TEXAS DEPARTMENT OF TRANSPORTATION

GUIDELINES ON SELECTION AND USE OF SNOW AND ICE CONTROL MATERIALS

RESEARCH PRODUCT 0-6793-P1

RESEARCH STUDY NO. 0-6793

Texas Department of Transportation

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Cover image: Anti-icing is a proactive strategy consisting of placing snow and ice control chemicals onto the roadway surface *prior to* the storm event. These chemicals depress the freezing point and prevent snow and ice from forming a bond to the roadway surface.

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PREFACE

This document presents guidelines for the selection of snow and ice control materials for winter weather roadway maintenance applications in Texas. The following topics are covered:

- An introduction to winter weather roadway maintenance in Texas
- TxDOT's winter weather roadway maintenance strategy
- Snow and ice control materials used in Texas
- Application and effectiveness of snow and ice control materials
- Guidance on procurement of snow and ice control materials
- Corrosion, environmental impacts, and cleanup

Expressed within the broader context of winter weather operations, the guidance on snow and ice control materials presented herein is intended to help TxDOT maintenance professionals address the challenges of winter roadway maintenance in order to better provide safe and reliable transportation solutions for Texas.

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SECTION 1. INTRODUCTION

PURPOSE

This document presents guidelines for the selection of snow and ice control materials for winter weather roadway maintenance applications in Texas. The purpose of this document is to provide Texas Department of Transportation (TxDOT) roadway maintenance professionals with the information they need to know in order to procure, apply, and otherwise implement snow and ice control materials and achieve satisfactory results in their respective areas of the State.

SIGNIFICANCE

TxDOT maintenance and operations personnel are responsible to keep Texas roadways open and safe during winter storm events – a responsibility which can be met through clear understanding of service expectations, careful planning and preparation, and effective communication both internally within TxDOT and externally with the traveling public.

Texas is fortunate not to have several months of harsh winter weather each year like many northern states do. Nevertheless, major storms such as the 2011

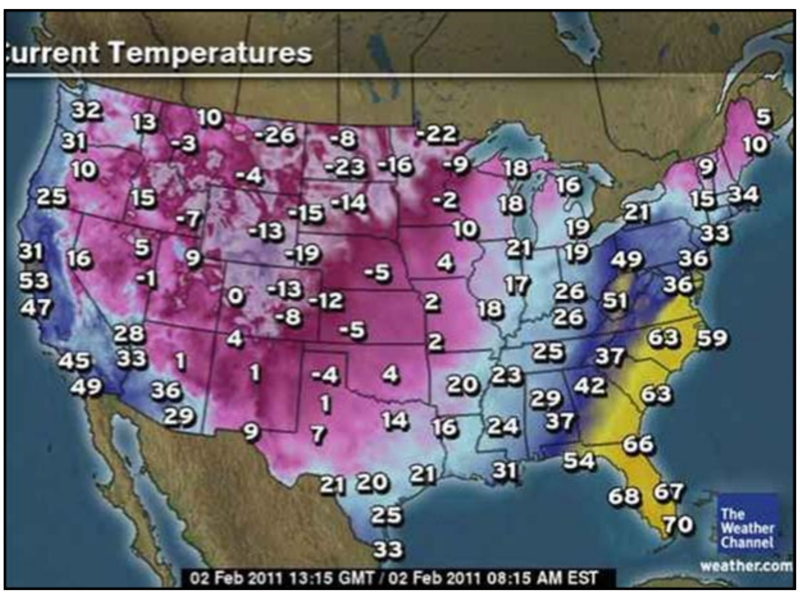

FIG 1. The 2011 Groundhog Day Blizzard was identified by the National Weather Service as one of the "biggest snowstorms in the United States from 1888 to present"

Groundhog Day Blizzard during Super Bowl XLV (Figure 1) have revealed the importance of being adequately prepared *before* snow and ice strike.

One key element of TxDOT's winter weather maintenance strategy is the effective use of snow and ice control materials. Planning and preparation are critical in this regard, and TxDOT employees at all levels must understand what is expected of them when responding to a winter storm event.

The citizens of Texas expect TxDOT to keep Texas roadways safe and open for movement and people and commerce in all seasons of the year (Figure 2). The guidelines presented herein on the selection, procurement, application, and management of snow and ice control materials support TxDOT's goal of achieving an effective maintenance response, statewide, to winter storms.

FIG 2. TxDOT's goal is to keep Texas roadways safe and open for movement and people and commerce in all seasons

WINTER WEATHER RESEARCH

TxDOT's attention to winter weather roadway maintenance operations historically has focused on the "snowy" districts in the Texas Panhandle – especially Amarillo, Lubbock and Childress. While these areas routinely experience Texas' most severe winter storms, in recent years TxDOT recognized the need to promote effective winter weather roadway maintenance in *all* areas of the state. To this end, in 2011 TxDOT sponsored two major winter weather research studies:

- Project 0-6669, Best Practices for Emergency Operations
- Project 5-9044, Winter Weather Management and Operations Training Curriculum Development and Instruction

Project 0-6669 focused on identifying actionable practices relative to winter weather operations. The research objective was to develop a winter weather operations manual (Figure 3) that could be used by TxDOT districts vulnerable to weather related emergencies.

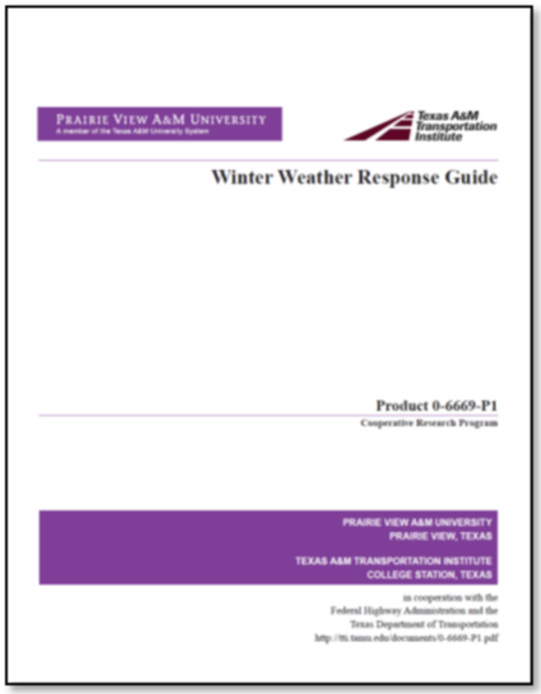

FIG 3. TxDOT 0-6669, Best Practices for Emergency Operations

Project 5-9044 consisted of two curriculum development and training programs. The first program created a 6-hour training course on management of winter weather events and delivered management training to 845 TxDOT maintenance professionals statewide (Figure 4). The second program created a 12-hour training course on winter weather operations and delivered train-the-trainer events to TxDOT training vendors who, in turn, offer the operations training to TxDOT maintenance personnel on a recurring basis.

FIG 4. TxDOT 5-9044, Winter Weather Management Training was attended by 845 maintenance professionals, statewide.

These two studies support TxDOT's need for a coordinated, statewide winter maintenance response.

RESEARCH STUDY 0-6793

In 2012, TxDOT sponsored a third major winter weather research study, 0-6793, Snow and Ice Chemicals for Texas Roads. The objective of project 0-6793 was to quantify and qualify the relative merits of common snow and ice chemicals used in TxDOT maintenance operations. Project 0-6793 considered all aspects of TxDOT's typical snow and ice control chemicals including their effectiveness, availability, environmental concerns, environmental regulations, and impact on infrastructure durability (corrosion). Taking all of these considerations into account, the study further evaluated the cost effectiveness of each chemical as a function of intended use and location (Figure 5). Work tasks included a series of literature and best practice reviews supported by both lab testing and a field trial over three winter seasons. This guidance document is a research product based on the findings of project 0-6793.

FIG 5. Project 0-6793 evaluated the cost effectiveness of TxDOT's typical snow and ice control chemicals as a function of intended use and location

ABOUT THIS DOCUMENT

This guidance document is to provide TxDOT roadway maintenance professionals with the information they need to know in order to select snow and ice control materials and achieve satisfactory results.

TxDOT's history and past research on winter weather roadway maintenance, presented in the Introduction (Section 1), provide context relative to the use of snow and ice control materials in Texas.

