ice Melt (EnviroTech Services 2015) is a homogenous granular chloride product that contains a mixture of magnesium chloride, calcium chloride, sodium chloride, potassium chloride, sulfur, iron, iodine, zinc, copper, manganese, phosphorous, and other trace minerals. Ice Slicer has a red appearance which absorbs more solar radiation than normal road salt. Ice Slicer also contains natural corrosion inhibitors. Many winter maintenance workers in Nebraska use Ice Slicer. Sometimes it is applied at 100% Ice Slicer and sometimes it is applied at 10% Ice Slicer mixed with Road Salt.

2.6.7 Other Deicers

There are various other deicer products used in the U.S. but not used in the State of Nebraska. These include but are not limited to Calcium Magnesium Acetate, Potassium Acetate, Potassium Formate and urea.

2.7 Laboratory Testing

Several standardized tests have been developed and published by the Strategic Highway Research Program (SHRP) to evaluate the performance characteristics of chemical deicers. These properties include ice melting capacity, ice penetration, ice debonding, thermal properties, and the resulting friction coefficient or a de-iced roadway.

The most important performance attribute of a chemical deicer is its ice melting capacity. There are two main ice melting capacity tests designated by the SHRP Handbook (Chappelow, McElroy, Blackburn, Darwin, and de Noyelles 1992). These are SHRP H-205.1 for solid deicers and SHRP H-205.2 for liquid deicers. Gerbino-Bevins and Tuan (2011) point out that there is not set standard for what volume of ice should be melted in this test to confirm an acceptable performance. This test is best used when comparing one deicer with an acceptable known field performance to another deicer. This test is also costly to perform because it requires the use of an indoor walk-in freezer. The price to acquire this room can be outside of researcher's budgets.

Gerbino-Bevins and Tuan (2011) present data from testing the SHRP H-205.1 and 205.2 along with the data from running other tests presented in the SHRP Handbook. Shi and Akin (2009) also present data for running a modified SHRP H-205.1 test but the equipment is very expensive. Using a small freezer, Gerbino-Bevins and Tuan (2011) present a new test by shaking a thermos that contains a given amount of ice cubes and liquid deicer to determine the ice melting capacity of the deicer.

2.8 Eutectic Curve

The eutectic temperature is the minimum temperature a deicer solution remains in liquid form, which depends on the concentration of the deicer, usually expressed as percent weight of the solution. During melting, additional liquid adds to the solution and dilutes the deicer. This may cause the solution to re-freeze. Thus the effective temperature can be significantly different from the eutectic temperature (Akin and Shi 2009). The eutectic curve presents the eutectic temperature as a function of deicer concentration by weight. The eutectic point is the lowest temperature that the solution will not freeze and solidify. The closer the temperature gets to the eutectic point, the slower the melting rate becomes. The eutectic temperature and concentration can be found using ASTM D 1177 and is normally used for engine coolants (Chappelow 1992; Melinder 2007). The eutectic curves of several chemicals are presented in Figure 2.

Using the Eutectic Curve Blackburn and Associates (2014) generated tables that present application rates for deicer chemicals. Starting with sodium chloride, tables were developed with recommended application rates for various temperatures and weather conditions based upon the eutectic temperature and the ice melting capacity that property reflects. Next, tables were developed that converted the weight of sodium chloride into an equivalent weight of other types of deicers (CaCl2, KaAc, MgCl2, CMA, etc.) based upon the ice melting capacity of that deicer at different temperatures (Table 2). The temperature was very important as Blackburn and Associates (2014) shows that at higher temperatures Road Salt has similar ice melting capabilities as magnesium chloride. This changes considerably however at lower temperatures. Using the conversion table and the table for Solid sodium chloride Blackburn and Associates (2014) develop a wealth of recommendations for many frequently used deicer chemicals in various weather scenarios. He does caution however that equivalent amounts of chemicals are not always equally effective under different conditions. For example, solid road salt

may be lost to bounce and scatter while salt brine may not. He also cautions that application rates developed from phase diagrams tended to be minimally twice as large as those used in the field or even exceeded the amount of chemicals that are ever applied in practice. The charts do however show a good starting point for developing best practices, and, with the proper judgement, the conversion table could be useful comparing current practices of different deicer types. An example of his Salt application rate recommendation is seen in Table 3.

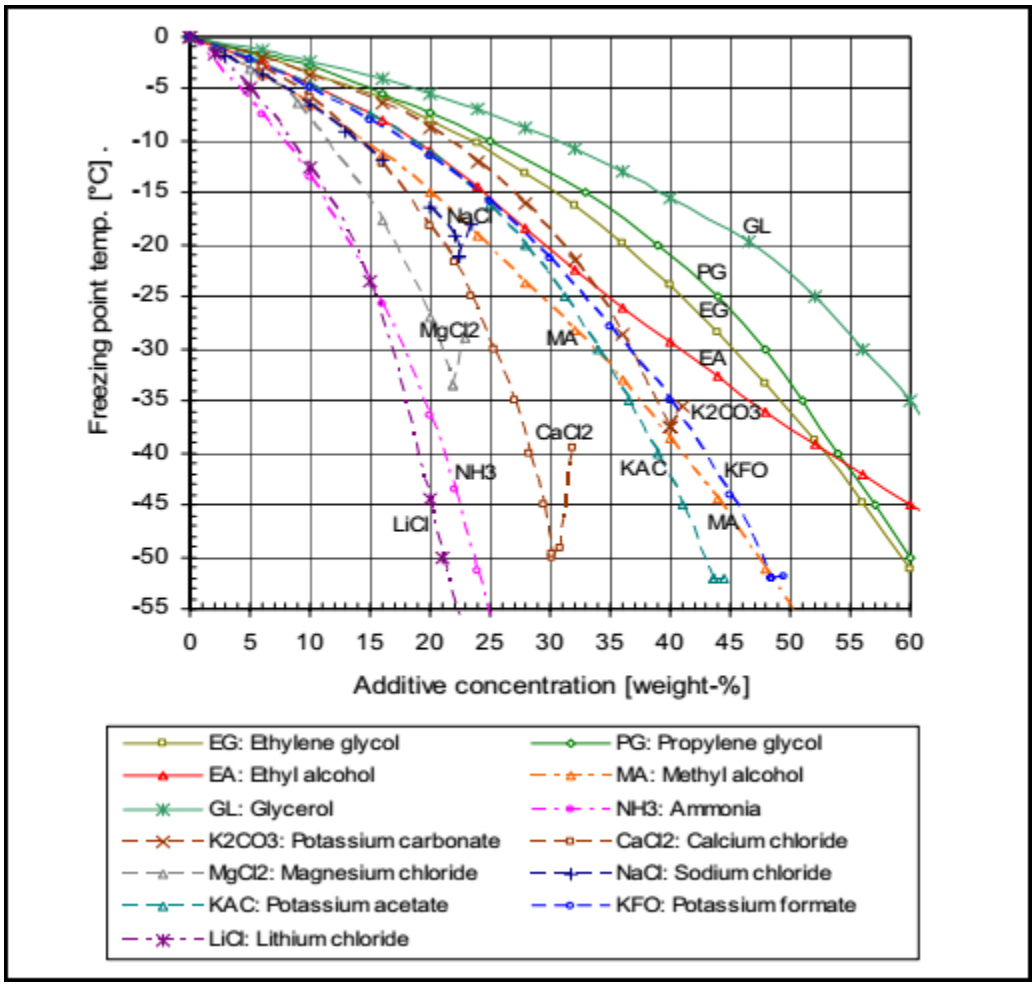

Figure 2: Eutectic Temperatures vs. Concentrations (Melinder 2007)

Table 2: Conversion of equivalent melting capabilities (Blackburn and Associates, 2014)

Pavement Temperature °F	Solid NaCl, lb/LM	23% NaCl liquid, gal/LM	Solid 90-92% $CaCl_2$, lb/LM	32% $CaCl_2$ liquid, gal/LM	Solid 100% $MgCl_2$, lbs/LM	27% $MgCl_2$ liquid, gal/LM	Solid 100% Kac, lb/LM	50% Kac liquid, gal/LM	Solid 96% CMA, lb/LM	25% CMA liquid, gal/LM
31-32	100	44	110	31	90	32	168	32	170	18
26-30	100	44	110	31	90	32	168	32	170	18
21-25	100	44	110	31	93	33	154	29	160	17
16-20	100	44	107	30	88	32	140	26	150	16
11-15	100	44	103	29	85	30	130	24	150	16
6-10	100	44	103	29	83	29	130	24	140	15
Below 5										

Table 3: Solid Application Recommended Rates for Solid NaCl based upon Eutectic Temperature (Blackburn and Associates, 2014)

Solid Application Rates for Common Snow and Ice Control Chemicals and Various Winter Weather Events

Pavement temperature, °F, at time of application	Solid NaCl Application Rates - pounds per lane-mile																							
	Pre-Treatment *				Within-Event **																			
	Snow		Frost/Black Ice		Freezing rain		Sleet		Light Snow		Moderate Snow		Heavy Snow		Frost and Black Ice		Light freezing rain		Moderate freezing rain		Heavy freezing rain		Light sleet		Moderate sleet		Heavy sleet	
	Anti-icing		Anti-icing		Anti-icing		Anti-icing		Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing	Anti-icing	Deicing
Over 30	110		100		125		120		110	240	130	265	150	290	100	225	110	240	130	265	150	290	130	265	145	290	165	320		
26 to 30	160		130		175		175		160	350	175	375	190	400	130	250	170	350	180	375	190	400	175	385	195	410	210	440		
21 to 25	210		160		225		230		200	425	210	450	220	475	160	275	200	425	210	450	220	475	220	465	230	500	240	525		
16 to 20	250		190		275		275		230	500	240	525	250	NR	190	300	230	500	240	525	250	NR	250	NR	260	NR	280	NR		
11 to 15	NR		NR		NR		NR		260	NR	270	NR	280	NR	NR	NR	260	NR	270	NR	280	NR	285	NR	300	NR	310	NR		
6 to 10	NR		NR		NR		NR		NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR		
Below 5	NR		NR		NR		NR		NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR		

2.9 Other Information on Deicers

Hossain, Fu and Lake (2014) field tested several types of alternative deicers in parking lots by applying deicers before, during, and after several snowstorms. Based on previous research they imply that sunlight and types of pavement have more to do with the recovery time than traffic, although this

has been disputed. They treat with Rock Salt, Blue Salt (a mixture of Sodium Chloride and Magnesium Chloride), Slicer (78% NaCl, 9.4% $MgCl_2$, and 2-3% proprietary ingredients), Green Salt (Sodium Formate treated with GEN3 runway deicing fluid), and Jet Blue (Sodium Chloride treated with polyol). They determined that plowing was mostly effective in reducing the time to bare pavement with the exception of Jet Blue. Slicer performed the best overall, but Jet Blue performed best without plowing. A salting rate of 5-15 lbs/1000 sq ft would be equivalent to 317-950 lbs/lane-mile. For applications of roadways this application rate is high, as 320 lbs/lane-mile is often a high end application rate reported by Nebraska Department of Roads winter maintenance crew. The tests were conducted at a temperature range of -7°C (20°F) to -10°C (14.2°F). Rock Salt was reported to be effective down to 5°F, although other research recommended 10°F. Hossain, Fu, and Lake (2014) claimed that NaCl reaches bare pavement in about 6-9 hours under 10-20°F, depending on the snow condition and after plowing. Unplowed sections under packed snow took twice as long retreat time (about 18-19 hours). Their main conclusions are that the Rock Salt retreat time is between 6-9 hours, longer for packed and shorter for loose snow. While raising the application rates reduces the amount of time to bare pavement, big increases in application rates do not reduce the regain time considerably. For instance, doubling the application rate from 5 to 10 lbs/1000 sq ft may decrease the time to bare pavement from 9 to 8 hours.

Shi et al. (2013) found that for warm winter storms (e.g., pavement at 26°F and high humidity), 30 gal/lane-mile of salt brine outperformed calcium chloride. Blending of agriculture-based products (e.g., beet juice products) with salt brine compromised the brine's ice melting capacity at higher temperatures (30°F). However, 80/20 ratios did perform better than they would have individually at 5°F.

To enhance the friction benefits of anti-icing or deicing pavement, plowing is highly recommended but allowing sufficient time for the chemical to interact with the pavement. Thicker

layers of snow and ice require more time to allow the chemical to interact, as does for lower volume of traffic. Shi et al. (2013) recommended the following practices:

- For high traffic volume and light snow

  Pavement temperature 15°F-20°F

  - Anti-icing using salt brine at 20-30 gal/lane-mile
  - Deice using salt brine at 30-60 gal/lane-mile.

  Pavement temperature 25°F-30°F

  - Anti-ice using salt brine at 20-40 gal/lane-mile
  - Deice using salt brine at 20-30 gal/lane-mile

- For low traffic volume roads under light snowfall

  Pavement temperature 15°F-20°F

  - Anti-ice and deice using products in current practice

  Pavement temperature 25-30°F

  - Anti-ice using products in current practice
  - Deice using salt brine at 20-30 gal/lane-mile

  For high traffic volume and heavy snow:

  Pavement temperature 15-20°F

  - Plow frequently while giving sufficient time for deicer to work after its application
  - Deice using salt-brine – prewet-salt at 16 gal/ton and 400-650 lbs/lane-mile

  Pavement temperature 25-30°F

  - Plow frequently while giving the deicer sufficient time to work
  - Deice using salt prewet at 8 gal/ton and 250-350 lbs/lane-mile

It should be noted to compare with results from the survey analysis in Chapter 4 that the pre-wet solid salt application rate is in the 250-300 lbs/lane-mile range for high pavement temperature and 400-600 lbs/lane-mile for low pavement range. When the recommendations from Blackburn and Associate's (2014) application rates are compared to Shi's (2013), it shows that Blackburns's application rates from the eutectic curve are indeed about twice as high. For example, while Shi shows an application rate of 30-60 gal/lane-mile of salt brine for light snow and heavy traffic at the temp of 15-20°F, Blackburn shows an application rate of salt brine for a similar condition of 100-108 gal/lane-mile. This is evidence that there needs to be more research of what should actually be applied in the field and what applications are working there. Properties determined in laboratories are not the only factors that contribute to ice melting.

2.10 Deicer Effects on Concrete

Chloride-based deicers cause corrosion on reinforcing steel bars is well known. Shi, Akin, Pan, Fay, Liu, and Yang (2009) reported that "Deicers may also pose detrimental effects on concrete infrastructure through their reactions with cement paste and/or aggregates." They have found that $MgCl_2$ and $CaCl_2$ deicers react with the cement paste in concrete and can cause additional degradation within the concrete through the formations of hydrates. $MgCl_2$ can cause $Mg(OH)_2$ and M-S-H (Magnesium silicate hydrate) to form. Snow (2006) claims that the winter of 2000-2001, the Idaho Falls Regional Area witnessed scaling of concrete surfaces increased approximately 10 times from that during the previous nine winters and the only change that occurred was the use of Magnesium Chloride. Shi et al. (2009) also states that $CaCl_2$ can react with $Ca(OH)_2$ and form a hydrated calcium oxychloride. $CaCl_2$ did not degrade concrete as quickly as $MgCl_2$. NaCl can initiate alkali-silica reaction (ASR) in concrete. Chlorides were not found to be as damaging to asphalt pavements, but they did reduce the traction resistance. A clear understanding of the effect of deicers on concrete structures is necessary for a

maintenance worker who is treating a bridge or parking structure. Sutter, Peterson, Julio-Betancourt G, Hooton D, Van Dam T, and Smith K (2008) points out that although there are many factors that affect the long-term durability of concrete during its construction, the best way to protect concrete from deicer attack is to use the least amount of deicer as possible.

2.11 Deicer Effects on the Environment

Fay and Shi (2011) have compiled a list of effects of deicers on the environment. Different deicers have different effects on the environment and the effects are not always intuitive. The harmful effects of using sand and gravel is a good example of this. Research shows that the use of abrasives can increase turbidity in water supplies and limit the oxygen supply in a body of water. Sand and gravel can also cause air quality issues. Chloride, Sodium, Calcium, and Potassium ions can harden water. Sodium chloride can decrease soil fertility, leading to reduced plant growth and increased erosion. It also can cause leaf singe and browning. Although not regularly used in Nebraska, Acetates, Formates, and Glycols have high biological oxygen demands. The use of urea can lead to increased nitrate concentration. The environmental effects of agriculture-based products are yet to be determined.

Fay, Volkening, Gallaway, and Shi (2007) conducted a nationwide survey of highway agencies to rank the advantages and disadvantages of different attributes of deicers. They found that agriculture-based products were perceived to have the greatest benefit to roadways, while abrasives such as sand and gravel were found to have the least benefit. They pointed out that acetates and formates were perceived by roadway workers to have the least environmental impacts compared to chlorides, while research findings in the literature suggested the opposite.

There is also evidence that suggests that deicers that were thought to not be as toxic tend to actually be more toxic because of corrosion inhibitors that are added to them (Pilgrim, 2013). Barr

Engineering Company tests the toxicity of several deicers and find and provide a list of least toxic deicers to most toxic. Although there are concerns about the salinity of water supplies with Sodium Chloride it tends to be the least toxic (Figure 3).