Section 2 of this document presents a description of TxDOT's winter weather roadway maintenance strategy. This includes TxDOT policy, information about the four different winter weather zones in Texas, level of service, and the equipment, materials, and training available to support winter weather roadway operations.

TxDOT uses abrasives, granular salt and liquid brine snow and ice control materials. Section 3 provides the details.

In Section 4, we summarize information on the usage, application and effectiveness of the snow and ice control materials used in Texas.

In Section 5, we provide guidance on material procurement including sources, availability, cost and storage.

Section 6 discusses impacts of snow and ice relative to corrosion, the environment, and operational best practices.

Section 7 provides particular guidance on material selection. Ultimately, TxDOT maintenance professionals need to be able to identify and select snow and ice control materials which are both effective and sustainable.

Section 8 discusses long-term considerations for winter weather operations including durability impacts (corrosion), environmental impacts, and cleanup considerations.

SECTION 2. WINTER ROADWAY MAINTENANCE STRATEGY

TXDOT POLICY

TxDOT has published several documents that provide policy on winter weather roadway operations. Key policy documents include:

TxDOT *Snow and Ice Control Operations Manual*. This manual provides detailed information specific to snow and ice control (Figure 6). Topics include district snow and ice control plans, materials, equipment maintenance, purchasing, bridge maintenance, personnel, reporting, weather forecasting, and alternate methods.

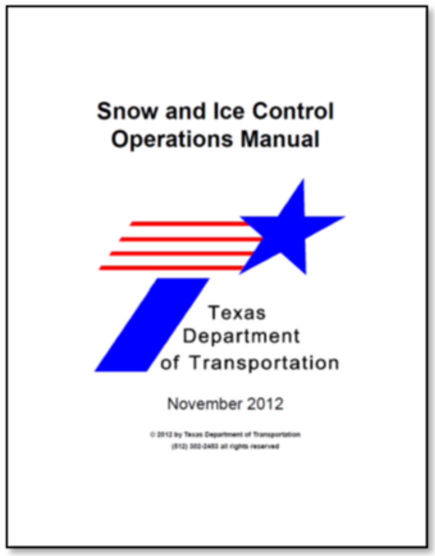

FIG 6. TxDOT Snow and Ice Control Operations Manual

TxDOT *Maintenance Operations Manual*. This manual provides operations policy for pavement maintenance, roadside maintenance, bridge maintenance, traffic operations, emergency operations, and work for or by others. Relative to snow and ice operations, Chapter 5, Section 2 provides information on priority of work, the District Snow & Ice Control Plan, control methods, road closures, highway condition reporting, and railroad grade crossings. This chapter references the TxDOT *Snow and Ice Control Operations Manual* for detailed methods.

TxDOT *Maintenance Management Manual*. This manual includes policies, procedures and guidelines for maintaining the TXDOT infrastructure. Relative to winter weather maintenance, Chapter 1, Section 2 identifies snow and ice control as a routine maintenance activity within the category of Emergency Operations. Chapter 5, Section 8 describes the Highway Condition Reporting System which allows the Department to collect, process and display accurate and timely highway condition information for situations including weather-related events. Finally, Chapter 7, Section 5 identifies the District Snow and Ice Control Plan as one of the emergency preparedness plans in place for Maintenance Sections.

District Snow and Ice Control Plan. Per the *Snow and Ice Control Operations Manual*, the *Maintenance Management Manual* and the *Maintenance Operations Manual*, each District shall have a written "Snow and Ice Control Plan." Varying climate conditions necessitate different snow and ice control plans for different areas of the state. The *District Snow and Ice Control Plan* provides (Figure 7) policy tailored to local snow and ice control conditions including weather, materials, methods, equipment, and related topics.

Other Documents. TxDOT publishes other documents associated with winter weather roadway maintenance and operations such as the Winter Weather Playbook (a public expectations document) and District standard operating procedures.

Collectively these policy documents provide administrative, procedural, and technical context for TxDOT winter weather roadway operations. This includes the selection and use of snow and ice control materials as described herein.

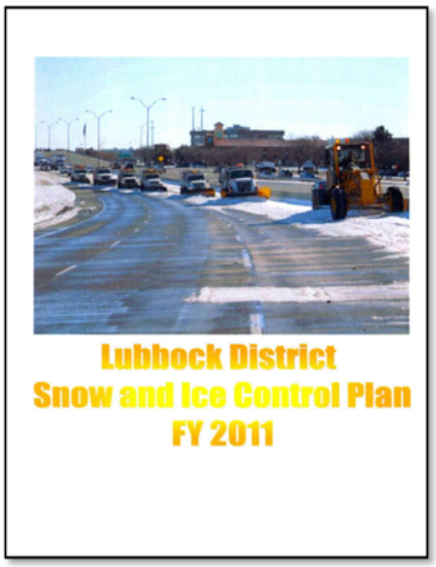

FIG 7. Lubbock District Snow and Ice Control Plan (FY2011)

WINTER WEATHER IN TEXAS

The type and quantity of snow and ice materials a state transportation department uses is fundamentally based on the weather. Snow and ice control materials are usually purchased and stored before the winter season, and climatology is used to predict the amount of material needed as well as the frequency of storms.

National climate data demonstrate that Texas winters are relatively mild compared to the northern parts of the United States. However, Texas faces some unique weather challenges. First, the number of Texas winter storms in any given year varies to a remarkable degree. Second, the types of winter storms are diverse and include snow, ice, and various forms of freezing rain. The most common storm type is "winter weather" which is defined as "a winter precipitation event that causes a death, injury, or a significant impact to commerce or transportation but does not meet locally/

regionally defined warning criteria." This is followed by "heavy snow" which is "snow accumulation meeting or exceeding locally/regionally defined 12 and/or 24 hour warning criteria, on a widespread or localized basis." The third most common is "winter storm" which is defined as "a winter weather event which has more than one significant hazard (i.e., heavy snow and blowing snow; snow and ice; snow and sleet; sleet and ice; or snow, sleet and ice) and meets or exceeds locally/regionally defined 12 and/or 24 hour warning criteria for at least one of the precipitation elements, on a widespread or localized basis."

The third key point about winter storms in Texas is their variability in intensity. As has been noted, the most common storm type is "winter weather" which is a winter precipitation event that does not meet locally/regionally defined warning criteria. In contrast, a blizzard, heavy snow, an ice storm, sleet, and others are more severe winter storm events which *do* meet defined warning criteria. Variability in intensity is another significant challenge for winter weather roadway maintenance in Texas.

Figure 8 was developed based on interviews with TxDOT maintenance supervisors and personnel. This figure illustrates that Texas winter weather typically

Mostly Snow	Snow and Ice	Ice and Freezing Rain
Atlanta (*Bowie*)	Abilene	Austin
Amarillo	Atlanta	Beaumont
Childress	Brownwood	Bryan
El Paso (*Brewster, Presidio*)	Bryan (*Freestone, Leon, Madison, Milam, Robertson*)	Corpus Christi
Lubbock (*Parmer, Castro, Swisher*)	Dallas	Houston
Paris (*Grayson, Fannin, Lamar, Red River*)	El Paso	Laredo
Wichita Falls	Fort Worth	Lufkin
	Lubbock	Odessa
	Paris	Pharr
	San Angelo	San Antonio
	Waco	Tyler
		Yoakum

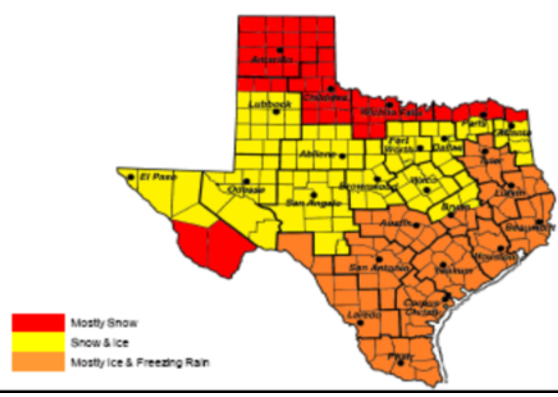

FIG 8. Winter weather in Texas as perceived by TxDOT maintenance personnel (source: Perkins, et al. 2012)

falls into one of three storm categories: mostly snow, snow and ice, and ice and freezing rain *(Perkins, et al. 2012).* Collectively, the winter weather categories in Figure 8 serve to "ground-truth" the observation that winter weather roadway maintenance is driven by climate, and these conditions can be associated with Texas geography.

TEXAS WINTER WEATHER ZONES

Winter weather varies across Texas and because of this, TxDOT's maintenance strategy should *not* be "one size fits all." Figure 9 presents a map from the National Climatic Data Center showing the mean annual number of days below freezing in Texas, this based on 30 years of data (1961-1990). This map is overlaid with hypothetical "zones" that seem to capture the nature of winter weather across Texas, as follows:

Zone 1. 23 or more freezing days, frequent snow and occasional ice

Zone 2. 15 to 22 freezing days, occasional ice and rare snow

Zone 3. 6 to 14 freezing days, rare ice and very rare snow

Zone 4. 5 or fewer freezing days, very rare ice and snow

Zone 1 is the Panhandle region characterized by frequent snow events with occasional ice events. In Zone 2, winter storms result in rare snow and occasional ice. Zone 3 experiences very rare snow and rare ice. Zone 4, a region in which temperatures rarely

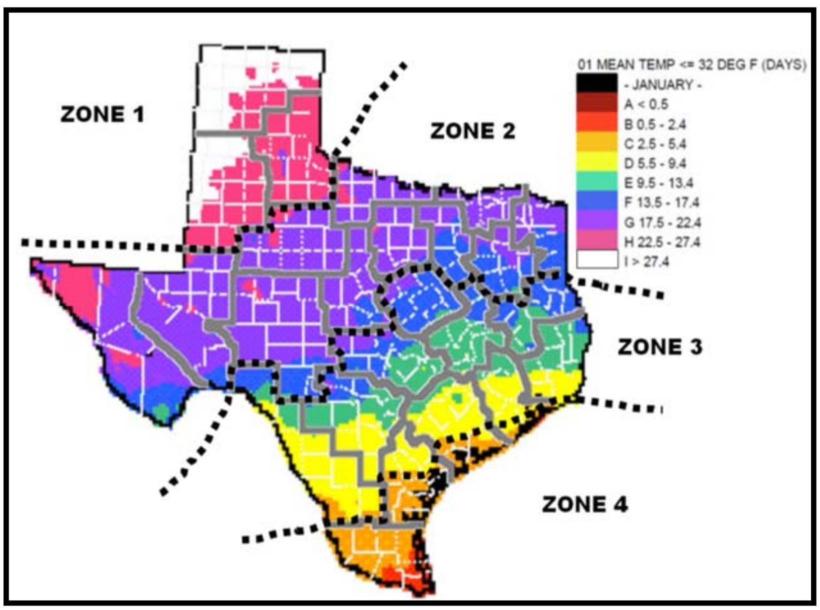

FIG 9. Texas classification of winter storm events by zones

drop below zero, experiences very rare snow and ice events.

The zone boundaries in Figure 9 could be drawn or described differently. The key reason for identifying these zones is that the geographic areas correspond to climatic conditions where different maintenance approaches make sense in a manner relatively consistent with Figure 8. On this basis, TxDOT's winter weather strategy recognizes that the maintenance response in each Zone will be different.

LEVEL OF SERVICE: INPUT-BASED VS. OUTPUT-BASED

Level of service (LOS) in the context of snow and ice control operations is defined as "…a set of operational guidelines and procedures that establish the timing, type, and frequency of treatments." These are maintenance actions directed toward achieving specific pavement condition goals for various highway sections (Blackburn, et al. 2004).

TxDOT policy documents and in particular, the *Snow and Ice Control Operations Manual,* briefly discuss LOS for winter maintenance. Two LOS approaches exist: input LOS and output LOS. The input LOS approach focuses on providing resources for winter maintenance including personnel, equipment, and materials. Methods for performing the work are described, and this approach addresses topics such as the sequence of calling out crews, the proper order of plowing the road, the speed at which plows should travel, the rate chemicals should be applied, the requirement that spreaders be calibrated, etc. The focus of the input-LOS approach is on prioritizing resource allocation with the objective being to provide added confidence that a given output will be achieved (Bourdon 1991).

Alternatively, outcome-based LOS approaches exist which reflect maintenance results as perceived by the motorist. Outcome-based approaches, also termed performance-based, include measures such as bareness of pavement, reaction time, friction improvement, reduction in accidents, duration and frequency of closures, advance warning time to customers, etc. (Bourdon 1991). *NCHRP Report 526* identifies performance-based LOS as the preferred LOS approach to winter maintenance, and this is viewed as a best practice.

Both TxDOT policy documents and interviews with TxDOT maintenance personnel indicate that for the most part, TxDOT uses a combination of input LOS and output LOS approaches for winter maintenance (Figure 10).

FIG 10. TxDOT uses a combination of input LOS and output LOS approaches for winter maintenance

OBSERVATIONS ABOUT TXDOT LEVEL OF SERVICE

Because winter weather is intermittent in Texas, it makes sense to think in terms of two LOS thresholds: "typical" and "extreme." "Typical" winter weather would be defined by season normals in a particular zone or District. This should be the LOS threshold that maintenance forces typically prepare for and respond to each and every year. "Extreme" winter weather should also be defined for a particular zone or District, and it will vary. For example, in Zone 1 or Zone 2, "extreme" might refer to a 20-year event or greater. In Zone 3 and Zone 4, any ice or snow storm would probably be considered extreme.

Further, maintenance professionals should express the level of service for each winter weather zone for both the typical and the extreme events. As a benchmark, consider a typical Zone 2 winter ice storm, say, two days duration. Here, a performance-based LOS might be expressed something like "for priority routes, keep all intersections and at least two lanes passable with at least one bare wheel path, to be accomplished within 8 hours following the storm and maintained throughout." In contrast, consider an *extreme* event in Zone 2. Here, the LOS might be expressed something like "for priority routes, keep all intersections and one lane passable with at least one bare wheel path, to be accomplished within 24 hours following the storm and maintained throughout."

The goal in expressing the LOS in this manner is not to specifically define what the level of service ultimately ought to be for a particular District or maintenance section in Zone 2, although that type of definition should be expressed in the District Snow and Ice Control Plan. Rather, it is helpful to point out that a clearly-articulated performance-based level of service directly relates to safety and mobility outcomes that directly impact the traveling public (Figure 11). From these outcomes, a performance-based LOS provides an operationally-sound guide for allocation of resources necessary to respond to such a storm. That is, a maintenance section supervisor will either have the resources on hand to provide this level of service, or s/he will not. If the maintenance supervisor does not have the resources, sound maintenance strategy would be require that s/he have a contingency plan to obtain these resources. In this way, the level of preparedness needed for the benchmark storm becomes clear.

FIG 11. A clearly-articulated performance-based level of service directly relates to safety and mobility outcomes that directly impact the traveling public

MATERIALS, EQUIPMENT, TRAINING

With the winter weather zones identified and performance-based LOS outcomes for both typical and extreme weather events defined, it should be possible to describe and plan out the various factors necessary to achieve a satisfactory roadway maintenance response in each zone or District. Success factors include, among other things, the type of weather information needed for an effective response, the type of equipment that is or should be available, the materials used for treating roads, the level of training needed for supervisors and operators, and others.

Maintenance strategies will vary by zone and by storm type, and it should be apparent that such a strategy will influence maintenance practices, procedures, equipment, materials, and other resources. Ultimately, these variables will establish the cost of the maintenance program and also provide a measure of its effectiveness.

SECTION 3. TEXAS SNOW AND ICE CONTROL MATERIALS

OVERVIEW

Interviews with TxDOT roadway maintenance personnel indicate that, with the exception of the heavy snow areas in the Texas Panhandle, roadway maintenance professionals in most areas of the state have relied on a localized approach to winter weather maintenance that leverages the benefits of Texas' typically mild winters which are characterized by infrequent and short-duration storms. The mild weather has allowed most areas of the state to manage and "get by" in this manner.

However, maintenance personnel in the heavy snow regions of the state, of necessity, have had to be more proactive. Snow and ice control chemicals, often blended with abrasives, have been used for many years to help keep roads open and safe during the more severe snow and ice storms these areas experience

FIG 12. Snow and ice control chemicals, often blended with abrasives, are used to help keep roads open and safe

every winter (Figure 12). Maintenance personnel in these northern districts, led by Amarillo, initiated a regional cooperative effort in the early 2000s to share knowledge and expertise associated with both management and operational response to winter storms. Topics have included winter weather maintenance operations strategies, lessons learned, results from limited field trials on various types of snow and ice control chemicals, and recommended practices.