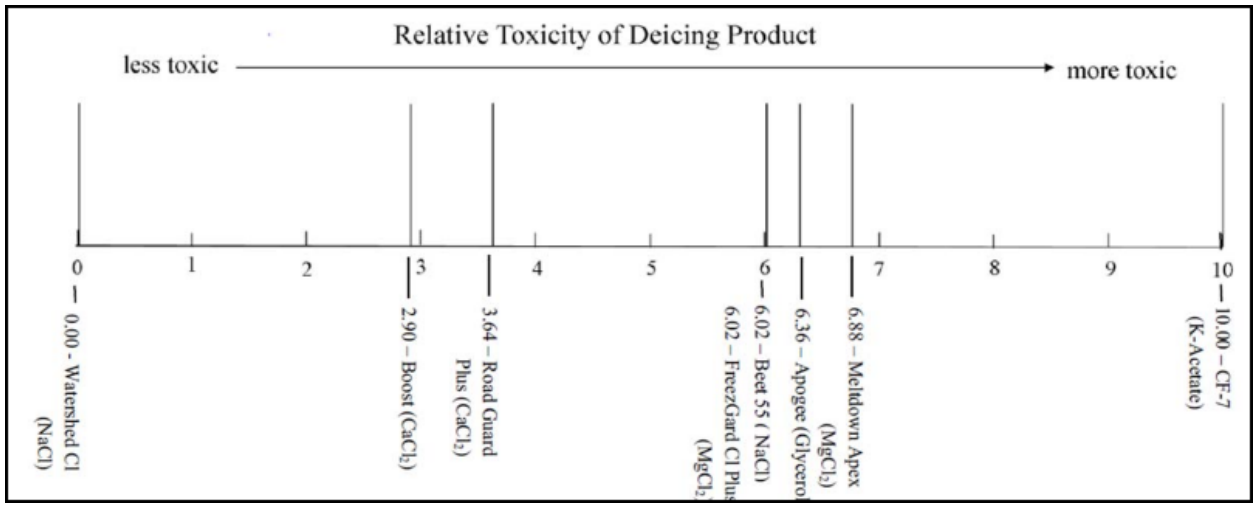

Figure 3: Relative Toxicity of Deicing Products (Barr Engineering, 2013)

2.12 Concluding Remarks

A literature survey was conducted to examine current practices for winter roadway maintenance. Different practices and methods that are currently used include anti-icing, deicing, and pre-wetting. Current deicers that are used in Nebraska include road salt, salt brine, apex meltdown (magnesium chloride), calcium chloride, sand and gravel, and Geomelt (beet juice blended product). Various application rates of deicers and the application methods were also surveyed.

Deicers can also impact environment and infrastructure. For these reasons it is very important that winter maintenance agencies utilize best management practices to minimize the amount of deicers introduced to the environment and infrastructure to minimize damage.

Chapter 3: Best Practice Winter Maintenance Survey

In the Spring of 2014, Winter maintenance professionals in the State of Nebraska were given a survey developed by the author with the approval of a committee of representatives from the Nebraska Department of Roads. The survey asked winter maintenance crews for their snow and ice removal practices for 5 specific winter weather scenarios that were agreed upon by the committee at NDOR. The goal of the survey was to obtain the best winter maintenance practices followed by the Nebraska Department of Roads (NDOR) to provide recommendations for city and county workers outside of NDOR. The survey was conducted and distributed through surveymonkey.com. First, general contact and background information of the responding agencies was gathered. Next, the respondents were asked a series of questions if they had treated a particular type of roadway in a given weather scenario. As a disclaimer to readers that reside outside of the State of Nebraska the recommendations provided may not reflect a best practice for areas outside of Nebraska. The recommendations given are based on the availability of materials here in Nebraska.

3.1 The Survey

The survey consisted of five weather scenarios that were designed and agreed upon by a committee at NDOR. It was determined that a survey that attempted to gather an entire set of maintenance practices for every possible weather would be too large, and the survey may not keep the attention of a survey participant. To make sure that the survey that was drafted would be user friendly, it was determined that participants would asked for practices for five weather scenarios that were similar to recent events that participants should have encountered in the field. The survey information could then be compared to corresponding scenarios in MDSS (Maintenance Decision Support System).

The information found in MDSS did not entirely match with the survey results, but some similarities were found. This is discussed in Chapter 4. Following are the survey scenarios and the survey questionnaire that accompanied each scenario:

Scenario 1:

The Storm forecast shows light snow (less than 0.5 in/hr.) is expected to fall from 9:00 a.m. to 3:00 p.m. A total accumulation of 2 to 3 inches is expected. The wind speed is less than 15 mph, and the air and pavement temperatures are in the mid-twenties Fahrenheit. The temperature the next day is forecast to be in the single digits, and it will be sunny. Determine the best practice for deicer application to keep a RURAL INTERSTATE/FREEWAY/EXPRESSWAY completely clear.

Scenario 2:

The Storm forecast shows sleet is expected starting from 6:00 to 10:00 a.m. The wind speed is less than 15 mph, the air temperature is in the low thirties, and the pavement temperature is in the twenties. The weather for the rest of the day is overcast with low wind, and the temperature is in the twenties. Determine the best practice for deicer application to keep an URBAN INTERSTATE completely clear.

Scenario 3:

It is the morning after a snow storm has passed. The road is covered in compacted snow. The temperatures of the air and pavement are in the mid-teens. It is sunny with low wind. For the rest of the day, the high temperature will be around twenty degrees. Clouds will move in between 2:00 and 3:00 p.m. Determine the best practice for deicer application to maintain a LOW VOLUME HIGHWAY/COLLECTOR STREET.

Scenario 4:

Light rain starts at 3:00 p.m. then turns to light snow (less than 0.5 in/hr) at 8:00 p.m. It continues to snow until 11:00 p.m. Total accumulation is expected to be 1 to 2 in. The temperatures of the air and pavement at the beginning of the rain are in the low to mid thirties. The air temperature drops to the mid-twenties at about 8:00 p.m. The wind speed is less than 15 mph. Overnight temperatures are expected to be in the mid to lower twenties. The temperature next day will stay in the low twenties, and it will be overcast with low wind. Determine the best practice for deicer application to maintain a HIGH VOLUME HIGHWAY/COLLECTOR STREETS.

Scenario 5:

It is the morning after a snow storm has passed. The road is covered in compacted snow. The temperatures of the air and pavement are in the mid-teens. It is sunny with low wind. For the rest of the day, the high temperature will be around twenty degrees. Clouds will move in between 2:00 and 3:00 p.m. Determine the best practice for deicer application to maintain a RESIDENTIAL STREET.

If the respondent indicated that he/she dealt with the particular type of roadway that was in each scenario, then the respondent would be directed to the corresponding scenario and the following question algorithm:

1. What form of chemicals would you apply in this scenario?
    a. Liquid
    b. Solid (may or may not include a pre-wet)
    c. Liquid and Solid treatments are applied separately
    d. No chemical treatment is required; Just Plowing
    e. No action is required

If the respondent answered “a. Liquid” on question 1 the survey continued to the question 2:

2. What type of Liquid Deicer would you choose?
    a. Straight Salt Brine (100%)
    b. Salt Brine with an additive
    c. Another type of liquid deicer

If the respondent answered “a. Straight Salt brine” on question 2:

3. You selected 100% straight salt brine. What application rate would you use to treat this scenario?
    a. 0-25 gal/lane mile
    b. 25-50 gal/lane mile
    c. 50-75 gal/lane mile
    d. 75-100 gal/lane mile
    e. >100 gal/lane mile

If the respondent answered “b. Salt Brine with an additive” on question 2:

4. You selected Salt Brine with an additive. What do you use as an additive?
    Shown in a Drop Down Box:
        -Geomelt C (not as a pre-wet)
        -Apex Meltdown
        -Calibur M-1000
        -Calibur M-2000
        -Ice Ban 200
        -Calcium Chloride
        -Freezeguard
        -Other (please specify)

    Other Liquid Deicer: _____

5. What application rate do you choose to apply your Salt Brine with additive?
    a. 0-25 gal/lane mile
    b. 25-50 gal/lane mile
    c. 50-75 gal/lane mile
    d. 75-100 gal/lane mile
    e. >100 gal/lane mile

If the respondent answered “c. another type of liquid deicer” on question 2:

6. What other type of liquid deicer do you use?
    Shown in a Drop Down Box:
        - Geomelt C (not as pre-wet)
        - Apex Meltdown
        - Calibur M-1000
        - Calibur M-2000
        - Ice Ban 200
        - Calcium Chloride

- Freezeguard
- Other (please specify)

Other Liquid Deicer: _____

7. What application rate do you choose to apply your previously specified liquid deicer?
    a. 0-25 gal/lane mile
    b. 25-50 gal/lane mile
    c. 50-75 gal/lane mile
    d. 75-100 gal/lane mile
    e. >100 gal/lane mile

Question 3, 5, and 7 proceeded to this question:

8. How often will you need to retreat with this previously specified liquid deicer treatment?
    a. No retreatment is required.
    b. Every one hour
    c. Every two hours
    d. Every three hours
    e. Every four hours
    f. Every five hours
    g. Every six hours
    h. More than every six hours
    i. The same treatment is not used (please elaborate):
    The different treatment used is: _____

If the respondent answered " b. Solid (may or may not include a pre-wet)" in question 1:

9. What type of solid material do you use?
    a. Road Salt
    b. Road Salt with Sand/Gravel
    c. 10% Ice Slicer with Sand/Gravel
    d. 10% Ice Slicer with Road Salt
    e. 10% Ice Slicer with Road Salt and Sand/Gravel mix
    f. Sand/Gravel
    g. Other (please specify: _____)

10. What application rate of your previously specified deicer do you use?
    Shown in a Drop Down Box:
        - 0-50 lb/lane mile
        - 50-100 lb/lane mile
        - 100-150 lb/lane mile
        - 150-200 lb/lane mile
        - 200-250 lb/lane mile
        - 250-300 lb/lane mile
        - 300-350 lb/lane mile
        - 350-400 lb/lane mile
        - 400-450 lb/lane mile

- 450-500 lb/lane mile
- 500-550 lb/lane mile
- 550-600 lb/lane mile
- 600-650 lb/lane mile
- 650-700 lb/lane mile
- 700+ lb/lane mile
-

11. Do you use a pre-wet with your treatment?
    a. Yes
    b. No

If a respondent answered "Yes" to question 11:

12. What do you use as a pre-wet?
    a. Salt Brine only
    b. Salt Brine mixed with geomelt?
    c. Other (please specify: _____)

If a respondent answered "b. Salt Brine mixed with geomelt" on question 12:

13. What Salt Brine/Geomelt ratio do you use?
    Shown in a Drop Down Box:
    - 95%-Brine 5%-Geomelt
    - 90%-Brine 10%-Geomelt
    - 85%-Brine 15%-Geomelt
    - 80%-Brine 20%-Geomelt
    - 75%-Brine 25%-Geomelt
    - 70%-Brine 30%-Geomelt
    - 65%-Brine 35%-Geomelt
    - 60%-Brine 30%-Geomelt
    - 55%-Brine 45%-Geomelt
    - 50%-Brine 50%-Geomelt

14. What application rate do you apply to your solid deicer
    a. 0-3 gal/ton
    b. 3-6 gal/ton
    c. 6-9 gal/ton
    d. 9-12 gal/ton
    e. 12-15 gal/ton
    f. 15-18 gal/ton
    g. 18-21 gal/ton
    h. 21+ gal/ton

15. How often will you need to retreat with this previously specified deicer?
    a. No retreatment is required.
    b. Every one hour
    c. Every two hours
    d. Every three hours

e. Every four hours
f. Every five hours
g. Every six hours
h. More than every six hours
i. The same treatment is not used (please elaborate):
The different treatment used is: _____

If a respondent answered "c. Liquid and Solid treatments are applied separately" to question 1, they would be given first the liquid questions 2-8 then the solid questions 9-15.

After whichever sequence of questions 1-15 were finished, the following questions were posed:

16. If you have any additional comments or descriptions of your practices that you feel are pertinent to this scenario please describe them: _____

17. How would you rank the effectiveness of this treatment?
    a. Very Effective
    b. Somewhat Effective
    c. Neutral
    d. Somewhat Ineffective
    e. Very Ineffective

The open-ended follow-up questions were also asked:

18. How would your practice change if:
    - Wind was greater than 15 mph?
    - If the snow fell overnight instead of at daytime?
    - If it was overcast the next day?
    - If there was heavy instead of light snow?

19. Describe the anti-icing practices that you would apply to this scenario, if any?

The survey then proceeded to the roadway environment from Scenario 2. If the respondents treated that specific type of roadway, they would be presented with questions 1-19 again. This process was repeated for Scenarios 3 to 5 subsequently. Most respondents answered no more than 3 scenarios. On average, the survey took respondents no more than 15 minutes to complete.

Of the 96 participants, 10 did not completely fill out the survey, and their responses were discarded. Of the remaining participants, 12 were from city agencies across Nebraska, and 2 were from county

agencies. The remaining 72 participants were from NDOR. The representations of the participants are shown in Figure 4. It is unclear whether the 14 city and county representatives are a good sample size for the state of Nebraska.

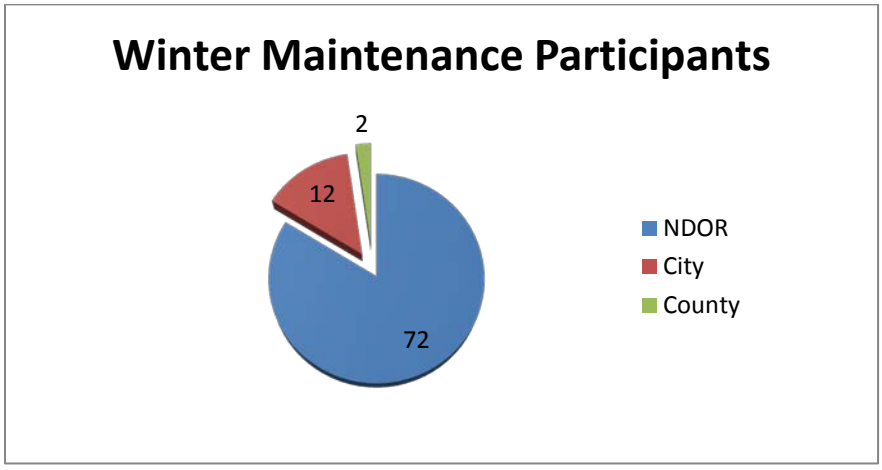

Figure 4: Composition of the Survey Participants

3.2 Cost Assumptions

The following list (Table 4) represents the prices that were used to estimate a cost per lane/mile of the reported treatments for the different winter maintenance scenarios. Costs were reported by NDOR, but are subject to change from year to year. Estimated costs of reported treatments may not reflect the actual cost per lane mile. They are "ball-park" figures and should be taken as such. Because participants were provided with a range to choose from for application rates, cost estimates are provided as a range where the first number represents the lower limit of the application rates and the second number represents the upper limit. It should also be noted if a treatment reported sand/gravel and road salt, it was assumed that these quantities were a 1:1 ratio. This is the same with liquids. If it was reported that both apex and salt brine were used, it was assumed that this was a 1:1 ratio of apex

and brine. This assumption may not hold true for every participant; however, it was acknowledged during the analysis of MDSS that this is a common practice. 10% Ice Slicer with road salt and sand/gravel was assumed to be 10% Ice Slicer, 45% road salt, and 45% sand gravel. Also, some agencies reported a "time to retreat". Originally, this time was used in calculating an average cost per lane mile. After conversations with experienced winter maintenance officials, it is concluded that the "time to retreat" reported reflects a time that rounds are made, and that treatments made on these rounds are most likely spot treatments. It was assumed as a result that the contribution of these retreatments is negligible. In all of the treatments that are recommended based upon the active practices, routes should be patrolled and treatments should be reapplied in "problem areas". Also, the estimated cost does not reflect the cost of wear and tear to a vehicle, gas and insurance expenditures, or depreciation costs that come from the use of a vehicle. Winter Maintenance teams should use their best judgement in estimating any costs of treatments they may wish to adopt.