Purchasing data show that TxDOT primarily uses only five types of snow and ice control materials for winter weather roadway maintenance operations. Granular chemicals include MeltDown® 20 and road salt. Liquid chemicals include MeltDown® Apex and more recently, an interest in both manufactured salt brine and natural brine. TxDOT also uses a variety of abrasives for temporary friction improvement. A brief description of each material follows.

ABRASIVES FOR FRICTION IMPROVEMENT

Abrasives increase the friction between vehicle tires and driving surface and thus are used for traction improvement. Normally abrasives are used as a reactive strategy after ice and/or snow have already bonded to the roadway. Roadway maintenance forces use many types of materials as abrasives including but not limited to crushed stone, metallurgical slag, bottom ash, and natural river sand. Abrasives are often blended with de-icing chemical such as salt; however, the amount of chemical used in the blend is small such that the intent is still traction improvement and not deicing in the formal sense. Blending with chemical helps to keep moist abrasive materials flowable (unfrozen) and helps improve workability of the stockpile.

TxDOT uses several types of abrasives for snow and ice control (Figure 13). Among the most common is Item 302, Grade 5 aggregate for surface treatments. The material is of various types (crushed stone, crushed gravel, etc.) and has a maximum nominal particle size of 3/8 inch. Similar products include Item 421 fine aggregate (concrete sand), crushed limestone screenings, and blotter sand. Where available, TxDOT personnel also use bottom ash, this being a by-product from coal-burning power plants. Aggregate-salt or bottom ash-salt blends are also common.

FIG 13. TxDOT uses several types of abrasives for snow and ice control

GRANULAR CHEMICALS FOR DE-ICING

De-icing with granular chemicals is a reactive strategy in which snow and ice control chemicals are applied during or after the storm, when ice and snow have bonded on the roadway surface. De-icing operations are intended to depress the freezing point and break the bond between the ice and road surface, allowing the snow and ice to be plowed from the roadway surface. Vehicular traffic is needed to work the chemical through snow-pack or ice for de-icing operations, and this commonly occurs during storms of extended duration. De-icing is not meant to completely melt the snow and ice as the application rates for this to occur would not be considered a best practice. De-icing specifically applies to the chemicals used to break the bond between the ice and road surface and does not apply to the use of abrasives, as abrasives materials are inert.

Road salt (NaCl) is the granular form of sodium chloride (Figure 15). TxDOT has extensively used road salt from a site near Carlsbad, New Mexico. Currently road salt is distributed by United Salt Corporation and by Envirotx.

FIG 14. MeltDown® 20 is a granular de-icing chemical distributed to TxDOT by Envirotx

FIG 15. Road salt (NaCl) for maintenance applications is the granular form of sodium chloride

LIQUID CHEMICALS FOR ANTI-ICING

Anti-icing applications typically consist of placing *liquid* snow and ice control chemicals onto the roadway surface prior to the storm event. These chemicals depress the freezing point and prevent snow and ice from forming a bond to the roadway surface. Anti-icing also helps by weakening the bonds that are formed and allowing for easier plowing of snow and ice. Because the chemical is applied prior to receiving snow and ice, anti-icing is termed a "proactive" winter weather maintenance strategy. Anti-icing requires less chemical per lane mile when compared to de-icing, with some studies identifying the benefit as 4 to 10 times compared to de-icing (AASHTO 2003). Best practice includes brine, but pre-wet granular chemicals are sometimes used.

Brine is defined as any snow and ice chemical mixed with water to form a liquid solution. This solution is then sprayed onto the roadway. Brines can be made from several snow and ice control chemicals, and can be further classified as to the type of brine, such as a sodium chloride brine, magnesium chloride brine, etc.

Natural brines and manufactured brines can possibly have a combination of chlorides. The eutectic point, the lowest temperature at the optimum solution concentration for a given chemical solution, is commonly used to determine the correct dry chemical to water ratio. from several snow and ice control chemicals, and can be further classified as to the type of brine, such as a sodium chloride brine, magnesium chloride brine, etc. Natural brines and manufactured brines can possibly have a combination of chlorides. The eutectic point, the lowest temperature at the optimum solution concentration for a given chemical solution, is commonly used to determine the correct dry chemical to water ratio.

MeltDown® Apex, one of the anti-icing chemicals TxDOT uses (Figure 16), is a magnesium chloride brine solution obtained by solarizing natural salt brine from the Great Salt Lake in Utah (Speer 2012). This liquid product is shipped from Utah to EnviroTech in Greeley, Colorado, where the proprietary blend is added. The final product is then distributed to TxDOT through Envirotx. MeltDown Apex contains 25-35 percent magnesium chloride, 65-75 percent water, and proprietary additives.

FIG 16. MeltDown® Apex is a magnesium chloride brine solution obtained by solarizing natural salt brine from the Great Salt Lake in Utah

Salt Brine (NaCl) is the liquid form of sodium chloride (NaCl). Salt brines may be naturally-occurring brine such as is available in Kent County, TX, or they may be manufactured on site. In 2011, the TxDOT Childress District invested in a salt brine manufacturing tank system (Figure 17) where they now make their own salt brine, at proper concentration for anti-icing applications (23 percent salt), in a dedicated mixing tank. The raw materials for salt brine are water and road salt. Recently TxDOT has also considered oil field brine as a potential snow and ice control material.

FIG 17. The TxDOT Childress District invested in a salt brine manufacturing tank system to make their own salt brine

OTHER MATERIALS

Other snow and ice control materials exist but are used on a very limited basis in Texas. Alternative products include Calcium Magnesium Acetate (CMA) and Potassium Acetate (KA), which have lower corrosion potential when compared to chlorides. CMA was the result of a Federal Highway Administration (FHWA) effort to find a low corrosion biodegradable substitute for sodium chloride. CMA has low corrosion but it is also costly to produce and is mainly used as an additive to other chloride salts or placed on bridges as a low corrosion alternative (Levelton Consultants Ltd., 2006). Potassium Acetate is a non-chloride, high-performance product originally designed for use as a runway deicer. Due to its high cost, potassium acetate is usually used as an additive to other chloride salts or in automated bridge de-icing systems (Levelton Consultants Ltd., 2006). These products are currently used in airport applications because corrosion to aluminum aircraft is a major concern. Automated bridge de-icing systems are becoming another area of increased use for these low corrosion alternatives. low corrosion but it is also costly to produce and is mainly used as an additive to other chloride salts or placed on bridges as a low corrosion alternative (Levelton Consultants Ltd., 2006). Potassium Acetate is a non-chloride, high-performance product originally designed for use as a runway deicer. Due to its high cost, potassium acetate is usually used as an additive to other chloride salts or in automated bridge de-icing systems (Levelton Consultants Ltd., 2006). These products are currently used in airport applications because corrosion to aluminum aircraft is a major concern. Automated bridge de-icing systems are becoming another area of increased use for these low corrosion alternatives.

SECTION 4. USAGE, APPLICATION AND EFFECTIVENESS

OVERVIEW

This section summarizes technical literature about the application and effectiveness of the types of snow and ice control materials suitable for use on Texas roads under Texas winter weather conditions. This includes the effectiveness, as a function of application, of the major snow and ice control chemicals which TxDOT maintenance forces use. The term “application” as used herein refers to how the materials are applied to the roadway, under what weather and roadway conditions, and at what rates. “Effectiveness” refers to the range of pavement temperatures, concentrations, and related factors through which these chemicals suppress the freezing point of water and thus facilitate removal of snow and ice from the roadway surface.

NATIONAL USAGE

The national perspective on usage of snow and ice control materials has been studied by the National Cooperative Highway Research Program (NCHRP). NCHRP conducted an agency survey to determine the products used for snow and ice control. Twenty two states (U.S.), three provinces (Canada), and three cities responded to the survey and the information is presented in Table 1 as a percentage of respondents as per NCHRP Report 577 (Levelton Consultants Ltd., 2006).

Table 1. National Ranking of Snow and Ice Control Material Preference (source: NCHRP 577).

Material	1st Choice	2nd Choice	3rd Choice	4th Choice	5th Choice	6th Choice
NaCl solid	57%	18%	4%	0	0	0
NaCl brine	11%	32%	7%	0	4%	0
Salt-based solid products plus other ingredients	4%	4%	0	0	0	0
Chloride-based brines plus organic additive	0	4%	0	4%	7%	0
$CaCl_2$	7%	18%	18%	14%	0	0
$MgCl_2$	14%	7%	29%	0	14%	0
CMA	0	4%	0	7%	0	0
KA	4%	7%	0	0	0	4%
Abrasives	21%	18%	7%	11%	7%	4%
Abrasives/NaCl mixture	4%	0	0	0	0	0
Sand mixed with salt solids plus inhibitor	0	4%	0	0	0	0

Table 1 shows that chloride salts were by far the respondent's first preference. Sodium Chloride (NaCl) was the most common material with 57 percent of the respondents placing granular sodium chloride as their first preference and 11 percent of respondents placing sodium brine as their first preference. Respondents noted that for the most part, sodium brine was produced in house by the agency (Levelton Consultants Ltd., 2006). In all, 79 percent of respondents considered solid sodium chloride as their first, second or third choice, and 50 percent of respondents considered sodium brine to be their first, second, or third choice. Some respondents placed both solid and brine sodium as their first choice, possibly showing that they use both methods of salt application as a winter weather strategy, one for anti-icing and one for de-icing.

Magnesium chloride was shown to be the next most popular chemical with 14 percent of respondents claiming as their first choice and 50 percent of respondents claiming as their first, second, or third choice. Finally, 43 percent of respondents claimed calcium chloride as their first, second, or third choice. For the most part, respondents said that they use magnesium and calcium chloride with corrosion inhibitors. Many western states reported that a natural product with a combination of sodium chloride, magnesium and potassium chloride was a high preference product (Levelton Consultants Ltd., 2006).

TEXAS USAGE

A study of best practices for winter weather operations by Prairie View A&M/ Texas Transportation Institute identifies the primary and secondary chemicals used by each TxDOT District for snow and ice control, as reported by the Districts in 2011. Table 2 presents this information (Perkins, et al. 2012). A total of 18 out of 25 districts participated in the survey. In the case where chemicals are used interchangeably, both are listed as primary.

Table 2. Snow and Ice Control Materials Used by TxDOT (source: Perkins, et al. 2012)

District	Anti-Icing Treatment	Deicing Material Used*				
		Chloride Salts$^{\beta}$			Organic Products	Abrasives
		$NaCl_2$	$MgCl_2$	$CaCl_2$	CMA/KA	
Abilene		1	1			1
Amarillo	☑	2	1		1	1
Atlanta			1			1
Austin		2	1		2	2
Beaumont			1			1
Brownwood			1			1
Bryan			1			1
Childress	☑		1			1
Corpus Christi		1				1
Dallas						
El Paso	☑					
Fort Worth						
Houston						
Laredo						1
Lubbock	☑	1	1		1	1
Lufkin			1			1
Odessa						
Paris			1			1
Pharr						1
San Angelo						
San Antonio	☑		1			1
Tyler						
Waco						
Wichita Falls	☑	1	1			1
Yoakum			1			1

1–Primary chemical; 2–Secondary chemical
β–Liquid and/or granular forms

Table 2 indicates that only 6 of the 18 reporting districts use anti-icing as part of their winter weather maintenance operations strategy. Most districts address snow and ice using a de-icing strategy. Of these, 17 of 18 districts use abrasives, with abrasives being a primary snow and ice control material in 16 districts. When it comes to deicing chemicals, the dominant material is identified as "$MgCl_2$" – i.e., magnesium chloride – which is used in 14 of 18 reporting districts, all of these identifying MgCl2 as primary. This material is actually not $MgCl_2$ but rather is the granular "Meltdown 20" product which often is (mistakenly) referred to as magnesium chloride. Just 6 of 18 reporting districts indicate that they use road salt (NaCl) for deicing, with road salt being primary in only 4 of these. Overall, Table 2 indicates that TxDOT districts do not use anti-icing to a great degree, they use abrasives extensively, and when they use deicing chemical, the material is most likely granular Meltdown 20 although a few districts use road salt.

MATERIAL APPLICATION RATES, NATIONAL DATA

Application rates for snow and ice control materials have been a topic of significant inquiry, with studies performed at both the national and state levels. In 1996, the Federal Highway Administration (FHWA) presented the *Manual of Practice for an Effective Anti-icing Program-A Guide for Highway Winter Maintenance Personnel*. This manual of practice set a guide to the current usage of snow and ice chemicals (Ketcham, 1996). Guidance is presented in six tables for six distinctive winter weather events. The six events are: light snow storm, light snow storm with period(s) of moderate or heavy snow, moderate or heavy snow storm, frost or black ice, freezing rain storm, and sleet storm. The tables suggest the appropriate maintenance action to take during an initial or subsequent (follow-up) anti-icing operation for a given precipitation or icing event. Each action is defined for a range of pavement temperatures and an associated temperature trend.

In 2004, the NCHRP published NCHRP 526, *Snow and Ice Control: Guidelines for Materials and Methods* (Blackburn, et al., 2004). This report further refined the usage of chemicals with factors such as type of precipitation, precipitation rate, dilution potential, cycle time, traffic load, and application (anti-icing or de-icing). Attachment 1 of NCHRP 526 presents a 6-step procedure entitled "Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions."

In addition to these national-level studies, various state DOTs have published guidance on material application rates. Minnesota DOT is a case in point. In 2005, the Minnesota DOT published "*Minnesota Snow and Ice Control – Field Handbook for Snowplow Operators*." This easy-to-use guide provides recommended application rate ranges based on pavement temperature and weather conditions.

Published national guidance on snow and ice control material application rates appears in Table 3 which identifies the range of application rates for different winter maintenance treatment strategies.

Table 3. Application Rates for various snow and ice control strategies (source: NCHRP 577)

Strategy/ Method	Materials	Pavement Temperature Ranges[1]	Application Rates[2]
Anti-Icing	Liquid Chemicals Solid Chemicals Pre-wet Solid Chemicals	0° C to 12° C (32° F to 10° F)	18-110 Kg/Lane/ Km (65-400 Lbs/Lane/ Mile)
De-Icing	Pre-wet Solid Chemicals Dry Solid Chemicals	0° C to -18° C (32° F to 0° F)	113-400 Kg/Lane/ Km (200-700 Lbs/
Abrasives	Pre-wet Abrasives Dry Abrasives	No limits	225-2700 Kg/ Lane/Km (500-6,000 Lbs/ Lane/Mile)
	Abrasive/Salt Mixes	0° C to -18° C (32° F to 0° F)	225-2,700 Kg/ Lane/Km (500-6,000 Lbs/ Lane/Mile)

The ranges are wide, but Table 3 captures the idea that anti-icing applications use less chemical than deicing, and abrasives require the highest application rates by far. Collectively, these documents and other published guidance present a systematic way for maintenance personnel to think about snow and ice control material application rates as they perform their winter maintenance operations.

MATERIAL APPLICATION RATES, MANUFACTURER'S RECOMMENDATION

Material application rates greatly depend on pavement temperatures, weather conditions, the amount of snow or ice currently on the road, the frequency at which material can be placed on the road, and other factors.

The Envirotx publication, "MeltDown 20 and MeltDown Apex vs. Rock Salt: A Comparison & Review," provides a suggested range of application rates. Envirotx, the supplier MeltDown® 20 and MeltDown® Apex recommends the following:

- For MeltDown® 20, an application rate of 200 pounds per lane mile is a reasonable starting point for de-icing.

- For MeltDown® Apex, an application rate of 15 to 20 gallons per lane mile is a reasonable starting point for anti-icing.

The *Snowfighter's Handbook*, published by The Salt Institute (SI 2013), states that spreading rates for road salt differ based on type of storm, weather conditions and operational procedures. Granular salt application rates for de-icing applications generally range from 150 to 400 lbs per lane mile with the heavier application rates associated with colder temperatures.

MATERIAL APPLICATION RATES, TXDOT DATA

In 2010, TxDOT performed an internal analysis of cost effectiveness and usage of various snow and ice control materials (Markwardt 2010). This study looked at not only the initial purchase price, but also the typical application rates and the normalized cost per lane mile for treatment. Table 4 summarizes the findings from this internal analysis. Among other things, this chart shows nominal application rates for typical snow and ice control materials used in Texas, as well as the statewide average unit cost for 2010. TxDOT practice is consistent with published national guidance on snow and ice control material application rates.