Table 4: Prices of Deicers currently in use

Chemical	Price	
Apex Meltdown	$1.19	$/gal
Beetjuice/Geomelt	$1.03	$/gal
Calcium Chloride	$0.58	$/gal
Calibur-M	$1.10	$/gal
Freeze Guard	$1.03	$/gal
Ice Slicer	$154	$/ton
Road Salt	$59.40	$/ton
Salt Brine	$0.06	$/gal
Sand/Gravel	$12.50	$/ton
Mixed Chemicals		
10%-Ice Slicer/90%-Road Salt	$68.89	$/ton
10-Ice Slicer/90%-Sand & Gravel	$26.68	$/ton
10%-IceSlicer/45%-Road Salt/45%-Sand & Gravel	$47.79	$/ton
25%-IceSlicer/37.5%-Road Salt/37.5%-Sand & Gravel	$65.54	$/ton
50%-Geomelt/50%-Brine	$68.89	$/gal
50%-Ice Slicer/50%-Road Salt	$106.85	$/ton
60%-Brine/40%-Geomelt	$0.45	$/gal
80%-Brine/20%-Geomelt	$0.25	$/gal
90%-Brine/10%-Geomelt	$0.16	$/gal
95%-Brine/5%-Geomelt	$0.11	$/gal
50%-Apex/50%-Salt Brine	$0.63	$/gal
50%-Road Salt/50%-Sand & Gravel	$35.95	$/ton
50%-Salt Brine/50%-Calbur M	$0.58	$/gal

3.3 Analysis of Survey Results

It was the objective of this study to present recommendations and treatment methods to the City and County workers across the State of Nebraska who do not fall under the Nebraska Department of Roads umbrella. The recommendations and practices presented are a compilation of the survey responses and are completely anonymous for the purpose of confidentiality. The types of chemicals and treatments most commonly used by the cities and counties are determined. These treatments were compared to current NDOR practices, while the best practices were determined based upon the deicer materials that are typically available to the cities and counties.

Unfortunately, only one response to the first and the second scenarios was from the county or city officials. This individual responded with similar treatments for every scenario with the exception of scenario 3, where the application rate was increased. This data is not likely to be useful; nevertheless, it indicates that some county and city workers may have to treat freeways. In the event that the city and county workers do treat these roads, recommendations are made for these scenarios using both road salt and ice slicer. These two chemicals are frequently used by the city and county workers as evident from responses for Scenarios 3 to 5.

3.3.1 Scenario 1 Analysis

Table 5 shows the complete list of responses of NDOR participants who used a solid deicer only for treatment. For this scenario it was assumed that full treatments were applied for 6 hours. Based on the responses from participants #59, #9 and #48 ("Part. #" in Table 5 and all subsequent tables refers to the participant's number which was assigned randomly for the sake of anonymity), applications of salt should be limited to no more than 200-250 lbs/lane-mile. While these are probably good application rates for road salt, a "best practice" will take advantage of the use of pre-wet to reduce scatter, and the addition of Ice Slicer and Pre-wet will intuitively reduce that application rate further. There are 5 reported treatments that are deemed effective and are in the 100-150 lbs/lane mile application rate range that utilize Ice Slicer and/or pre-wet. Therefore a best practice is probably in this range. The use of 10% Ice Slicer at 100-150 lbs./lane-mile with a 6-9 gal/ton Apex pre-wet and retreated every 2 hours by participant #70 appears to be one promising treatment. This treatment had an estimated cost of $15.92-$23.88/lane mile. Another effective treatment was reported by participants #55 and #43, who used 100-150 lbs/lane-mile with a Geomelt pre-wet. Participant #55 used 80/20 ratio of salt brine to Geomelt at a 12-15 gal/ton rate for prewet, while participant #43 used 50/50 ratio at 6 gal/ton for prewet. These treatments had an estimated cost of $12.79-$18.96 and $12.37-$18.8, respectively.

Using a generous amount of salt brine/Geomelt would be a good practice because it does not increase the cost per lane mile significantly, yet accelerates melting. The only concern is that using the higher ratio of Geomelt could clog up the spreader. The Geomelt prewet helps the road salt to stick to the roadways and enhances the efficiency of the salt dispensed.

Table 5: Scenario 1 NDOR Solid Respondents

Part. #	Solid	App Rate (lb/lane mi)	Pre wet	App Rate (gal/ton)	Retreat Time (hrs)	Effectiveness	Cost Estimate
70	10% Ice Slicer with Road Salt	150	apex	9	2	Very Effective	$15.92 - $23.88
21	10% Ice Slicer with Road Salt	350	Salt Brine	3	A/N	Very Effective	$10.33 - $12.09
62	10% Ice Slicer with Road Salt	500	Salt Brine	12	A/N	Somewhat Effective	$15.64 - $17.4
59	Road Salt	200			4	Very Effective	$8.91 - $11.88
9	Road Salt	250			2	Very Effective	$23.76 - $29.7
48	Road Salt	250			2	Very Effective	$23.76 - $29.7
8	Road Salt	150	apex	3	2	Somewhat Effective	$11.88 - $18.89
39	Road Salt	200	salt brine and Apex	6	3	Very Effective	$13.93 - $18.95
41	Road Salt	300	Apex	12	?	Very Effective	#VALUE!
55	Road Salt	150	80%-Brine/20%-Geomelt	15	2	Very Effective	$12.79 - $18.96
43	Road Salt	150	50%-Brine/50%-Geomelt	6	2	Very Effective	$12.37 - $18.8
17	Road Salt	150	Salt Brine	15	1	Somewhat Effective	$21.17 - $31.66
36	Road Salt	250	Salt Brine	3	A/N	Somewhat Effective	$5.94 - $7.45
27	Road Salt mixed with Sand/Gravel	400	apex	6	A/N	Very Effective	$7.01 - $8.62
23	Road Salt mixed with Sand/Gravel	600	Salt Brine	6	A/N	Somewhat Effective	$9.94 - $10.89

*A/N = patrol and spot treat problematic areas As Needed.

3.3.2 Scenario 2 Analysis

Scenario 2 represents a sleet situation where the temperatures are below freezing. For this scenario it was assumed that full treatments were applied for 4 hours. A list of NDOR respondents who responded using a solid treatment is given in Table 6. All the respondents reported the treatment was "very effective" with the exception of participant #8 who reported "somewhat effective."

Table 6: NDOR Scenario 2 Solid Respondents

Part. #	Solid	App Rate	Pre wet	App Ra	Retreat	Effectiveness	Cost Estimate
8	Road Salt	100	apex	3	2	Somewhat Effe	$4.46 - $9.45
39	Road Salt	200	Apex	6	3	Very Effective	$9.62 - $13.31
70	Road Salt	150	apex	6	2	Very Effective	$9.71 - $14.97
21	Road Salt	300	95%-Brine/5%-Geomelt	3	A/N	Very Effective	$7.43 - $8.96
2	Road Salt	100	80%-Brine/20%-Geomelt	12	3	Very Effective	$3.2 - $6.24
55	Road Salt	200	Salt Brine	12	1	Very Effective	$22.55 - $30.06
31	Road Salt	300	Salt Brine	9	2	Very Effective	$22.44 - $26.97
43	Road Salt	150	Salt Brine	6	2	Very Effective	$8.95 - $13.45
17	Road Salt	150	Salt Brine	15	1	Very Effective	$15.12 - $22.61
27	Road Salt mixed with Sand/Gravel	350	apex	6	2	Very Ineffective	$18.05 - $22.62

*A/N = patrol and spot treat problematic areas As Needed.

The responses for Scenario 2 show once again the subjectivity of the effectiveness rating. Participant #8 claims that the treatment was "somewhat effective." Participant #2 applied the same amount with a different pre-wet but less often, yet rated treatment "very effective." This implies that most of these treatments are probably effective, and the best practice may be the one that uses the least amount of materials and is the least expensive. Further, what is readily available for a county or city worker is important (which is road salt and Ice Slicer). Participant #2 uses the least amount of materials and still claims the treatment very effective. Hence, 50-100 lbs/lane-mile of road salt pre-wet with 9-12 gal/ton using 80/20 brine-Geomelt might be the best practice for this particular scenario. This treatment is commonly reapplied every 3 hours. Respondent #2 also keeps the cost of materials for this treatment down at $3.20-$6.24/lane mile. The data shows a user may alternatively prewet using 3 gal/ton of apex or at least 3-6 gal/ton of salt brine. If salt brine is used for prewet, the quantity of road salt may need to be increased to 100-150 lbs/lane-mile.

3.3.3 Scenario 3 Analysis

Table 7 shows that there were 2 county and 10 city respondents to this scenario. Of the 12 respondents, 7 stated that they would use a percentage of Ice Slicer mixed with road salt and/or sand and gravel as a solid deicer. Six of these respondents used 10% Ice Slicer while the 7th respondent used 25%. It is apparent that 10% Ice Slicer is favored by many city and county respondents.

Table 7: Scenario 3 County/City Respondents

Part. #	Liquid	App Rate	Retreat	Solid	App Rate	Pre wet	App Rate	Retreat	Effectiveness	Cost Estimate
		(gal/ln mi)	(hrs)		(lbs/ln mi)		(gal/ton)	(hrs)		
County										
72	Freezeguard	25	A/N	Road Salt mixed with Sand/Gravel	50			6	Somewhat Effective	$0 - $26.65
83	None		A/N	10% Ice Slicer with Road Salt and Sand/Gravel m	400	Calcium Chloride	6	A/N	Very Effective	$8.71 - $10.25
City										
28	Salt Brine with Geomelt C	25	A/N	None					Neutral	$0 - $6.35
84	100% Salt Brine	100	A/N	Road Salt	100	Apex	6	3	Neutral	$7.83 - $12.65
81	Calibur M-1000	25	A/N	Road Salt mixed with Sand/Gravel	50			6		$0 - $28.4
1	None			10% Ice Slicer with Road Salt	550				Somewhat Effective	$17.22 - $18.94
64	None			10% Ice Slicer with Sand/Gravel	250			A/N	Very Effective	$2.67 - $3.34
73	None			25% Ice Slicer with Road Salt or just Road Salt	550			A/N	Very Effective	$16.38 - $18.02
32	None			10% Ice Slicer with Road Salt	200	Apex	12	2	Very Effective	$18.71 - $24.95
74	None			10% Ice Slicer with Road Salt	250	80%-Brine/20%-Geomelt	12	A/N	Somewhat Effective	$7.17 - $8.99
4	None			10% Ice Slicer with Road Salt and Sand/Gravel m	100	90%-Brine/10%-Geomelt	6	A/N	Very Effective	$1.22 - $2.44
7	None			Road Salt mixed with Sand/Gravel	100			A/N	Somewhat Effective	$0.9 - $1.8

*A/N = patrol and spot treat problematic areas As Needed.

For this scenario it was assumed that full treatments were applied for 4 hours. Seven of the 12 city and county respondents used Ice Slicer in solid treatment, and 4 of these 7 respondents used a prewet. Although Ice Slicer can be expensive, using only 10% in treatments limits the cost. About half of all the treatments using Ice Slicer had an estimated cost of about $10/lane mile. Five of the 7 city/county respondents reported that their treatments were very effective. It seems reasonable that a best practice involving 10% Ice Slicer should be standardized for use by City/County maintenance workers for treating compacted snow. Table 8 represents a complete list of all the respondents from NDOR for Scenario 3 that used Ice Slicer. Some of the “very effective” treatments have a smaller application rate than some of the “somewhat effective” treatments. This reveals that the difference between “very effective” and “somewhat effective” is rather subjective. This also shows that different winter maintenance professionals may have different goals. For instance, winter maintenance teams may apply a large quantity of 10% Ice Slicer with sand/gravel to only curves and accident-prone areas to increase the traction and to initiate melting. A best practice using solid deicer might consist of 10% Ice Slicer with road salt at 150-200 lbs/lane mile with a pre-wet of Apex at 9-12 gal/ton. This practice has an estimated cost of $18.71-$24.95/lane mile. After reviewing literature and interviewing a few professionals, there are a few “tweaks” that may be made with little additional cost. For instance, using Apex as pre-wet should be limited to no more than 3 gal/ton to avoid leaching from the stock pile. Using 150-200 lbs/lane mile with the pre-wet makes sense when compared to the “very effective”

treatment of 10% Ice Slicer with road salt at 200-250 lbs/lane mile. In other words, using Apex pre-wet should reduce the solid application rate. Shi and O'Keefe (2005) stated in a Michigan study that "96 percent of the prewet material was retained on the road surface compared to only 70 percent of the dry salt because of reduced bounce and scatter." Therefore, it is reasonable to conclude that the solids used may be reduced by 25% when a prewet is applied.

Table 8: Scenario 3 complete list of all Ice Slicer Users (NDOR/counties/cities)

Part. #	Solid	App Rate	Pre wet	App Rate	Retreat	Cost Estimate
Very Effective						
78	10% Ice Slicer with Road Salt and Sand/Gravel m	400	Apex	6	A/N	$9.08 - $10.99
66	ice-slicer 50/50 with salt	200	Apex	6	5	$8.37 - $11.4
21	10% Ice Slicer with Sand/Gravel	400	90%-Brine/10%-Geomelt	6	A/N	$4.76 - $5.52
83	10% Ice Slicer with Road Salt and Sand/Gravel m	400	Calcium Chloride	6	A/N	$8.71 - $10.25
64	10% Ice Slicer with Sand/Gravel	250			A/N	$2.67 - $3.34
73	25% Ice Slicer with Road Salt or just Road Salt	550			A/N	$16.38 - $18.02
32	10% Ice Slicer with Road Salt	200	Apex	12	2	$18.71 - $24.95
4	10% Ice Slicer with Road Salt and Sand/Gravel m	100	90%-Brine/10%-Geomelt	6	A/N	$1.22 - $2.44
Somewhat Effective						
62	10% Ice Slicer with Road Salt	500			A/N	$15.5 - $17.22
59	10% Ice Slicer with Road Salt	200			4	$10.33 - $13.78
3	10% Ice Slicer with Road Salt and Sand/Gravel m	300	Apex	6	A/N	$6.51 - $8.24
23	10% Ice Slicer with Sand/Gravel	600	Salt Brine	6		$7.39 - $8.11
1	10% Ice Slicer with Road Salt	550				$17.22 - $18.94
74	10% Ice Slicer with Road Salt	250	80%-Brine/20%-Geomelt	12	A/N	$7.17 - $8.99

*A/N = patrol and spot treat problematic areas As Needed.

3.3.4 Scenario 4 Analysis

Scenario 4 represents a freezing rain situation which turns to snow. When temperature drops and the liquid precipitation freezes. This is a very slick and wet condition, but the temperatures never drop below 10°F to exclude the use of sodium chloride. Shown in Table 9, there were 1 county and 8 city respondents who answered questions related to scenario 4. Of these respondents, participants # 4, #64, #73, #74, and #84 all reported their treatments to be "very effective." Participant #28 reported a "neutrally effective" treatment, and participant #81 did not report the effectiveness. Participants #1 and #32 reported a "somewhat effective rating."

Table 9: Scenario 4 Respondents

Part. #	Liquid	App Rate	Retreat	Solid	App Rate	Pre wet	App Rate	Retreat	Effectiveness	Cost Estimate
County										
83	None			Road Salt mixed with Sand/Gravel	400	Calcium Chloride	6	A/N	Very Effective	$6.64 - $7.89
City										
28	Salt Brine with Geomelt C (not as pre-wet)	25		None					Neutral	$0 - $6.35
81	Calibur M-1000	25	4	None						$0 - $27.5
64	None			10% Ice Slicer with Sand/Gravel	150			A/N	Very Effective	$1.33 - $2
4	None			10% Ice Slicer with Sand/Gravel	100	90%-Brine/10%-Geomelt	6		Very Effective	$0.69 - $1.38
73	None			Road Salt	550			6	Very Effective	$14.85 - $16.34
1	None			Road Salt	550				Somewhat Effective	$14.85 - $16.34
32	None			Road Salt	200	Apex	12	2	Somewhat Effective	$11.05 - $14.74
74	None			Road Salt	150	80%-Brine/20%-Geomelt	12	1	Very Effective	$12.57 - $18.73

Respondents #64 and #4 reported treatments using 10% Ice Slicer mixed with sand/gravel were "very effective." Respondent #4 used a pre-wet of 90/10 Brine-Geomelt. No similar treatments were used by the NDOR respondents. Only two NDOR respondents used 10% Ice Slicer, but at a higher application rate of road salt without sand/gravel (250-500 lbs/lane-mile). Even though sand and gravel is not a deicer, it provides traction when precipitation becomes frozen to the road surface. When applying sand and gravel, timing is key; it is crucial to add sand and gravel immediately before the temperature drops below freezing. If applied to soon it will reduce friction before it can freeze to the surface. This treatment is effective, but a roadway professional will need to carefully watch the pavement temperatures. The treatment would also be most beneficial at stop signs, intersections, curves and other areas where extra traction is required. Sand and gravel treatments should be limited because they could result in high clean-up costs. Treatments used by respondents #4 and #64 are estimated to cost about $1.33-$2.00/lane mile respectively.

Four of the nine city/county respondents (#73, #1, #32, and #74) reported using road salt only, with or without a prewet. Two of these respondents (#73 and #74) reported "very effective" treatment. The other two respondents reported "somewhat effective." One respondent (#83) used road salt mixed with sand/gravel and prewet with $CaCl_2$. Table 10 shows that all but 3 of the 19 NDOR respondents used road salt with a pre-wet. All but one of these 16 respondents used a pre-wet. Most NDOR respondents reported an effective treatment with the exception of #62, #8, #17, and #77 who reported "somewhat effective" and #2 did not report an effectiveness rating. It seems that a road salt only treatment is

effective and should be developed for cities and counties for this type of scenario. Several NDOR respondents who claimed their treatments were "very effective" treated with road salt within the 100-150 lbs/lane mile range. This appears to be a good application rate for road salt with various pre-wets. Pre-wets can be salt brine or 80/20 Brine-Geomelt at 9-15 gal/ton. However, if Apex is used for prewet, it should be limited to no more than 3 gal/ton. These treatments are estimated to cost about $6.50-$10.50/lane-mile with a 2 hour retreatment time.

Table 10: Scenario 4 NDOR Solid Only Responses

Part. #	Solid	App Rate	Pre wet	App Rate	Retreat	Effectiveness	Cost Estimate
NDOR							
62	10% Ice Slicer with Road Salt	500	Salt Brine	12	A/N	Somewhat Effective	$15.64 - $17.4
59	10% Ice Slicer with Road Salt	250	Apex	6	4	Very Effective	$7.34 - $9.5
9	Road Salt	300			2	Very Effective	$14.85 - $17.82
70	Road Salt	150	apex	9	2	Very Effective	$7.01 - $10.52
76	Road Salt	250	Apex Meltdown	9	2	Very Effective	$13.67 - $17.53
8	Road Salt	100	apex	3	5	Somewhat Effective	$1.49 - $3.15
24	Road Salt	200	apex	12	3	Very Effective	$11.05 - $14.74
39	Road Salt	150	Apex	6	3	Very Effective	$6.48 - $9.98
58	Road Salt	400	Apex	6	A/N	Very Effective	$11.11 - $13.31
2	Road Salt	150	80%-Brine/20%-Geomelt	12	2		$6.28 - $9.37
40	Road Salt	200	90%-Brine/10%-Geomelt	6	A/N	Very Effective	$4.5 - $6.03
31	Road Salt	300	Salt Brine	9	2	Very Effective	$14.96 - $17.98
36	Road Salt	150	Salt Brine	3	A/N	Very Effective	$2.97 - $4.47
52	Road Salt	100	Salt Brine	9	2	Very Effective	$3.01 - $5.99
43	Road Salt	100	Salt Brine	6	2	Very Effective	$2.99 - $5.98
17	Road Salt	150	Salt Brine	15	1	Somewhat Effective	$12.1 - $18.09
77	Road Salt mixed with Sand/Gravel	400			2	Somewhat Effective	$12.58 - $14.38

3.3.5 Scenario 5 Analysis

Scenario 5 represents the same situation as Scenario 3 with the exception that, instead of treating a Low Volume Highway/Collector Street, the candidate is asked what they would do for a residential street. Originally the scenario was created to attempt to pick up smaller rural area respondents. Most respondents who responded to Scenario 5 also responded to Scenario 3. Therefore Scenario 5 became a look at how maintenance workers practices change in residential areas. Table 11 represents a list of everyone who responded to both Scenario 3 and 5 for comparison.

Table 11: Scenario 3 Respondents vs. Scenario 5 Respondents

Part. #	Liquid	App Rate	Retreat T	Solid	App Rate	Pre wet	App Rate	Retreat
		(gal/ln mi)	(hrs)		(lbs/ln mi)		(gal/ton)	(hrs)
Scenario 3 Respondents								
NDOR								
13	Salt Brine with Beat 55	75	A/N	Road Salt mixed with Sand/Gravel	400	60%-Brine/40%-Geomelt	12	A/N
CITY								
28	Salt Brine with Geomelt C	25	A/N	None				
84	100% Salt Brine	100	A/N	Road Salt	100	Apex	6	3
81	Calibur M-1000	25	A/N	Road Salt mixed with Sand/Gravel	50			6
73	None			25% Ice Slicer with Road Salt or just	550			A/N
7	None			Road Salt mixed with Sand/Gravel	100			A/N
32	None			10% Ice Slicer with Road Salt	200	Apex	12	2
74	None			10% Ice Slicer with Road Salt	250	80%-Brine/20%-Geomelt	12	A/N
4	None			10% Ice Slicer with Road Salt and S	100	90%-Brine/10%-Geomelt	6	A/N
COUNTY								
72	Freezeguard	25	A/N	Road Salt mixed with Sand/Gravel	50			6
83	None		A/N	10% Ice Slicer with Road Salt and S	400	Calcium Chloride	6	A/N
Part. #	Liquid	App Rate	Retreat T	Solid	App Rate	Pre wet	App Rate	Retreat
		(gal/ln mi)	(hrs)		(lbs/ln mi)		(gal/ton)	(hrs)
Scenario 5 Respondents								
NDOR								
13	None			Road Salt mixed with Sand/Gravel	450	60%-Brine/40%-Geomelt	12	A/N
CITY								
28	Salt Brine with Geomelt C	25		None				
84	100% Salt Brine	50	2	Road Salt	100	Apex	6	2
81	Calibur M-1000	25	6	Road Salt mixed with Sand/Gravel	50			6
73	None			None				
7	None			None				
32	None			10% Ice Slicer with Road Salt	200	Apex	9	5
74	None			Road Salt	150	80%-Brine/20%-Geomelt	12	A/N
4	None			10% Ice Slicer with Sand/Gravel	100	90%-Brine/10%-Geomelt	6	
COUNTY								
72	Freezeguard	25	6	Road Salt mixed with Sand/Gravel	50			6
83	None			Road Salt mixed with Sand/Gravel	400	Calcium Chloride	6	A/N

As can be seen From Table 11, respondents 28, 4, 72, and 83 reported no change in their treatment application rates. Respondents 28, 4, and 72 did change their treatment rates from "As

needed" (A/N) to either no retreat time reported or to a high hour value such as 6 hours. Respondents are still patrolling when they respond with "As Needed" and are spot treating areas. Respondents 13 and 84 reduced the amount of liquid that they applied, which effectively reduces their cost for the residential roads. Respondent 13 raised the solid rate slightly as a result as well, but still effectively cut the cost. Respondents 7 and 73 did not treat residential at all and chose only to plow. Respondent 32 reduced the pre-wet. This does not effectively reduce the cost per lane mile of materials, as pre-wetting does not add much extra material. Respondent 74 reduced the solid material used. This slightly reduced the cost from about $8.00 per lane mile to roughly $3.50-$4.00 per lane-mile. Overall, every respondent reported small changes that can be interpreted as a reduction in treatment, indicating that residential neighborhoods are of low priority.

3.4 Summary

Winter maintenance personnel across Nebraska participated in an online survey designed to determine the best practices for 5 different roadway scenarios. Best practices were to be determined for County and City participants who do not fall under the Nebraska Department of Roads umbrella. Data were skewed due to heavy NDOR results and few City and County worker results. Survey results from City and County workers were cross-referenced with NDOR practices to derive recommendations for City and County workers.

Reviewing the Best Practices of Winter Roadway Maintenance project shows a few points for winter maintenance workers of Nebraska:

- Many city and county workers across Nebraska prefer to treat with either Road Salt or a mixture of 10% Ice Slicer with Road Salt.
- If Apex Meltdown is used as a pre-wet, it should be limited to 3 gal/ton. Salt brine or a Salt brine/Geomelt mix can be used more liberally (up to 12-15 gal/ton).

- Using a pre-wet can possibly reduce solid material usage by 25%.
- If Geomelt is used the optimum ratio is 80% Brine to 20% Geomelt. Higher ratios of Geomelt have been known to clog spreaders.

City and County workers treating with Ice Slicer and Road Salt may have a basis to compare winter maintenance practices with those by Nebraska Department of Roads. Table 12 shows the summarized survey results for the Scenarios. Table 14 in Chapter 5 shows an updated best practices table combining results from Barb Gerbino-Bevins research and this research into one table aimed at providing recommendations for City and County workers working with high volume roadways.

Table 12: Summarized Recommendations from the Survey

Winter Weather Event	Best Practice	Best Practice (Alternate)
Light Snow (less than 0.5 in/hr) (Rural Interstate/Freeway)	10% Ice Slicer with Road Salt @100-150 lbs/lane mile Prewet: Apex @ 3 gal/ton Retreat every 2 hours	Road Salt @100-150 lbs/lane mile Prewet: 80/20 Brine-Geomelt @12-15 gal/ton Retreat every 2 hours
Sleet (Urban Interstate)	Road Salt @50-100 lbs/lane mile Prewet: 80/20 Brine-Geomelt @12-15 gal/ton Retreat every 3 hours	Road Salt @100-150 lbs/lane mile Prewet: Salt Brine @12-15 gal/ton Retreat every 2 hours
Compact Snow (Low Volume Highway/Collector Streets)	10% Ice Slicer with Road Salt @200-250 lb/lane mile Prewet: Apex @3 gal/ton Retreat as needed	
Rain turning to Snow With a temperature dropping below freezing (High Volume Highway/Collector Streets)	Road Salt w/ Sand/Gravel @100-150 lb/lane mile Prewet: Salt Brine or 80/20 Brine Geomelt @12-15 gal/ton or Apex @ 3 gal/ton Every 2 hours *Timing is crucial	

Chapter 4: Maintenance Decision Support System Data Analysis

4.1 Introduction

During roadway snow/ice removal operations, field data are collected by plow trucks equipped with GPS or Automatic Vehicle Location Systems (AVL) and with the Maintenance Decision Support System (MDSS). MDSS collects weather data along specific routes from regional weather stations and compiles real-time data, including air temperature, pavement temperature, precipitation type and accumulation, wind speed and direction, forecast, types of deicers used and application rates. In addition, trucks can be tracked via Global Positioning System (GPS) along a route on a map by MDSS, which records real-time vehicle location, amount of materials dispensed per lane-mile, and pictures of the roadway condition taken from the plow truck and pictures from roadside cameras.

The maintenance actions and the results from a few storms of the winter of 2014 in MDSS have been analyzed and compared to the maintenance actions and results from the survey in Chapter 3. The snow/ice events are generally described in terms of time-histories of temperature, wind speed and direction, and type of precipitation. The treatments from a particular AVL truck could be retrieved, and before and after pictures taken to show that how a particular treatment performed. Gerbino-Bevins and Tuan (2011) developed a system to rate the Level of Service (LOS) of a roadway based on a subjective interpretation of the picture of a snow covered roadway (see Table 13).

4.1.1. Issues Encountered using MDSS

Several problems were encountered in the MDSS data analysis. Often plow trucks had problems with the cab cameras. Cameras were either pointed too high so the roadway was not visible, or cameras

were pointed downward into the dash. Other times snow and ice on the windshield covered the cameras causing the roadway to not be visible. In many cases MDSS did not display a picture from a truck due to software issues. Further, the maintenance workers did not always log in the applied treatment to MDSS. All these issues may lead to questionable data. To make matters worse, quality pictures of roadways are unattainable at nighttime. Analyses of icy events where the pavement temperature dropped below freezing become difficult after sunset. Pictures of icy roadways tend to look similar to wet roadways. Many times trucks did not make a second pass and no pictures were available after treatments. Criteria that would ensure a reliable analysis were established by Gerbino-Bevins and Tuan (2011). For instance, a route that was operated by only one plow truck should be selected for analysis such that results would not be skewed by other trucks. Despite all the difficulties of meeting the minimum criteria to find usable data, some data was retrieved from MDSS for analysis herein.

Table 13: Rating System for Roadway Level of Service

Description	**Picture**
Clear • Can See Inner and Outer Lines • Very Little Snow on Roadway • Snow will not cause Traffic Issues	
25% Covered • Can See 2 or more Wheel Tracks • Can See 1 or more Lines • Snow may cause some Slowdown	
50% Covered • Can See 2 Wheel Tracks • Cannot See Lines • Snow will cause Difficulty when Changing Lanes	

75% Covered • Can See Some of the Dark Colored Roadway • Cannot See 2 Defined, Continuous Wheel Tracks	
100% Covered • Cannot See the Roadway	

4.2 MDSS Scenarios

Following are four scenarios that were found in MDSS that met the following criteria:

- Only one truck plowed and treated each route.
- Roadway pictures were obtainable.
- All weather data and application rates were obtainable.
- Pictures of both before treatment and after the treatment were obtainable.

If applicable the data was compared to results from the survey results from Chapter 3 to verify the practices that were recommended. The title of each section is designated with the truck ID that was reported in MDSS.

4.2.1 Truck ID: Mullen_26520

This was a light snow (< 0.5 in/hour) event north of Mullen, Nebraska, on Highway N97, Mullen to Brownlee Turnoff. At about 11:50 a.m. on January 21st, 2015, snow began to fall at about 0.6 in/hr and quickly diminishing to 0.1 in/hr. Snow continued to fall until 4:00 p.m. A total of 1.1 inches of snow accumulated. There was high wind at 28 mph with gusts around 38 mph. The wind was blowing south, parallel to the road, justifying treatment. Air temperature was below freezing at 27°F. Pavement temperature fluctuated around freezing at 32°F. MDSS reported slush on the road. Mullen_26520 reported treating the roadway with 50% Gravel/40% NaCl/10% Ice Slicer mixture at 400 lbs/lane-mile.

Time	12:22			
Deicer	50% Gravel/40% NaCl/10% Ice Slicer			
App Rate	400	lbs/ln-mi		
Weather	Light Snow			
Acc	0.13	in		
Air Temp	27	°F		
Road Tem	32	°F		
Winds	28	mph		
Gusts	38	mph		
RH	30%			

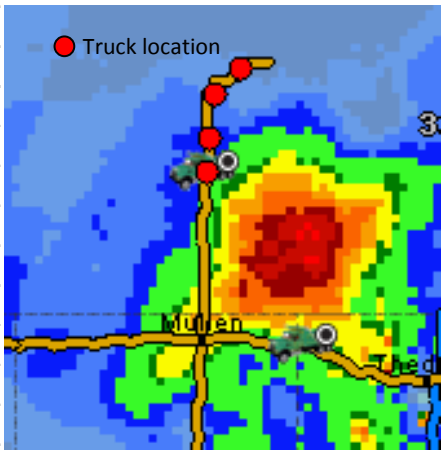

Figure 5: January 21st 2015 12:22 PM by Mullen_26520

Time	2:12			
Deicer	50% Gravel/40% NaCl/10% Ice Slicer			
App Rate	0	lbs/ln-mi		
Weather	Light Snow			
Acc	0.46	in		
Air Temp	29	°F		
Road Tem	33	°F		
Winds	29	mph		
Gusts	40	mph		
RH	86%			

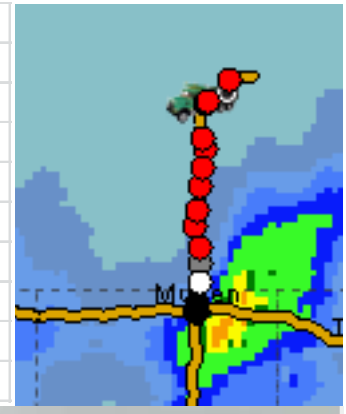

Figure 6: January 21st 2015 2:12 PM by Mullen_26520

At 2:12 p.m., Mullen_26520 made a second round back north. Figures 5 and 6 show pictures taken at the locations indicated by a truck and a red dot on the map, respectively. The distance between the two locations where pictures were taken can thus be determined from the map. As can be seen in Figure 6, snow had accumulated on the roadsides. It was reported at this point that 0.46 in. of snow had accumulated along with sustained high wind. However, the roadway LOS was improved from about 25% covered to almost clear. There was slight cross wind from the picture and was graphically shown in Figure 7 as the wind direction reported by MDSS. This might have caused the truck to stop

treating after this pass. The mixture used by Mullen_26520 validates the assumption in the survey results analysis that gravel was applied in a 1:1 ratio to the solid deicer. Also, gravel was added for traction when the roadway temperature was close to freezing. Excluding the use of gravel, the solid treatment by Mullen_26520 would have been composed of Road Salt at 160 lbs/lane-mile and Ice Slicer at 40 lbs/lane-mile. This treatment is comparable to using 10% Ice Slicer and 90% Road Salt with a pre-wet at 100-150 lbs/lane-mile, a best practice proposed for the light snow scenario in the survey (Scenario 1 in Chapter 3). The temperature and wind in this event are quite different from the lower temperature and low wind situation presented in the Scenario 1 of the survey. The time-histories of wind speeds, temperatures, and snow accumulations are presented graphically in MDSS, as shown in Figure 7.