Table 4. Application Rates and Unit Costs for Typical Snow and Ice Chemicals used by TxDOT, statewide averages (source: Markwardt 2010)

Product	Material	Application Rate	$/Unit	$/Lane Mile	Comments
Meltdown Apex	$MgCl_2$	20 gal/Lmi	$1.68/gal	$33.60	Anti-icing/ brine
Freeze-guard	$MgCl_2$	20 gal/Lmi	$1.26/gal	$25.20	
Road Salt	NaCl	60 gal/Lmi	$0.066/gal	$3.96	
Meltdown 20	NaCl/ Proprietary	150 lb/Lmi	$0.23/ lb	$34.50	De-icing/ granular
Road Salt	NaCl	300 lb/Lmi	$0.033/lb	$9.90	
Meltdown Apex	$MgCl_2$	40 gal/Lmi	$1.68/gal	$67.20	De-icing/ brine
Freeze-guard	$MgCl_2$	40 gal/Lmi	$1.26/gal	$50.40	

EFFECTIVENESS OF ABRASIVES

Abrasives by themselves are inert and are not used to melt snow and ice. The use of abrasives has been a longtime strategy for many agencies as a low-cost approach to improving pavement friction. However, when abrasives are placed on the road surface without significant pre-wetting, they provide at best, a very short term increase in road surface friction (Levelton Consultants Ltd., 2006). Also, as roadway traffic levels and speeds are increased, any benefit from abrasive use diminishes (Levelton Consultants Ltd., 2006).

Sanding has long been a winter weather roadway maintenance strategy of choice in Texas. This is because of Texas' generally mild winters in most geographic areas of the State and because sanding is a very visible low-cost approach to managing pavement friction. Chemically-inert, granular materials are applied to ice and snow on the roadway surface with the intention of improving traction on the pavement surface. While research has shown that the traction improvement from abrasives can be very short-lived, abrasives continue to be commonly used in many parts of Texas.

EFFECTIVENESS OF SNOW AND ICE CONTROL CHEMICALS

The effectiveness of each snow and ice control chemical is a function of the chemical's ability to depress the freezing point of water. Freeze point depression prevents ice and snow from bonding to the road surface in an anti-icing application. For de-icing applications, the chemical melts the snow or ice and breaks the bond between the road surface and ice to allow the snow, ice, and slush mix to be plowed from the roadway surface.

Depending on weather conditions, some materials may be more effective than others. By assessing the phase diagram of the chemicals and calculating differences in dilution factors between products at a given temperature, it is possible to gauge the performance of the material. Table 5 shows the effectiveness and application ranges for the most common types of snow and ice control chemicals used for roadway snow and ice operations. Actual application rates depend on several factors which include the application strategy (anti-icing or de-icing), pavement temperature, amount of precipitation, traffic load, and application time rates.

Table 5. Comparison of the Effectiveness of Snow and Ice Chemicals (source: AASHTO).

Chemical Property	NaCl	$CaCl_2$	$MgCl_2$	CMA	KAc
Eutectic Tempera-ture	-6°F	-59°F	-28°F	-17.5°F	-76°F
Lowest melting Tempera-ture	15°F	-25°F	5°F	20°F	-13°F
Eutectic Concentra-tion	23.3%	30%	22%	32.5%	50%
Thermody-namics	Absorbs heat when melting	Releases heat when melting	Releases heat when melting	Releases heat when melting	Releases heat when melting

PROJECT 0-6793 FIELD COMPARISON DATA ON CHEMICAL EF-FECTIVENESS

FIELD TRIAL RESEARCH DESIGN

As part of project 0-6793, the research team identified and established a field test site in the Amarillo District, Randall County, along the southbound service road of IH 27, about 6 miles south of Canyon, TX (Figure 18). The field trials at this site were designed to obtain a comparative determination of how selected snow and ice control chemicals perform on Texas roads under representative winter weather conditions. That is, the field research essentially consisted of a side-by-side comparison of the performance of typical snow and ice control chemicals at an established field site.

FIG 18. Locations of field treatment test sections (*source:* Yahoo Maps, 2014).

The basic research method was to respond to candidate storms at the field test site in a manner similar to how TxDOT maintenance forces would work such storms, and then document and compare the treatment results. This included both anti-icing and de-icing winter maintenance strategies. The research team applied TxDOT's typical snow and ice control chemicals at recommended rates, we slushed and plowed the pavement test sections as would be done under operational conditions, and we observed the impact of our activities on the roadway surface for the duration of the storm.

The primary data gathering method, therefore, was observational. The researchers observed the roadway surface condition at specific intervals associated with maintenance activities during and throughout a winter storm, and we documented this condition through video, still images, and – for a limited number of storms – through decelerometer tests. These observational data were captured, summarized and analyzed using statistical methods. For this reason, the findings of the field study are essentially qualitative. Although numerical summaries, rankings, comparisons and evaluations are performed, the basis for most of this work was the visual appearance of pavement surface – snow-covered, slushy or bare – and in a few cases, an indication of its slipperiness.

ANTI-ICING RESULTS

Anti-icing test sections at the field research site were used to compare and evaluate the effectiveness of the two typical liquid chemicals TxDOT uses for anti-icing operations, namely, Meltdown Apex™ (MDA) and road salt brine (RSB). For anti-icing, two storms – Storm 3-4 and Storm 3-5 – provided sufficient field data for analysis. Anti-icing data from five other storms supported limited or qualitative analysis only, and these data were incorporated where possible (Figure 19).

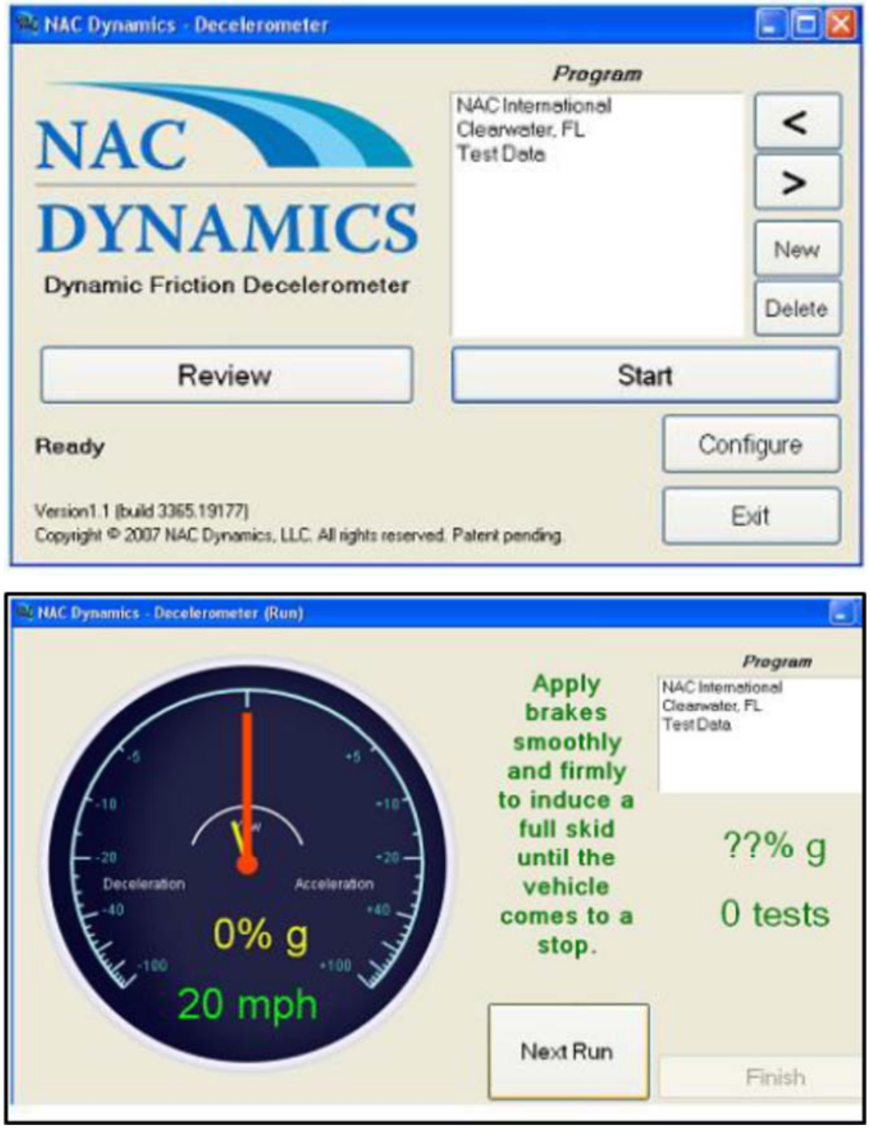

FIG 19. NAC Dynamic Friction Decelerometer for Evaluation of Roadway Surface Friction, Anti-Icing Treatment Sections

Overall results from analyses of the photo and video datasets for anti-icing applications associated with two storm events typically showed no statistically-significant difference in the amount of visible bare pavement for pavement sections treated with RSB vs. sections treated with MDA anti-icing chemical. Decelerometer tests indicated that the MDA-treated test sections could be 10 to 20 percent slicker (lower deceleration) than the RSB-treated test sections.