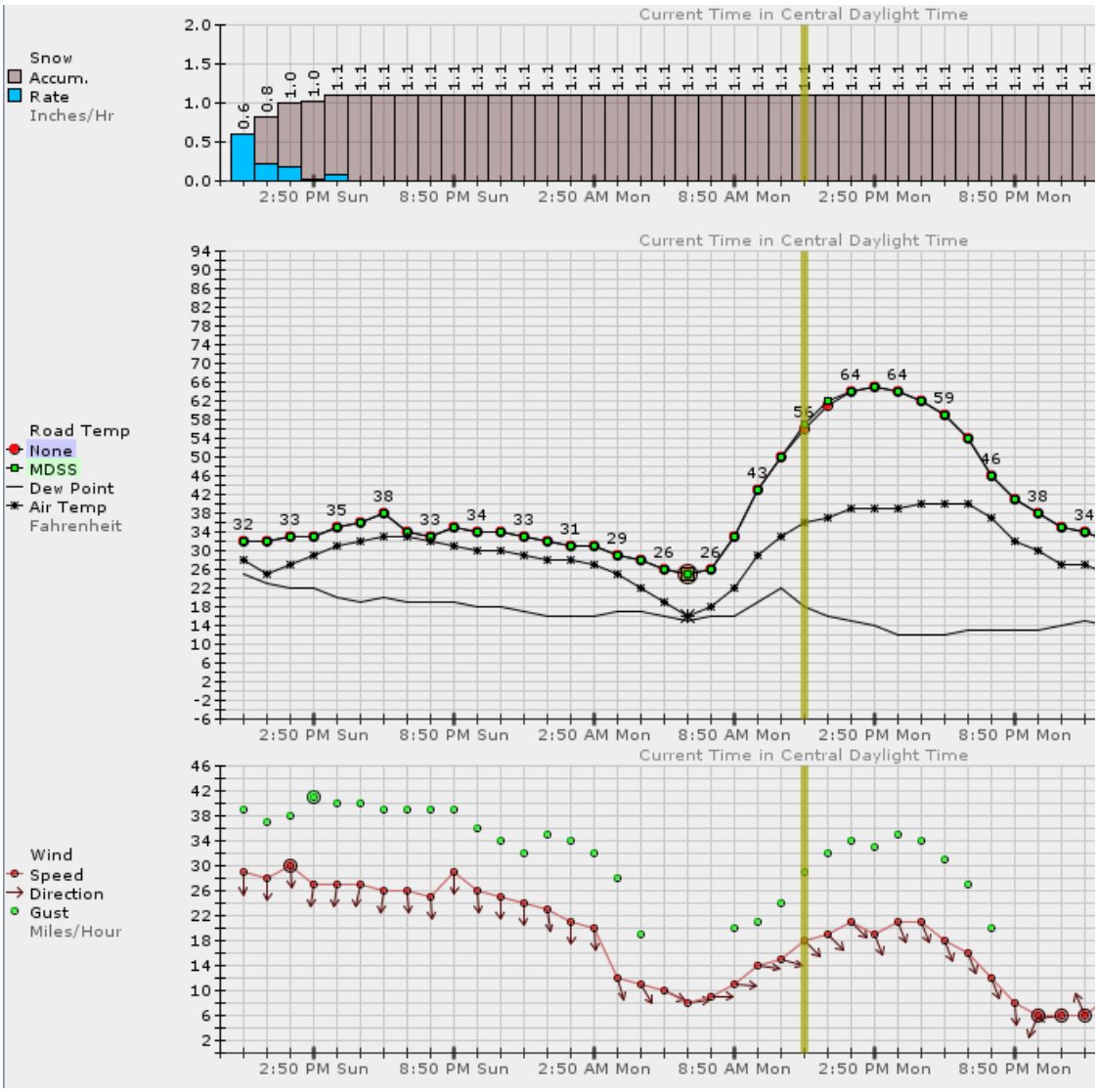

Figure 7: Mullen to Brownlee Turnoff Route Weather Data Time-histories

4.2.2 Truck ID: Stapleton_27524

In the early morning of Sunday, January 31, 2015, there was mixed precipitation that changed to snow. Stapleton_27524 left Stapleton, NE at approximately 5:30 p.m. to treat Highway 83 with 50% Gravel/40% NaCl/10% Ice Slicer at 400 lbs/lane-mile as the roadway temperature approached freezing. Figure 8 shows that Highway 83 had a road temperature of 34°F, and the sun was setting. The wind speed was only 9 mph in a direction fairly parallel to the roadway. The roadway was about 50% covered. Similar to Mullen_26520, gravel was dispensed by Stapleton_27524 to help with traction for the freezing roadway. The combination of NaCl and Ice Slicer used was very close to the best practice proposed for Scenario 4 in the survey study. Note that the weather conditions presented in Scenario 4 are very similar to this event. Stapleton_27524 treated the roadway only once while plowing.

Jan 31 2015				
Time	17:50			
Deicer	50% Gravel/40% NaCl/10% Ice Slicer			
App Rate	400	lbs/ln-mi		
Weather	Light Snow			
Acc	0.1	in		
Air Temp	27	°F		
Road Tem	34	°F		
Winds	9	mph		
Gusts	0	mph		
RH	93%			

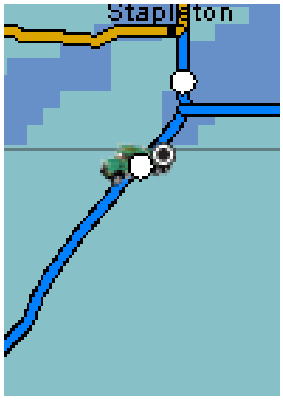

Figure 8: January 31st 2015 5:20 PM by Stapleton_27524

MDSS did not report any other activity on this highway until the next morning at 8:10 a.m. when Stapleton_27524 made a second round. The roadway temperature was 10°F and the wind speed was 24 mph with gusts of 38 mph, changing into a crosswind to Highway 83. Stapleton_27524 only plowed, as solid deicer dispensed would have been lost from the scatter. As shown in Figure 9, the roadway did not change much since last treatment, with the LOS slightly improved to about 40% covered. However, there had been over an inch of additional snow fallen since the first treatment. It is uncertain if the

crosswind blew the additional snow off the roadway or the treatment was effective to keep the roadway clear. Note that Stapeton_27524 anticipated the dropping temperature and the increasing wind, and successfully treated the roadway before it froze. Detailed weather data during this event in MDSS is presented in Figure 10.

Feb 1 2015				
Time	8:10			
Deicer	50% Gravel/40% NaCl/10% Ice Slicer			
App Rate	0	lbs/ln-mi		
Weather	Light Snow			
Acc	0.22	in		
Air Temp	7	°F		
Road Tem	10	°F		
Winds	24	mph		
Gusts	38	mph		
RH	77%			

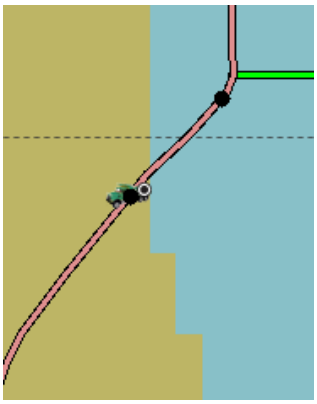

Figure 9: February 1st 2015 8:10 AM by Stapleton_27524

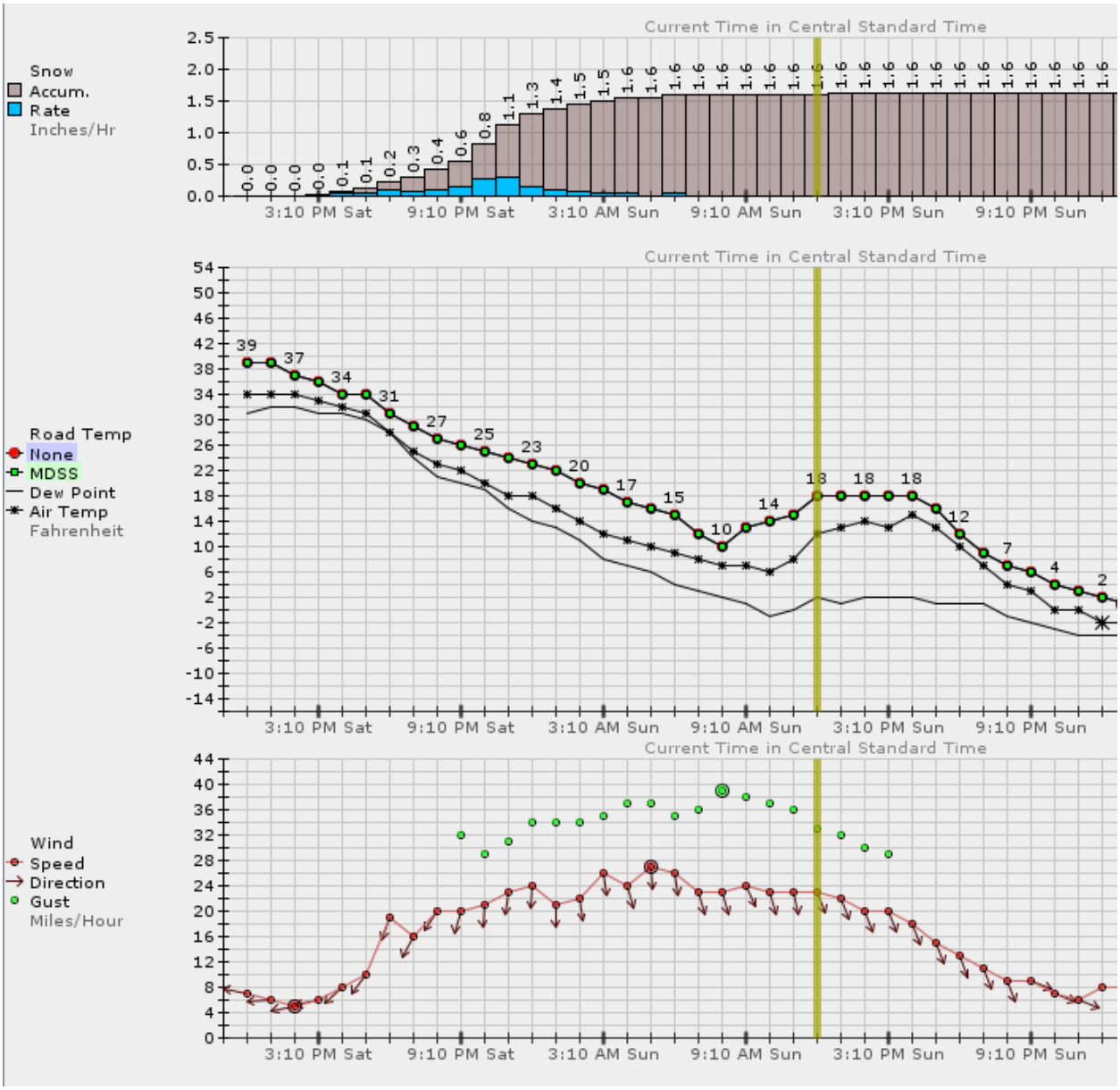

Figure 10: Highway 83 Route Weather Data Time-histories

4.2.3 Truck ID: NE-236_Platts_27507

Light snow began to fall at around 9:40 p.m. on Monday, February 3rd 2014. There was about 2 in. of snow accumulation at 12:40 p.m. the next day on February 4. As shown in Figure 11, Platts_27507 was treating Highway 34 north of Union, NE with 200 lbs of road salt per lane-mile heading south. The road temperature was 26.3°F and the air temperature was around 22°F. The roadway was about 50-60% covered. The temperatures continued to drop, and it started to snow again. The wind speed was at 9 mph along with 25 mph gusts, blowing in the southwest direction. MDSS reported that the road salt was pre-wet although it did not state with what liquid or the application rate. Platts_27507 turned around at Union going north and continued treatment on its way back.

Time	12:40		
Deicer	100% NaCl		
App Rate	200	lbs/ln-mi	
Weather	Light Snow		
Acc	0.23	in	
Air Temp	22	°F	
Road Temp	26.3	°F	
Winds	9	mph	
Gusts	25	mph	
RH	94%		

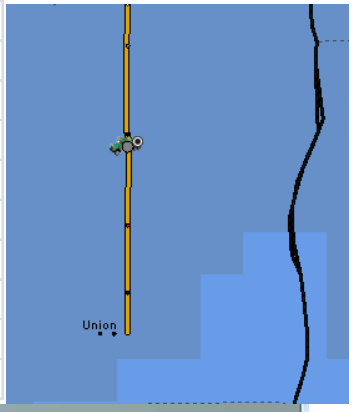

Figure 11: February 4th 2014 12:40 PM by Platts_27507

Figure 12 shows that at 1:40 p.m. Platts_27507 made a second round of treatment with 250 lbs of road salt per lane-mile heading south. The higher application rate of road salt was used due to the higher rate of snow falling. The roadway was still about 50-60% covered. The road temperature was 25.5°F and the air temperature was 20°F. The wind speed was at 13 mph along with 23 mph gusts, still blowing in the southwest direction.

Time	1:40	
Deicer	100% NaCl	
App Rate	250	lbs/ln-mi
Weather	Light Snow	
Acc	0.17	in
Air Temp	20	°F
Road Temp	25.5	°F
Winds	13	mph
Gusts	23	mph
RH	92%	

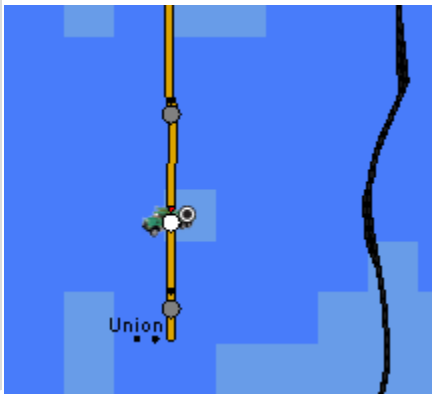

Figure 12: February 4th 2014 1:40PM by Platts_27507

Figure 13 shows that at 2:40 PM Platts_27507 made a third round of treatment of Highway 34, heading south again and was very close to the location during the first round 2 hours prior. The application rate of road salt remained at 250 lbs/lane-mile, but the roadway did not show marked improvement. However, the rate of snow fall was at its peak for the day at about 1.0 in./hr. The road temperature was at 22.5°F, and the air was at 18°F. Wind speed increased to 15 mph along with 22 mph gusts. Based on the LOS evaluation, the treatment is deemed ineffective for this weather event. The weather data along Highway 34 for this event is presented in Figure 14.

Time	2:40	
Deicer	100% NaCl	
App Rate	250	lbs/ln-mi
Weather	Light Snow	
Acc	0.39	in
Air Temp	18	°F
Road Temp	22.3	°F
Winds	15	mph
Gusts	22	mph
RH	92%	

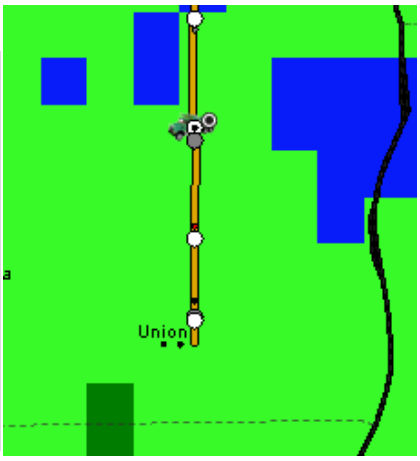

Figure 13: February 4th 2014 2:40 PM by Platts_27507

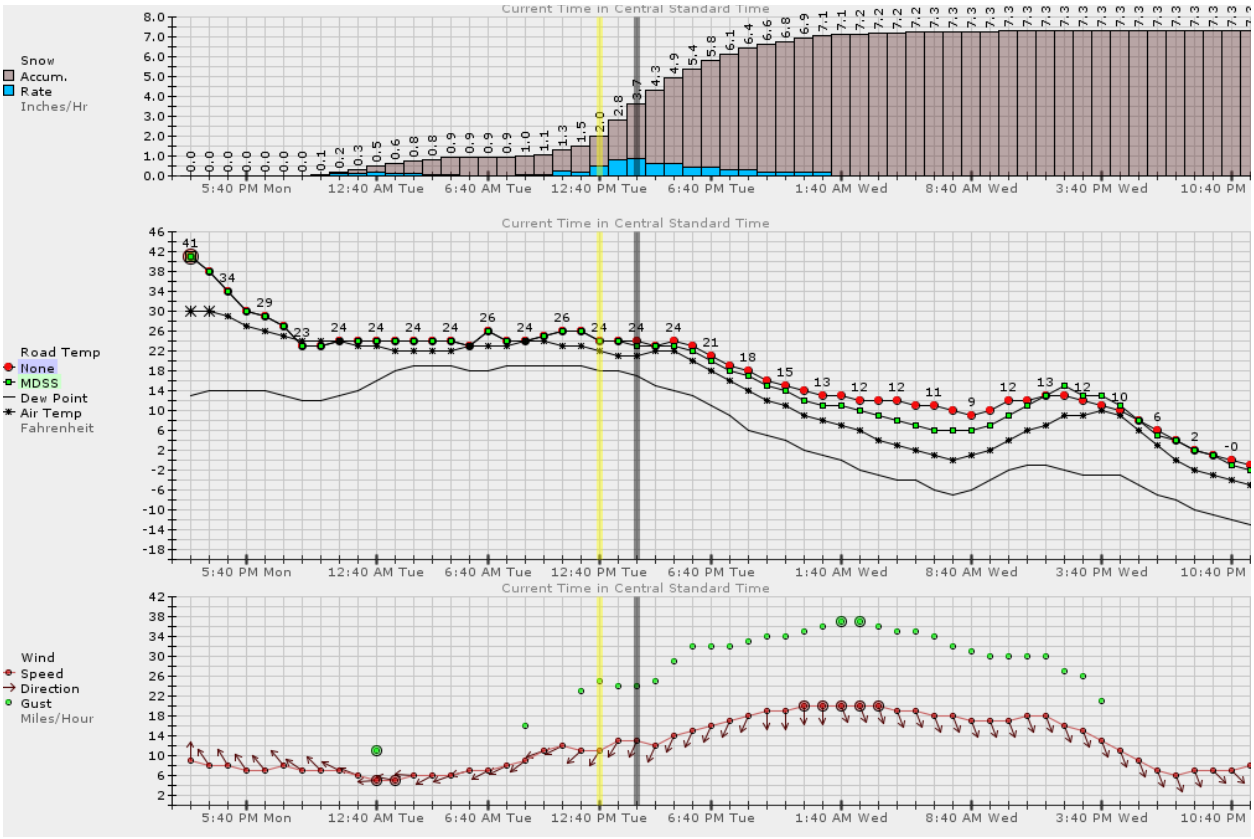

Figure 14: Hwy 34 Route Weather Data Time-histories

4.2.4 Truck ID: NE-642_Arnold_29547

A late spring snow storm occurred on April 13th, 2014. Rain changed to light snow around 2:10 p.m. As shown in Figure 15, Arnold_29547 at 2:40 p.m. was treating Highway 92 with a mixture of 78.5%-Gravel/20%-Ice Slicer/1.5% $CaCl_2$ at 1060 lbs/lane-mile, after 1.2 inches of snow had accumulated on the roadway. The same treatment was applied going the other direction 40 minutes prior. The air temperature was at 28°F, and the roadway temperature was at 30°F. This event presented a very slick road condition that warranted the use of gravel for traction. The wind was very high cross wind at 36 mph along with 47 mph gusts. These high winds most likely prompted the high treatment rate due to losing material to scatter. The roadway was about 75% covered at the time.

Time	2:40	
Deicer	78.5% Gravel/20% Ice Slicer/1.5% CaCl	
App Rate	1060	lbs/ln-mi
Weather	Rain changing to Light Snow	
Acc	1.2	in
Air Temp	28	°F
Road Temp	30	°F
Winds	36	mph
Gusts	47	mph
RH	93%	

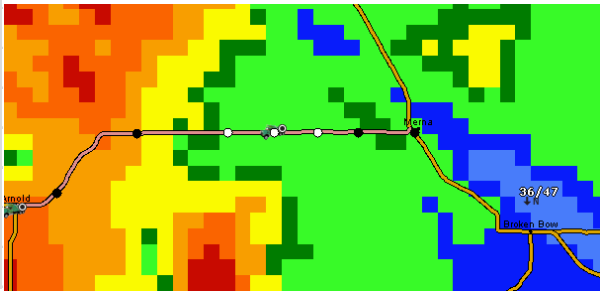

Figure 15: April 13th 2014 2:40 PM by Arnold_29547

As shown in Figure 16, Arnold_29547 made another pass at 4:10 p.m. heading the other direction applying the same treatment. The location in Figure 16 should be within a few miles of the location in Figure 15. At this time the wind was still very high at 29 mph with 41 mph gusts, blowing perpendicular to the road. The accumulation on roadway dropped to 1.05 inches, and the roadway appeared to be slushy. The roadway cover also dropped to about 25%. The temperature of the roadway had risen from 30°F to 33°F. It is uncertain if the improved LOS was due to the treatment or the above freezing temperature. The treatment consisted of 210 lbs of Ice Slicer per lane-mile, which

should prove to be effective even with a percentage lost to high wind. It may be debatable if Arnold_29547 should have just plowed to attain the same improvement in LOS. The weather data along Highway 92 for this event is presented in Figure 17.

Time	16:10	
Deicer	78.5% Gravel/20% Ice Slicer/1.5% CaCl	
App Rate	1060	lbs/ln-mi
Weather	Rain changing to Light Snow	
Acc	1.05	in
Air Temp	29	°F
Road Temp	33	°F
Winds	29	mph
Gusts	41	mph
RH	92%	

Figure 16: April 13th 2015 4:10 PM by Arnold_29547

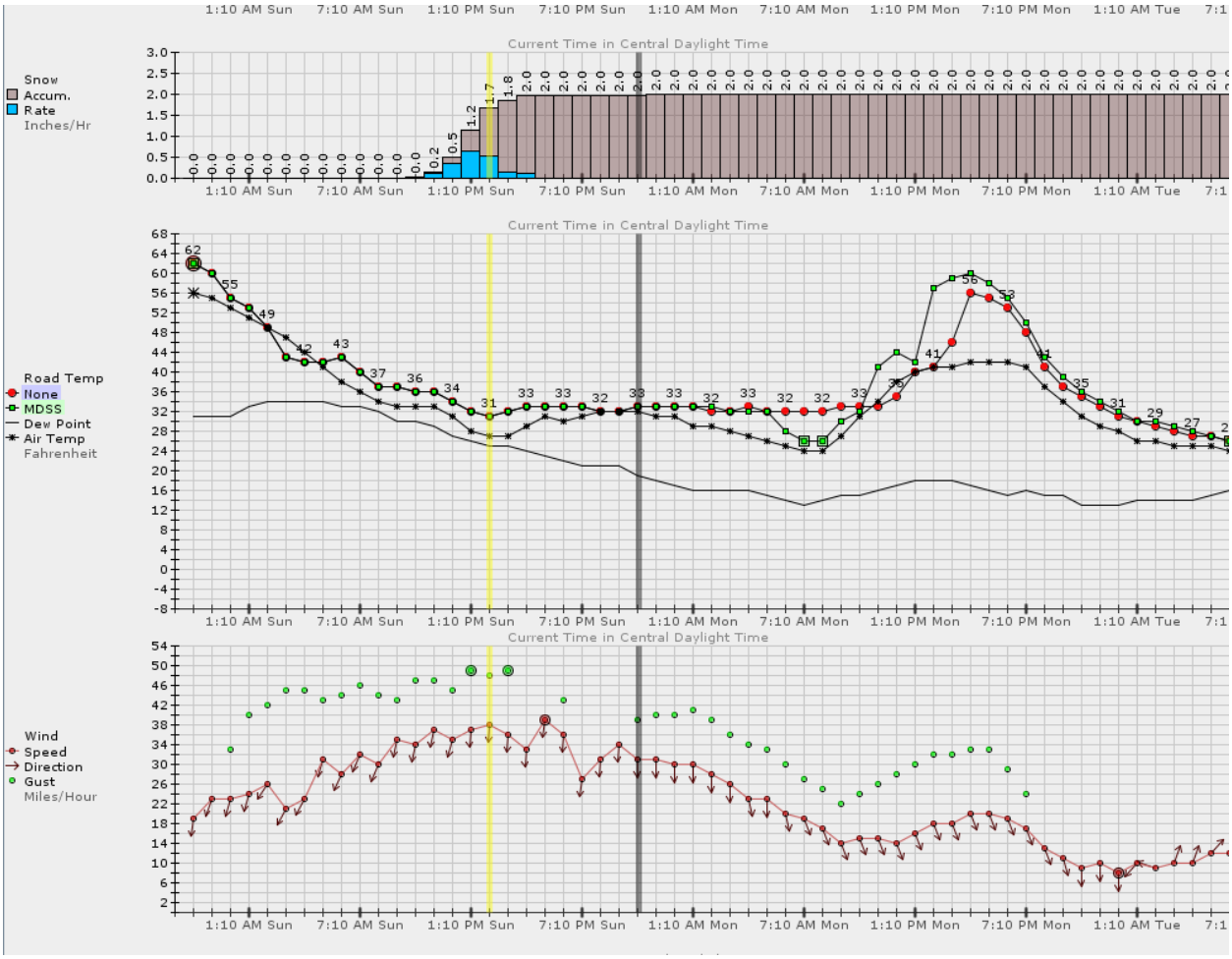

Figure 17: Hwy 92 Route Weather Data Time-histories

4.3 Conclusions

Largely the data from the MDSS analysis was, unfortunately, unobtainable or inconclusive. There appear to be several problems in the system in Nebraska that need to be resolved as of yet to draw any reasonable conclusions from roadway pictures. A way needs to be determined to analyze the MDSS data at night time without relying on roadway pictures to determine if nighttime treatments are effective. Some MDSS data that was obtained possibly verifies results from the survey presented in Chapter 3. Mullen_26520's treatment of 10% Ice Slicer/40% Road Salt/50% Gravel at 400 lbs/lane-mile in light snow was potentially effective and is comparable to Scenario 1 of the survey in Chapter 3.

Stapleton_27524's treatment of 10% Ice Slicer/40% Road Salt/50% Gravel at 400 lbs-lane mile was also potentially effective and comparable to the survey results in Chapter 3 for Scenario 4 where mixed precipitation changes to snow. Both of these treatments in MDSS are comparable to the survey results from Scenarios 1 and 4 in Chapter 3 when neglecting the use of gravel. Platts_27507's treatment was not deemed effective, and Arnold_29547's treatment was very large due to high winds.

Chapter 5: Conclusions

Winter Maintenance is a significant portion of state budgets. Summarizing best practices for winter maintenance is a very comprehensive task. The scope of this project was to make best practice recommendations for winter maintenance crews that worked in cities and counties and were not part of the Nebraska Department of Roads. A best practice for a different demographic may be a different set of recommendations. However, in the construction of any best practice a Level of Service (LOS) must be taken into account. The Level of Service dictates the time that a roadway needs to be back to bare pavement. For high volume roadways this is quicker than for low. The type of deicer used and the amount of application rates affects the cost and can be damaging to the environment and infrastructure. Different winter maintenance practices affect application rates as well. Anti-icing before an event helps loosen the bond formed between ice and the pavement so that the ice can be plowed away easily. Pre-wetting chemicals can reduce the amount of dry material lost due to scatter.

It was seen from a survey that was conducted of winter maintenance crews across Nebraska that city and county workers that do not fall under the umbrella of NDOR prefer to treat with road salt or 10% Ice Slicer with road salt. Responses from NDOR and city and county workers were compared and best practices were chosen for city and county workers. The results from the survey in Chapter 3 and findings from the MDSS analysis in Chapter 4 have been merged with the table that was developed by Gerbino-Bevins and Tuan (2011) to create a best practice recommendation table for these workers (Table 14).

Table 14: Recommendations for Deicer Usage for Urban Commuter LOS (20,000-50,000 ADT)*

<table>
<tr><th></th><th colspan="3">Temperature Range, °F</th></tr>
<tr><th>Weather/Road Conditions</th><th>Above 32</th><th>32-20</th><th>20-12</th><th>Below 12</th></tr>
<tr><td>Rain</td><td colspan="2" rowspan="2">Road Salt
@100-150 lb/lane mile
Prewet: Salt Brine or 80/20 Brine Geomelt
@12-15 gal/ton or Apex @ 3 gal/ton Every 2 hours
Use additional 100-150 lb/lane mile of Sand/Gravel if available immediately before roadway freezes around curves and stops in rural areas. Timing is crucial.</td><td>Not Applicable</td><td rowspan="8">Use abrasives prewet with 8-10 gal/ton. Prewet can be hot water or NaCl to help “root” the abrasives.

Using $MgCl_2$ or $CaCl_2$ could cause slippery conditions.

Do not use Beet Juice in a liquid application unless it is a sunny day.</td></tr>
<tr><td>Freezing Rain</td><td rowspan="3">Use Road Salt prewet with 8-10 gal/ton NaCl.

Using $MgCl_2$ or $CaCl_2$ could cause slippery conditions.

If liquids must be used, retreat every 1.5-2hrs to prevent refreeze</td></tr>
<tr><td>Sleet</td><td colspan="2">Road Salt @50-100 lbs/lane mile
Prewet: 80/20 Brine-Geomelt @12-15 gal/ton
Retreat every 3 hours
Or
Road Salt @100-150 lbs/lane mile
Prewet: Salt Brine @12-15 gal/ton
Retreat every 2 hours</td></tr>
<tr><td>Ice</td><td colspan="2">If not preceded by any of the above, pre-treat with liquid NaCl 20-50 gal/lane-mile. Post-treat with road salt prewet with 8-10 gal/ton NaCl.</td></tr>
<tr><td>Light Snow (less than 0.5 in/hr)</td><td colspan="2">10% Ice Slicer with Road Salt @100-150 lbs/lane mile
Prewet: Apex @ 3 gal/ton Retreat every 2 hours
OR

Road Salt @100-150 lbs/lane mile
Prewet: 80/20 Brine-Geomelt @12-15 gal/ton
Retreat every 2 hours</td><td>Use Road Salt prewet with 8-10 gal/ton. Use $MgCl_2$ or $CaCl_2$ if humidity is low.

If liquids must be used, patrol every 1.5-2hrs to prevent refreeze. Beet Juice can be used in direct sunlight.</td></tr>
<tr><td>Moderate to Heavy Snow (greater than 0.5 in/hr)</td><td colspan="2">Pre-treat with liquid NaCl 20-50 gal/lane-mile. A mix of 15/85 Beet Juice/NaCl can be used.

Use road salt during and after the event.

Prewet is not necessary during the event.</td></tr>
<tr><td rowspan="2">Compacted Snow</td><td>Use Road Salt if Necessary</td><td>Use Road Salt prewet with 8-10 gal/ton NaCl</td><td rowspan="2">10% Ice Slicer with Road Salt
@400-500 lb/lane mile
Prewet: Apex @3 gal/ton
Retreat as needed</td></tr>
<tr><td colspan="2">A prewet mix of 15/85 Beet Juice/NaCl is recommended on sunny days</td></tr>
<tr><td>Winds Greater than 15 mph</td><td colspan="3">Treatment may cause blowing snow to stick to roadway. Beet Juice is NOT recommended on overcast days.</td><td>No Treatment</td></tr>
</table>

* ***Developed for City/County workers in Nebraska.***
* ***It is essential to give sufficient time to allow deicer to take effect before plowing. (30-45 minutes).***
* ***If treating low volume roadways (<20,000 ADT), reduce application rate in table by no more than 50%.***
* ***Double the deicer and abrasives quantities and/or increase retreatment frequency to accommodate for Super Commuter LOS (>50,000 ADT).***

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Appendix A: Development of a Winter Maintenance Survey Using Surveymonkey.com

SurveyMonkey.com provides a user with an intuitive, user-friendly software platform to develop, distribute, and analyze a survey. SurveyMonkey.com includes many options to make a survey user-friendly such as drop-down boxes, multiple choice boxes, tables that can be filled out, etc. Perhaps one of the most interesting features that can help to keep the attention of a respondent is the question logic feature. This feature is not included in one of the free trial versions on surveymonkey.com but is included in a higher tier. Instead of progressing linearly through a survey by page number (page 1 to page 2 to page 3, etc.) the question logic allows a survey to skip pages or questions that are unnecessary to the participant. In the winter maintenance survey, this meant that a candidate who did not treat RURAL INTERSTATE/FREEWAY/EXPRESSWAY would not be bogged down by answering or seeing pages or questions that had to do with the scenario that included RURAL INTERSTATE/FREEWAY/EXPRESSWAY. In an even larger scale, some questions were set up to catch participants who did not have set winter maintenance practices or did not make use of deicer applications. By these questions if a candidate was discovered to not have set practices or use deicer applications then the candidate was directed to the end of the survey and thanked for their time. It was understood that the people who responded to the survey are busy people and that their time was valuable. The survey was, thus, designed in a way that would not waste their time. While a participant may have only seen 20-30 pages of the survey in his or her questionnaire, the total survey length was 140 pages.

Some pages would not allow a respondent to move to the next page without answering a given question. This ensured that crucial information was gathered, such as name and contact information, and also so that the question logic described previously would not be broken.

Following is a more thorough outlook of the survey tree and where the question logic directed a respondent than what was provided in Chapter 3. An asterisk in front of a question number means that a participant was required to answer that question before they were allowed to proceed to the next page. Not all of the answers to questions were used or found to be helpful. These questions were excluded from the survey summary that was provided in Chapter 3.

It should also be noted for clarification that on the following pages the order of questions are presented by PAGE #. A reader may note that the questions have numbers and that these numbers are not in order from page to page. Surveymonkey.com orders the questions as a respondent sees them, and this is what resulted in the varying number.

PAGE 1:

Thank you, in advance, for taking the time to complete this survey. This study will allow NDOR to have a better understanding of the best practices for the application of deicer chemicals during winter maintenance. This survey should only take at most 15-20 minutes to complete, but most people surveyed will take less. You may be contacted and asked additional follow up questions. Please fill in all answers to your best knowledge. Thank you!

*** 1. Please specify:**

Name:

Title:

Agency:

Location:

Phone Number:

Email:

2. Estimate how many lane-miles are treated with deicer for the following categories :

	None	<10	10-50	50-100	100-250	>250
Interstate/Freeway /Expressway	○	○	○	○	○	○
Highway	○	○	○	○	○	○
Collector/Streets	○	○	○	○	○	○
Residential Streets (low traffic volume)	○	○	○	○	○	○

*** 3. Do you have set procedures developed for winter maintenance practices and deicer applications given different weather scenarios and conditions?**

○ Yes

○ No

Next

Notes:

*Survey respondents were required to answer questions with an asterisk besides the number.