How did the performance of these chemicals compare to pavement sections having "no treatment"? Again, photo and video datasets for anti-icing applications associated with two storm events typically showed no statistically-significant difference in the amount of visible bare pavement for sections treated with RSB or MDA anti-icing chemical compared to untreated control sections. Similarly but less prominent, decelerometer tests suggested that the MDA-treated test sections could be slicker (lower deceleration) than untreated sections.

DE-ICING RESULTS

De-icing test sections at the field research site were used to compare and evaluate the effectiveness of the two typical granular chemicals TxDOT uses for de-icing operations, namely, Meltdown 20® (MD) and road salt (RS). For de-icing, three storms – Storm 2-3, Storm 3-4 and Storm 3-5 – provided sufficient field data for analysis (Figure 20). De-icing data from one other storm supported limited analysis only, and these data were incorporated where possible.

FIG. 20. Road Surface Condition Before Plowing, Drive Lane Treated w/Road Salt for De-Icing/ Opposite Lane Not Treated (Control)

Overall results from analyses of the photo and video data obtained during field trials associated with three storm events were used to evaluate the effectiveness of de-icing applications. These data provided mixed results but generally showed sections treated with RS (at the TxDOT rate of 300 lb/lane mile) yielded the same or more visible bare pavement vs. sections treated with MD de-icing chemical (at the TxDOT rate of 150 lb/lane mile). Decelerometer tests indicated no statistically-significant difference in pavement friction between sections treated with RS vs. sections treated with MD.

How did the performance of the de-icing chemical applications compare to pavement sections that received "no treatment"? These data provided mixed results but generally showed sections treated with RS (at the TxDOT rate of 300 lb/lane mile) yielded the same or more visible bare pavement compared to untreated control sections. Sections treated with MD de-icing chemical (at the TxDOT rate of 150 lb/lane mile) typically showed no statistically-significant difference in the amount of visible bare pavement compared to untreated control sections. Decelerometer tests suggested that both MD-treated test sections and RS-treated sections are less slippery (better deceleration) than untreated sections.

SECTION 5. PROCUREMENT

QUALIFIED SNOW AND ICE CONTROL CHEMICAL PRODUCTS

Snow and ice control chemicals are available from multiple sources. The Pacific Northwest Snowfighters (PNS) is an association of transportation agencies dedicated to ensuring the safety of winter maintenance products through structured testing and evaluation. The PNS group has established procedures for testing de-icing and anti-icing chemicals and maintains specifications that these products must meet to be considered for widespread use.

The PNS maintains a qualified product list of snow and ice control chemicals including corrosion-inhibited and non-corrosion inhibited solid sodium chloride (*e.g.*, road salt), corrosion inhibited solid sodium-magnesium chloride blends (*e.g.*, Meltdown 20), standard gradation brining salt (*e.g.*, for making salt brine), corrosion-inhibited liquid magnesium chloride (*e.g.*, Meldown Apex), and more.

TXDOT PRE-QUALIFIED PRODUCTS LIST FOR DMS-6400 “DE-ICER/ANTI-ICER”

TxDOT vendor information identifies three pre-approved producers of snow and ice control chemicals:

- Meltdown products (Meltdown 20 and Meltdown Apex) and Road Salt are offered through Envirotx, Fort Worth, TX which is a subsidiary of EnviroTech Services, Inc., Greeley, CO,
- Freezeguard products are offered through Scotwood Industries, Overland Park, KS
- Road Salt is offered through United Salt Corporation, Houston, TX

AVAILABILITY OF ROAD SALT

Salt production fluctuates with demand. According to U.S. Geological Survey (USGS) data as of 2014, 28 companies operated 61 salt-producing plants in 16 states in the US. The five leading states in the US for total salt sold are Louisiana (33 percent), Texas (18 percent), New York (17 percent), Kansas (6 percent), and Utah (5 percent). The majority of salt is used for snow and ice control with highway deicing consuming about 43% of total salt. Figure 21 identifies the average salt usage, salt price, and material sources in the United States for the 2012-2013 winter season.

FIG 21. Salt Sources, Cost Comparison and Usage Based on 2012-2013 State Survey (*source*: Washington State DOT).

COST OF SNOW AND ICE OPERATIONS, NATIONAL LEVEL

Snow and ice removal represents a considerable roadway maintenance cost in the United States. The average annual cost for snow and ice removal in the United States was $1.7 billion for the years 2007 through 2011. The average cost for snow and ice removal per state ranges from $0/year (Hawaii and Florida) to $253 million/year (Pennsylvania). Texas ranks 30th with an average cost for snow and ice removal of $17.4 million/year. On a cost per lane mile basis, the range is $0/year (Hawaii and Florida) to $8,615/lane mile (Massachusetts), illustrated in Figure 22.

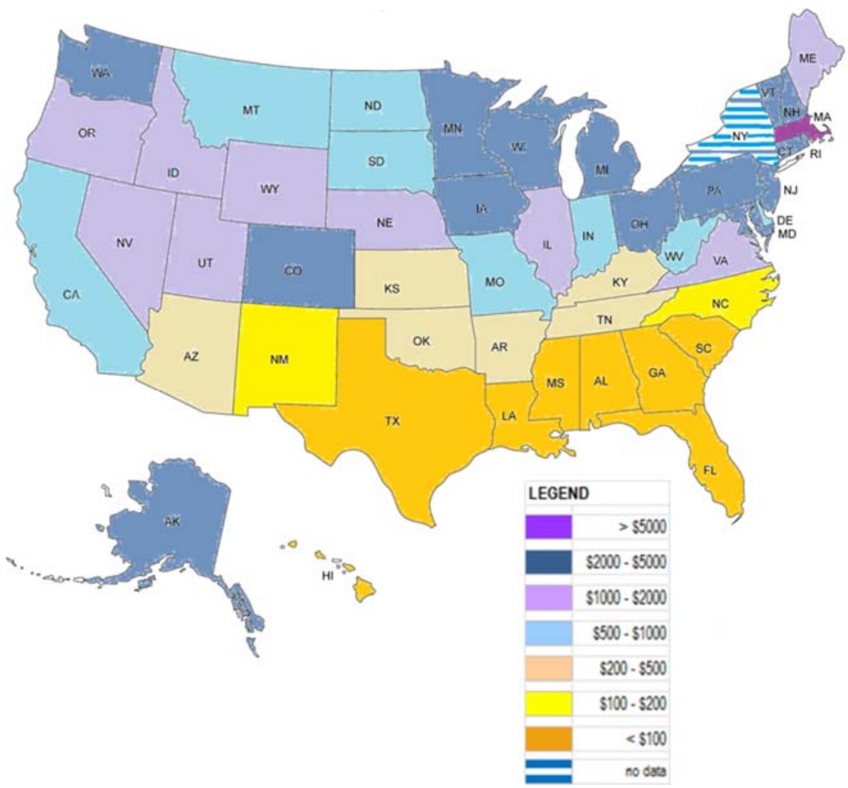

FIG 22. United States removal of snow and ice, annual average maintenance cost per lane mile.

Texas ranks 42nd with an average annual cost for snow removal of $89/lane mile. In terms of the percentage of cost for snow and ice removal as a function of physical maintenance effort, the range is 0% (Hawaii and Florida) to 424% (New Hampshire). Texas ranks 42nd in the U.S. with the average annual cost for snow and ice removal representing only 1 percent of the physical maintenance expenditures.