**If a respondent answered “No” to question #3 they were then directed to PAGE 140.

PAGE 2:

4. How do you determine the appropriate weather conditions to decide how to respond to a storm event? (Select all that apply)

- ☐ MDSS (Maintenance Decision Support System)
- ☐ Manual/handbook (please specify below)
- ☐ Local weather/own experience
- ☐ Paid weather service (please specify below)
- ☐ Spotters
- ☐ NDOR webcam

Other (please specify)

5. What are your hours of operation during a winter storm event? (Select all that apply)

- ☐ Regular Daytime Hours
- ☐ Extended Daytime Hours
- ☐ Nighttime Hours

*** 6. Does your agency apply deicer materials to the roadway during winter storm events?**

- ○ Yes
- ○ No

Prev Next

Notes:

*Survey respondents were required to answer questions with an asterisk besides the number.

**If a respondent answered “No” to question #6 they were then directed to PAGE 140.

PAGE 3:

7. Does your agency use liquid and/or solid deicer materials?

- ○ We use liquid materials only.
- ○ We use solid materials only.
- ○ We use both liquid and solid materials.

Prev Next

PAGE 4:

8. In my area of responsibility, a high volume roadway (high priority) has an ADT (Average Daily Traffic) of:

- ○ >12,000 vehicles/lane/day
- ○ 8,000-12,000 vehicles/lane/day
- ○ 5,000-8000 vehicles/lane/day
- ○ 3,000-5,000 vehicles/lane/day
- ○ I have no high volume roads.

9. In my area of responsibility, a low volume road (low priority) has an ADT (Average Daily Traffic) of:

- ○ 8,000-12,000 vehicles/lane/day
- ○ 5,000-8,000 vehicles/lane/day
- ○ 3,000-5,000 vehicles/lane/day
- ○ 1,000-3,000 vehicles/lane/day
- ○ <1,000 vehicles/lane/day

Prev Next

PAGE 5:

Scenario 1:

*** 10. Do you treat Rural Interstate/Freeway/Expressway in your agency?**

- ○ Yes
- ○ No

Prev Next

Notes:

*If respondents answered “Yes” to this question they proceeded to page 6 and began the iteration of questions that was developed for each scenario.

**If a respondent answered “No” to this question then he or she was directed to PAGE 32 where a similar question screened him or her for participation in Scenario 2.

PAGE 6:

Scenario 1: Rural Interstate

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

*** 11. What form of deicer chemicals would you apply in this scenario?**

- ○ Liquid
- ○ Solid (may or may not include pre-wet)
- ○ Liquid and Solid treatments are both applied separately
- ○ No chemical treatment is required; Just plow
- ○ No action is required

Prev Next

Notes:

*For each scenario a header was used through the questionnaire to continuously show and remind the candidate lest they forget the scenarios details

**If a respondent answered “Liquid”, he or she proceeded to PAGE 7. If a respondent answered “Solid” he or she proceeded to PAGE 12. If a respondent answered “Liquid and Solid Treatments are both applied separately” the respondent was directed to PAGE 19.

PAGE 7:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

*** 12. What type of liquid deicer would you choose?**

- ○ Straight Salt Brine (100%)
- ○ Salt Brine with an additive
- ○ Another type of liquid decier

Prev Next

Notes:

*Responding "Straight Salt Brine (100%)" directed a respondent on to PAGE 8. Responding "Salt Brine with an additive" directed a respondent on to PAGE 9. Responding "Another type of liquid deicer" directed a respondent of PAGE 10.

PAGE 8:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

13. You selected 100% straight salt-brine. What application rate would you use to treat this scenario?

- ○ 0-25 gal/lane mile
- ○ 25-50 gal/lane mile
- ○ 50-75 gal/lane mile
- ○ 75-100 gal/lane mile
- ○ >100 gal/lane mile

Prev Next

Notes:

*After answering this page the survey respondent proceed to PAGE 11.

PAGE 9:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

13. You selected Salt Brine with an additive. What do you use as your additive?

Other Liquid Deicer:

14. What application rate do you choose to apply your salt brine with additive?

- 0-25 gal/lane mile
- 25-50 gal/lane mile
- 50-75 gal/lane mile
- 75-100 gal/lane mile
- >100 gal/lane mile

Prev Next

Notes:

*This page takes advantage of a drop down box feature. This was used because there were too many choices to select from for a question that used bubbles to click. The drop down presented a list of common additives to choose from.

**After answering this page a respondent was directed to PAGE 11.

PAGE 10:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

13. What other type of liquid deicer would you use for treatment?

Other Liquid Deicer:

14. What application rate do you choose to apply your previously specified liquid deicer?

- 0-25 gal/lane mile
- 25-50 gal/lane mile
- 50-75 gal/lane mile
- 75-100 gal/lane mile
- >100 gal/lane mile

Prev Next

Notes:

*After answering this question a respondent was then directed on to PAGE 11.

PAGE 11:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

14. How often will you need to re-treat with this previously specified liquid deicer treatment?

- ○ No re-treatment is required
- ○ Every one hour
- ○ Every two hours
- ○ Every three hours
- ○ Every four hours
- ○ Every five hours
- ○ Every six hours
- ○ More than every six hours
- ○ The same treatment is not used (please elaborate below)

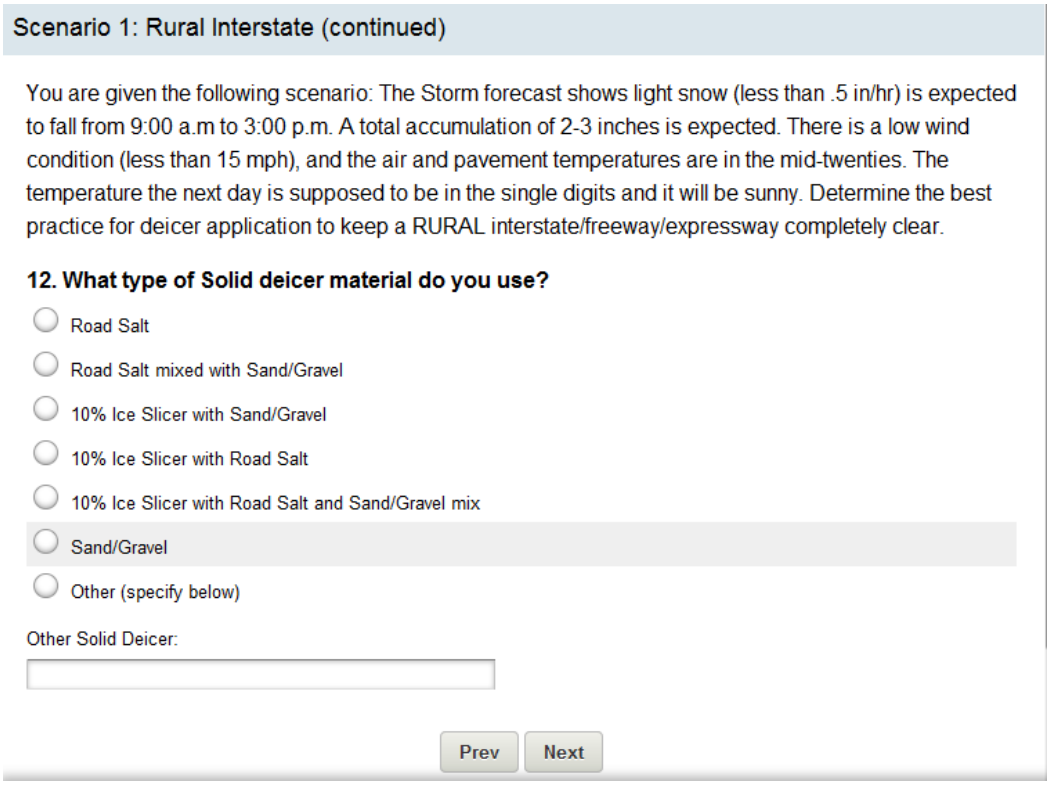
The different treatment used is:

Prev Next

Note:

*After answering this question the respondent was directed to PAGE 31. At this point all the information has been gathered for collecting Liquid Only treatments.

PAGE 12:



Notes:

*After answering this page the respondent proceeded to PAGE 13.

PAGE 13:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

13. What application rate of your previously specified Solid Deicer material do you use?

Prev Next

Notes:

*The application rate drop down box had ranges of applications from 0-50 lb/lane-mile to 700+ lb/lane-mile.

**After answering this question a respondent proceeded on to PAGE 14.

PAGE 14:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

*** 14. Do you use a pre-wet with your treatment?**

- yes
- no

Prev Next

Note:

*If the respondent answered this question “yes” then he or she was directed to PAGE 15. If he or she answered the question “no” then he/she was directed to page 18.

PAGE 15:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

*** 15. What do you use as a pre-wet?**

- ○ Salt Brine only
- ○ Salt Brine mixed with Geomelt
- ○ Other (please specify)

Other:

Prev Next

Note:

*This page proceeds on to PAGE 16.

PAGE 16:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

16. What Salt-Brine/Geomelt mix ratio do you use?

Prev Next

Note:

*This page proceeds on to PAGE 17.

PAGE 17:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

17. What application rate of pre-wet do you apply to your solid deicer?

- ○ 0-3 gal/ton
- ○ 3-6 gal/ton
- ○ 6-9 gal/ton
- ○ 9-12 gal/ton
- ○ 12-15 gal/ton
- ○ 15-18 gal/ton
- ○ 18-21 gal/ton
- ○ >21 gal/ton

Prev Next

Note:

*This page proceeds on to PAGE 18.

PAGE 18:

Scenario 1: Rural Interstate (continued)

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

25. How often will you need to re-treat with this previously specified solid deicer treatment?

- ○ No re-treatment is required
- ○ Every one hour
- ○ Every two hours
- ○ Every three hours
- ○ Every four hours
- ○ Every five hours
- ○ Every six hours
- ○ The same treatment is not used (please elaborate below)

The different treatment used is:

Prev Next

Note:

*After answering this page the respondent was directed to PAGE 31. At this point all the information for Solid Only treatments has been gathered for Scenario 1.

PAGE 19-PAGE 30:

Note:

*PAGE 19 through 30 were a set of pages that were exact copies of PAGE 7 through PAGE 18 with the exception that the logic that moved a respondent from PAGE 11 to PAGE 31 (after finishing a liquid only response) instead directed him or her on to PAGE 12. Therefore a respondent who selected “Liquids and solids are applied separately” on PAGE 6 proceeded through all the questions that gathered liquid information followed by all the pages that gathered Solid information. The respondent then proceed on to PAGE 31.

PAGE 31:

Scenario 1: Rural Interstate: Additional Questions

You are given the following scenario: The Storm forecast shows light snow (less than .5 in/hr) is expected to fall from 9:00 a.m to 3:00 p.m. A total accumulation of 2-3 inches is expected. There is a low wind condition (less than 15 mph), and the air and pavement temperatures are in the mid-twenties. The temperature the next day is supposed to be in the single digits and it will be sunny. Determine the best practice for deicer application to keep a RURAL interstate/freeway/expressway completely clear.

16. If you have any additional comments or descriptions of your practices that you feel are pertinent to this scenario please describe them:

17. How would you rank the effectiveness of this treatment for this scenario that you prescribed?

- Very Effective
- Somewhat Effective
- Neutral
- Somewhat Ineffective
- Very Ineffective

18. How would your practices change if:

Wind was greater than 15 mph?

If the snow fell overnight instead of the daytime?

If it was overcast the next day?

If there was heavy snow instead of light snow?

19. Describe the Anti-icing practices you would apply to this scenario, if any?

Prev Next

Notes (for PAGE 31):

*This page was the final page for Scenario 1 that gathered an effectiveness rating as well as attempted to gather some additional best practice information.

**After answer this question Respondents were directed to PAGE 32.

PAGE 32:

Scenario 2:

*** 11. Do you treat Urban Interstate/Freeway/Expressway in your agency?**

- ○ Yes
- ○ No

Prev Next

Note:

*This question screened a candidate for Scenario 2 the same way that PAGE 5 screened a candidate for Scenario 1. If a respondent answered “yes” he or she was directed on to PAGE 33. If a respondent answered “no” then he or she was directed on to PAGE 59.

PAGE33 – PAGE 58

Scenario 2: Urban Interstate

You are given the following scenario: The Storm forecast shows sleet is expected starting from 6:00 a.m. to 10:00 a.m. There is a low wind condition (less than 15 mph), and the air temperature is in the low thirties and the pavement temperature is in the twenties. The temperature for the rest of the day is overcast with low wind, and the temperature is in the twenties. Determine the best practice for deicer application to keep an URBAN interstate completely clear.

*** 12. What form of deicer chemicals would you apply in this scenario?**

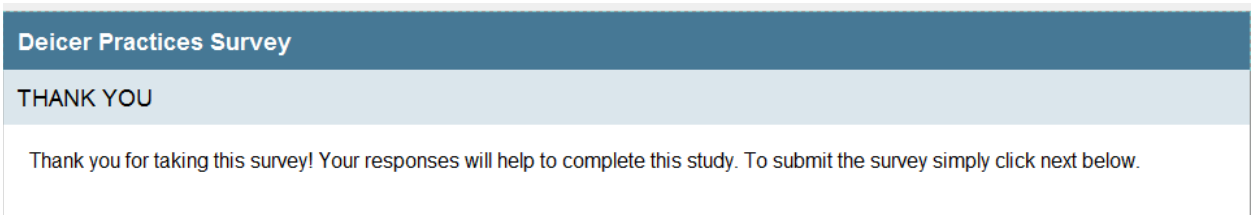
- ○ Liquid
- ○ Solid (may or may not include pre-wet)
- ○ Liquid and Solid treatments are both applied separately
- ○ No chemical treatment is required; Just plow
- ○ No action is required

Prev Next

Note:

*PAGES 33-58 were exact copies of PAGES 7 –PAGES 31 with a few exceptions. The header of the page is different. Above you can see an example of PAGE 33 which is exactly the same as PAGE 7 with the exception of the Scenario 2 header. After finishing the final Scenario 2 page (PAGE 58) the respondent was directed on to PAGE 59, which screened them for Scenario 3 the same way they were screened for Scenario 1 and Scenario 2. For the sake of simplicity, the rest of the pages are not provided. Scenario 3 resided upon PAGE 59 – PAGE 86. Scenario 4 resided upon PAGE 87 – PAGE 112. Scenario 5 resides upon PAGE 113-139. After either all the screening questions or the scenarios are answered the survey finishes out on PAGE 140.

PAGE 140



Note:

*Thus concluded the survey.

Appendix B: Digest of Survey Results

What follows is a complete digest of the treatment practices and application rates that were obtained from the survey. The results were exported from surveymonkey.com into an Excel spreadsheet and compressed into single tables where treatment costs were then calculated. The estimated treatment costs were for given time frames, and these time frames need to be known if prices from one scenario are to be compared to another. Those time frames will be provided. These time frames were necessary to judge how many times an application rate was applied in a given time frame and they are inconsequential as long as they are compared only to estimates of the same scenario. As was in Chapter 3 there are two columns for estimated prices. These represent a range of the treatment cost due to the spread of application rates.

If a reader wishes to compare costs from one scenario to another then they should divide the estimated cost range by the treatment hours used to determine the cost and compare these numbers. They would then convert their costs to a cost per lane-mile per hour result. As costs are now provided they would be in a cost per lane mile for the given amount of hours. The estimated treatment cost columns are presented with a color coding where green represent least costly and red represents the most costly. The prices are ordered along the red-green color spectrum.

The estimated costs do not reflect any wear and tear of the vehicle, gas use, insurance, or operating expenses. These costs reflect only the cost of materials.

Scenario: 1 Hours of Treatment = 6 hours

Resp.	Liquid Application	Rate	Retreat	Solid Application	Rate	Pre-wet	Rate	Retreat	Material Cost (L)	Material cost (U)
#	Type	gal/ln mi	(hours)	Type	lb/ln mi	Type	gal/ton	(hours)	$/ln mile	$/ln mile
69	100% Salt Brine	50	A/N	None					1.50	3.00
86	100% Salt Brine	75	2	None					12.00	18.00
44	Apex Meltdown	50		Road Salt mixed with Sand/Gravel	600	apex	5		40.35	72.07
12	Apex Meltdown	50		Road Salt mixed with Sand/Gravel	300	apex	6		34.78	65.96
42	Apex Meltdown	50	2	Road Salt mixed with Sand/Gravel	100			2	122.60	245.19
53	Apex Meltdown	50	4	Road Salt	400			A/N	69.90	130.88
50	Salt Brine with Apex Meltdown	75	A/N	Road Salt	100	Salt Brine	6	A/N	32.74	49.86
76	Salt Brine with Apex Meltdown	75	2	Road Salt	250	Apex Meltdown	9	2	152.33	222.56
67	100% Salt Brine	75	3	Road Salt	50	apex	3	3	9.00	18.22
80	100% Salt Brine	75		Road Salt	350	Apex	9	A/N	13.16	16.77
25	100% Salt Brine	50	2	Road Salt	200	Apex	6	2	25.25	38.62
11	100% Salt Brine	75	4	Road Salt mixed with Sand/Gravel	100			4	7.80	12.60
61	100% Salt Brine	75	3	Road Salt mixed with Sand/Gravel	100			3	11.70	18.89
77	100% Salt Brine	100	2	Road Salt mixed with Sand/Gravel	400			2	43.17	52.76
26	None			None					0.00	0.00
3	None			None					0.00	0.00
31	None			None					0.00	0.00
66	None			None					0.00	0.00
70	None			10% Ice Slicer with Road Salt	150	apex	9	2	15.92	23.88
21	None			10% Ice Slicer with Road Salt	350	Salt Brine	3	A/N	10.33	12.09
62	None			10% Ice Slicer with Road Salt	500	Salt Brine	12	A/N	15.64	17.40
59	None			Road Salt	200			4	8.91	11.88
9	None			Road Salt	250			2	23.76	29.70
48	None			Road Salt	250			2	23.76	29.70
8	None			Road Salt	150	apex	3	2	11.88	18.89
39	None			Road Salt	200	salt brine and Apex	6	3	13.93	18.95
41	None			Road Salt	300	Apex	12	?	#VALUE!	#VALUE!
55	None			Road Salt	150	80%-Brine/20%-Geomelt	15	2	12.79	18.96
43	None			Road Salt	150	50%-Brine/50%-Geomelt	6	2	12.37	18.80
17	None			Road Salt	150	Salt Brine	15	1	21.17	31.66
36	None			Road Salt	250	Salt Brine	3	A/N	5.94	7.45
27	None			Road Salt mixed with Sand/Gravel	400	apex	6	A/N	7.01	8.62
23	None			Road Salt mixed with Sand/Gravel	600	Salt Brine	6	A/N	9.94	10.89
County										
64	None			10% Ice Slicer with Sand/Gravel	150			A/N	1.33	2.00

Scenario: 2 Hour of Treatment = 4 hours

Resp.	Liquid Application	Rate	Retreat	Solid Application	Rate	Pre-wet	Rate	Retreat	Material Cost (L	Material cost
#	Type	gal/ln mile	(hours)	Type	lb/ln mile	Type	gal/ton	(hours)	$/ln mile	$/ln mile
69	100% Salt Brine	50	A/N	None					1.50	3.00
80	100% Salt Brine	50	A/N	Road Salt	350			A/N	10.41	13.40
25	100% Salt Brine	50	1	Road Salt	200			1	29.78	44.70
61	100% Salt Brine	50	2	Road Salt mixed with Sand/Gravel	50			2	4.50	11.70
41	None			None					0.00	0.00
8	None			Road Salt	100	apex	3	2	4.46	9.45
39	None			Road Salt	200	Apex	6	3	9.62	13.31
70	None			Road Salt	150	apex	6	2	9.71	14.97
21	None			Road Salt	300	95%-Brine/5%-Geomelt	3	A/N	7.43	8.96
2	None			Road Salt	100	80%-Brine/20%-Geomelt	12	3	3.20	6.24
55	None			Road Salt	200	Salt Brine	12	1	22.55	30.06
31	None			Road Salt	300	Salt Brine	9	2	22.44	26.97
43	None			Road Salt	150	Salt Brine	6	2	8.95	13.45
17	None			Road Salt	150	Salt Brine	15	1	15.12	22.61
27	None			Road Salt mixed with Sand/Gravel	350	apex	6	2	18.05	22.62
County										
64	None			10% Ice Slicer with Sand/Gravel	150			A/N	1.33	2.00

Scenario: 3				Hours of Treatment Time = 4 hours						
Resp	Liquid Application	Rate	Retreat	Solid Application	Rate	Pre-wet	Rate	Retreat	Material Cost (L)	Material cost
#	Type	gal/ln mile	(hours)	Type	lb/ln mile	Type	gal/ton	(hours)	$/ln mile	$/ln mile
12	Apex Meltdown	50	A/N	None					29.75	59.50
11	Apex Meltdown	50	4	None					59.50	119.00
5	100% Salt Brine	100	3	None					9.00	12.00
40	100% Salt Brine	100	A/N	None					4.50	6.00
48	Apex Meltdown	25	A/N	50-50 iceslicer and salt	300			2	40.07	77.83
53	Apex Meltdown	75	4	Road Salt	350			4	136.82	199.29
67	Apex Meltdown	50	3	Road Salt	50	apex	3	3	59.50	122.15
24	Apex Meltdown	50	4	Road Salt	200	APEX	12	3	70.55	133.74
39	Apex Meltdown			Road Salt	200	Apex or Sa	6	3	9.62	13.31
41	Apex Meltdown	25	3	Road Salt	300	Apex	12	3	18.06	81.60
44	Apex Meltdown	75		Road Salt mixed with Sand/Grave	650	Apex	5	A/N	71.06	102.87
37	Apex Meltdown	50	A/N	Road Salt, Sand/Gravel and Apex	400			6	#VALUE!	#VALUE!
46	Apex Meltdown	50	A/N	Road Salt mixed with Sand/Grave	100			6	30.65	61.30
61	Apex Meltdown	50	3	Road Salt mixed with Sand/Grave	100			3	61.30	122.60
42	Apex Meltdown	50	2	Road Salt mixed with Sand/Grave	100			2	91.95	183.89
77	Apex Meltdown	50	2	Road Salt mixed with Sand/Grave	400			2	108.12	200.07
18	Salt Brine with Apex Meltdo	75	3	10% Ice Slicer with Road Salt	250			A/N	69.39	102.36
50	Salt Brine with Apex Meltdo	75	A/N	Road Salt	100	Salt Brine	6	A/N	32.74	49.86
51	Salt Brine with Apex Meltdo	100	2	Road Salt	250	Apex	9	2	161.12	213.79
30	Salt Brine with Calibur M-20	75		Road Salt	200	90%-Brine/	15		33.64	49.68
26	Salt Brine with Apex Meltdo	75	2	Road Salt mixed with Sand/Grave	50			2	93.75	143.32
33	Salt Brine with Geomelt C (	100	2	Road Salt	100			5	58.64	79.17
52	Salt Brine with Geomelt C (	25	2	Road Salt	200	80%-Brine/	9	2	13.82	37.56
45	Salt Brine with geo melt 55	100	2	Road Salt	500			A/N	70.52	91.05
82	Salt Brine with Geomelt C (	100		Road Salt mixed with Sand/Grave	100			A/N	19.95	27.20
20	Salt Brine with Geomelt C (	100	1	Road Salt mixed with Sand/Grave	200	80%-Brine/		1	108.73	144.98
13	Salt Brine with Beat 55	75	A/N	Road Salt mixed with Sand/Grave	400	60%-Brine/	12	A/N	19.80	27.32
29	100% Salt Brine	100	2	Road Salt	150				16.47	22.46
47	100% Salt Brine	75	2	Road Salt	150	Salt Brine	12	3	15.02	22.52
80	100% Salt Brine	50	A/N	Road Salt	350	Apex	9	A/N	11.66	15.27
86	100% Salt Brine	125	2	Road Salt	500	Salt Brine	6	2	58.23	67.32
49	100% Salt Brine	75	A/N	Road Salt mixed with Sand/Grave	400			A/N	9.29	11.69
79	100% Salt Brine	100	A/N	Road Salt mixed with Sand/Grave	100	Salt Brine	9	A/N	5.42	7.82
63	100% Salt Brine	50	2	Road Salt mixed with Sand/Grave	300			3	13.49	19.79
69	100% Salt Brine	75	2	Road Salt mixed with Sand/Grave	200			A/N	11.70	17.10
14	100% Salt Brine	50	4	None	150	APEX	6	4	3.54	7.07
62	None			10% Ice Slicer with Road Salt	500			A/N	15.50	17.22
59	None			10% Ice Slicer with Road Salt	200			4	10.33	13.78
3	None			10% Ice Slicer with Road Salt and	300	Apex	6	A/N	6.51	8.24
78	None			10% Ice Slicer with Road Salt and	400	Apex	6	A/N	9.08	10.99
66	None			ice-slicer 50/50 with salt	200	Apex	6	5	8.37	11.40
21	None			10% Ice Slicer with Sand/Gravel	400	90%-Brine/	6	A/N	4.76	5.52
23	None			10% Ice Slicer with Sand/Gravel	600	Salt Brine	6		7.39	8.11
9	None			Road Salt	300			2	22.28	26.73
31	None			Road Salt	300			2	22.28	26.73
57	None			Road Salt	400				10.40	11.88
68	None			Road Salt	400			4	20.79	23.76
76	None			Road Salt	250	Apex Meltd	9	3	13.67	17.53
8	None			Road Salt	150	apex	6	A/N	3.24	4.99
58	None			Road Salt	400	Apex	6	A/N	11.11	13.31
55	None			Road Salt	200	80%-Brine/	12	2	14.05	18.73
16	None			Road Salt	350	95%-Brine/	9	2	27.07	31.70
43	None			Road Salt	150	90%-Brine/	6	2	9.02	13.58
17	None			Road Salt	150	80%-Brine/	15	2	9.60	14.22
36	None			Road Salt	250	Salt Brine	3	A/N	5.94	7.45
54	None			Road Salt mixed with Sand/Grave	300				4.49	5.39
75	None			Road Salt mixed with Sand/Grave	150	Calcium Ch	6	A/N	1.93	2.96
15	None			Road Salt mixed with Sand/Grave	100	Salt Brine	6		0.91	1.82
10	None			Road Salt mixed with Sand/Grave	400	APEX	6	A/N	7.01	8.62
County										
72	Freezeguard	25	A/N	Road Salt mixed with Sand/Grave	50			6	0.00	26.65
83	None		A/N	10% Ice Slicer with Road Salt and	400	Calcium Ch	6	A/N	8.71	10.25
City										
28	Salt Brine with Geomelt C (	25	A/N	None					0.00	6.35
84	100% Salt Brine	100	A/N	Road Salt	100	Apex	6	3	7.83	12.65
81	Calibur M-1000	25	A/N	Road Salt mixed with Sand/Grave	50			6	0.00	28.40
1	None			10% Ice Slicer with Road Salt	550				17.22	18.94
64	None			10% Ice Slicer with Sand/Gravel	250			A/N	2.67	3.34
73	None			25% Ice Slicer with Road Salt or ju	550			A/N	16.38	18.02
32	None			10% Ice Slicer with Road Salt	200	Apex	12	2	18.71	24.95
74	None			10% Ice Slicer with Road Salt	250	80%-Brine/	12	A/N	7.17	8.99
4	None			10% Ice Slicer with Road Salt and	100	90%-Brine/	6	A/N	1.22	2.44
7	None			Road Salt mixed with Sand/Grave	100			A/N	0.90	1.80

Scenario: 4				Hours of Treatment = 3 hours						
Resp	Liquid Application	Rate	Retreat	Solid Application	Rate	Pre-wet	App Rate	Retreat	Material Cost (L)	Material cost
#	Type	gal/ln mile	(hours)	Type	lb/lane mi	Type	gal/ton	(hours)	$/ln mile	$/ln mile
69	100% Salt Brine	50	2	None					3.00	6.00
47	100% Salt Brine	75	2	None					6.00	9.00
5	100% Salt Brine	75	3	None					6.00	9.00
86	100% Salt Brine	100	2	None					9.00	12.00
53	Apex Meltdown	50		Road Salt	300				37.18	68.41
14	Apex Meltdown	25	4	Road Salt	100	apex	6	4	1.66	33.08
12	Apex Meltdown	50		Road Salt mixed with Sand/Gravel	300	apex	6		34.78	65.96
11	Apex Meltdown	50	A/N	Road Salt mixed with Sand/Gravel	100			4	30.65	61.30
42	Apex Meltdown	50	2	Road Salt mixed with Sand/Gravel	100			2	61.30	122.60
3	Salt Brine with Apex Meltdown	50	A/N	Road Salt	300	Salt Brine	6	A/N	23.08	40.21
26	Salt Brine with Apex Meltdown	75	2	Road Salt mixed with Sand/Gravel	50			2	62.50	95.55
18	Salt Brine with Apex Meltdown	75	3	10% Ice Slicer with Road Salt	250			3	76.28	110.97
45	Salt Brine with Geomelt C (not as pre-wet)	100	2	Road Salt	200			A/N	42.56	56.74
33	Salt Brine with Geomelt C (not as pre-wet)	100	2	Road Salt	100			4	39.59	53.77
67	100% Salt Brine	75	3	Road Salt	50	apex	3	3	6.00	12.15
16	100% Salt Brine	50	3	Road Salt	350	Apex	9	3	23.32	30.54
55	100% Salt Brine	75	1	Road Salt	200	Salt Brine	12	1	30.04	42.05
80	100% Salt Brine	50	A/N	Road Salt	350	Salt Brine	9	A/N	10.47	13.49
63	100% Salt Brine	50	3	Road Salt mixed with Sand/Gravel	350			3	13.79	18.58
61	100% Salt Brine	50	3	Road Salt mixed with Sand/Gravel	100			3	4.80	9.60
22	100% Salt Brine	100	2	Road Salt mixed with Sand/Gravel	350			6	14.39	18.29
44	100% Salt Brine	100	A/N	Road Salt mixed with Sand/Gravel	500	apex	5	A/N	13.18	16.48
79	100% Salt Brine	100	A/N	Road Salt mixed with Sand/Gravel	100	Salt Brine	9	A/N	5.42	7.82
20	100% Salt Brine	125	1	Road Salt mixed with Sand/Gravel	250	Salt Brine		1	38.38	47.98
57	None			None					0.00	0.00
49	None			None					0.00	0.00
62	None			10% Ice Slicer with Road Salt	500	Salt Brine	12	A/N	15.64	17.40
59	None			10% Ice Slicer with Road Salt	250	Apex	6	4	7.34	9.50
9	None			Road Salt	300			2	14.85	17.82
70	None			Road Salt	150	apex	9	2	7.01	10.52
76	None			Road Salt	250	Apex Meltdown	9	2	13.67	17.53
8	None			Road Salt	100	apex	3	5	1.49	3.15
24	None			Road Salt	200	apex	12	3	11.05	14.74
39	None			Road Salt	150	Apex	6	3	6.48	9.98
58	None			Road Salt	400	Apex	6	A/N	11.11	13.31
2	None			Road Salt	150	80%-Brine/20%-Geomelt	12	2	6.28	9.37
40	None			Road Salt	200	90%-Brine/10%-Geomelt	6	A/N	4.50	6.03
31	None			Road Salt	300	Salt Brine	9	2	14.96	17.98
36	None			Road Salt	150	Salt Brine	3	A/N	2.97	4.47
52	None			Road Salt	100	Salt Brine	9	2	3.01	5.99
43	None			Road Salt	100	Salt Brine	6	2	2.99	5.98
17	None			Road Salt	150	Salt Brine	15	1	12.10	18.09
77	None			Road Salt mixed with Sand/Gravel	400			2	12.58	14.38
City										
28	Salt Brine with Geomelt C (not as pre-wet)	25		None					0.00	6.35
81	Calibur M-1000	25	4	None					0.00	27.50
64	None			10% Ice Slicer with Sand/Gravel	150			A/N	1.33	2.00
4	None			10% Ice Slicer with Sand/Gravel	100	90%-Brine/10%-Geomelt	6		0.69	1.38
73	None			Road Salt	550			6	14.85	16.34
1	None			Road Salt	550				14.85	16.34
32	None			Road Salt	200	Apex	12	2	11.05	14.74
74	None			Road Salt	150	80%-Brine/20%-Geomelt	12	1	12.57	18.73
County										
83	None			Road Salt mixed with Sand/Gravel	400	Calcium Chloride	6	A/N	6.64	7.89

Scenario: 5				Hours of Treatment = 4 hours						
Resp.	Liquid Application	Rate	Retreat	Solid Application	Rate	Pre-wet	App Rate	Retreat	Material Cost (L)	Material cost
#	Type	gal/ln mile	(hours)	Type	lb/lane mi	Type	gal/ton	(hours)	$/ln mile	$/ln mile
22	Apex Meltdown	50		Road Salt mixed with Sand/Gravel	150			3	33.35	64.89
20	100% Salt Brine	125	1	Road Salt	500	80%-Brine/20%-Geomelt		1	96.83	111.75
48	None			50-50 iceslicer and salt	250			1	53.43	66.78
13	None			Road Salt mixed with Sand/Gravel	450	60%-Brine/40%-Geomelt	12	A/N	8.10	9.30
36	None			Road Salt	250	Salt Brine	6	A/N	5.96	7.47
									0.00	0.00
28	Salt Brine with Geomelt C (	25		None					0.00	6.35
84	100% Salt Brine	50	2	Road Salt	100	Apex	6	2	9.49	18.98
81	Calibur M-1000	25	6	Road Salt mixed with Sand/Gravel	50			6	0.00	28.40
73	None			None					0.00	0.00
7	None			None					0.00	0.00
32	None			10% Ice Slicer with Road Salt	200	Apex	9	5	5.88	7.96
4	None			10% Ice Slicer with Sand/Gravel	100	90%-Brine/10%-Geomelt	6		0.69	1.38
74	None			Road Salt	150	80%-Brine/20%-Geomelt	12	A/N	3.14	4.68
									0.00	0.00
72	Freezeguard	25	6	Road Salt mixed with Sand/Gravel	50			6	0.00	26.65
83	None			Road Salt mixed with Sand/Gravel	400	Calcium Chloride	6	A/N	6.64	7.89