COST OF SNOW AND ICE OPERATIONS, TEXAS

Expenditures on snow and ice control activities in Texas are captured by Function Code 811 of TxDOT's Maintenance Management Information System (MMIS) and summarized by month, district, and cost categories. This dataset provided an insight to how snow and ice control activities were performed and therefore enabled a detailed analysis on the spending pattern across spatial and temporal boundaries.

Cost data retrieved from MMIS were presented in six categories: labor, material, equipment, contractor, miscellaneous, and preparation. Per Figure 23, the majority of spending on snow and ice control went to labor (28%), material (23%), and equipment (18%) as incurred by TxDOT itself while only 2% was awarded to contractors.

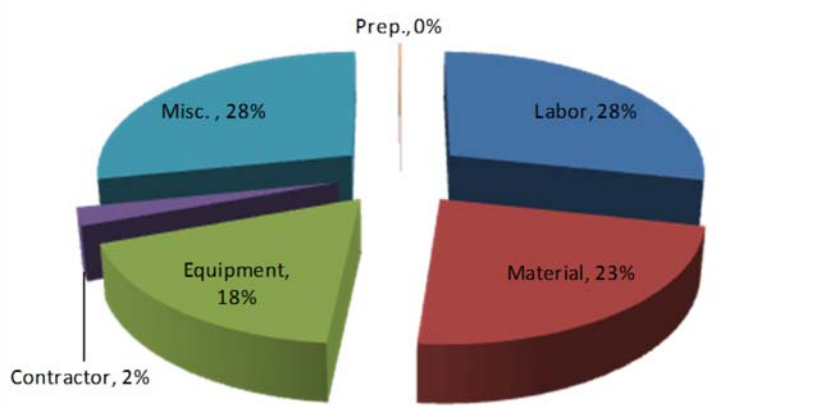

FIG 23. Distribution of cost categories on snow and ice control activities (2008-2012)

During the 5-year study period (2008-2012), TxDOT spent $72 million in total on snow and ice control or $14.5 million per year. As would be expected, monthly spending did not occur on a uniform basis throughout the year. Figure 24 shows that TxDOT spent heavily on snow and ice control in January, February, March and December and these winter months accounted for 20%, 33%, 23%, and 16% of the annual budget respectively. Together, they had a share of 92% of total departmental expenditure on snow and ice control for a given year.

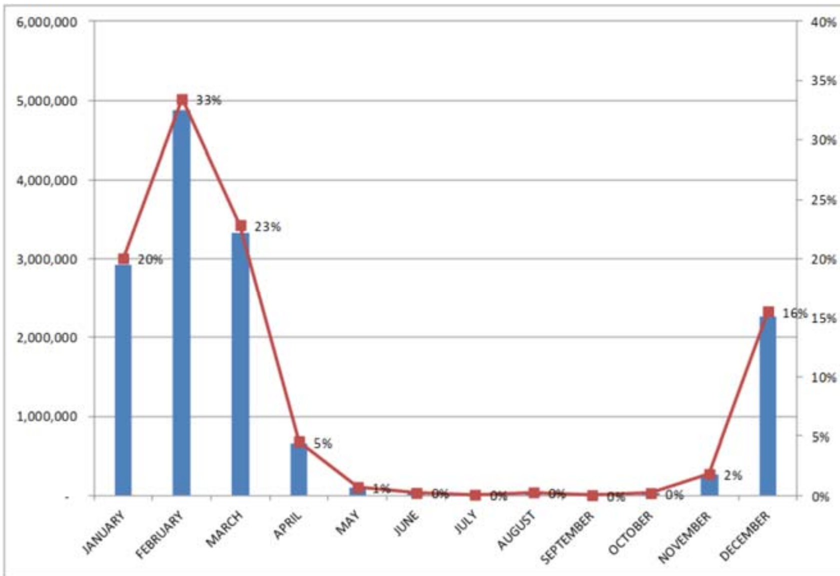

FIG 24. Average monthly expenditure on snow and ice control activities by TxDOT (2008-2012)

Similar to the pattern of spending on materials, a small number of districts accounted for the majority of departmental expenditures. Per Figure 25, the top three districts - Amarillo, Dallas, and Lubbock - spent $2,490,223, $1,511,807, and $1,415,494 a year on snow and ice control activities respectively, representing 37% of total amount by TxDOT. At the same time, the Top 10 districts (Amarillo, Dallas, Lubbock, Fort Worth, Abilene, Childress, Wichita Falls, El Paso, Paris, and Austin) collectively accounted for 80% of the total.

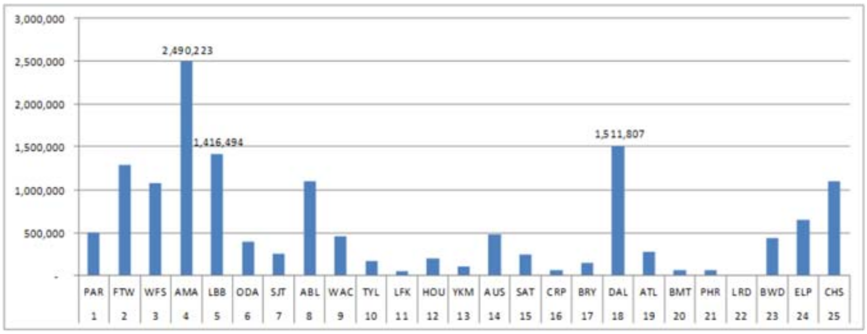

FIG 25. Annualized Expenditure on Snow and Ice Control Activities by Districts (2008-2012)

Total expenditure by districts on snow and ice control activities was normalized by lane-miles maintained by each district. The normalized values were expected to better reflect each district's commitment to winter maintenance and ranged from $2 (Laredo) to $265 (Amarillo) per lane-mile (Figure 26).

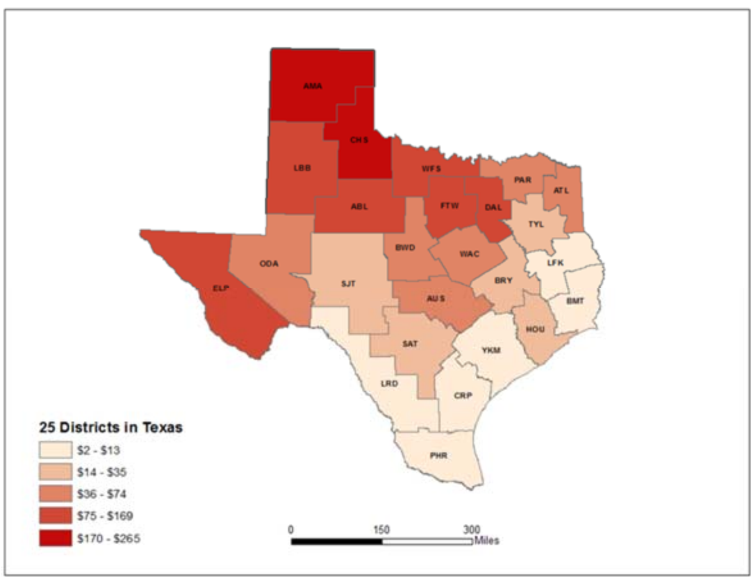

FIG 26. Annual expenditure on snow and ice control activities of 25 districts per lane mile

The median value was $48 per lane-mile. Childress and Wichita Falls ranked 2nd and 3rd with $201 and $169 per lane-mile. This pattern followed closely with the classification of winter weather into three regions: most snow, snow and ice, and ice and freezing rain. While Texas as a whole ranked near the bottom among 50 states in terms of spending on snow and ice control per lane mile, it was interesting to make a comparison at the district level. The average costs for Amarillo, Childress, and Wichita Falls were fairly close to those for states like Tennessee ($274/lm), Kansas ($213/lm) and Arizona ($167/lm) with the latest available data. The spending of these districts were significantly lower than that of the northern states such as Massachusetts ($10,504/lm), Rhode Island ($3,624/lm), and New Hampshire ($3,510/lm) as well as some bordering states including Colorado ($2,424/lm) and Oklahoma ($307/lm).

COST OF SNOW AND ICE MATERIALS, TEXAS

Figure 27 summarizes TxDOT's statewide average annual cost of snow and ice control materials, including abrasives, liquid chemical (Meltdown Apex), and granular chemical (road salt, Meltdown 20), for fiscal years 2008-2012. Between 2008 and 2012, TxDOT spent an average of $3,429,639 per year on four snow and ice control materials.

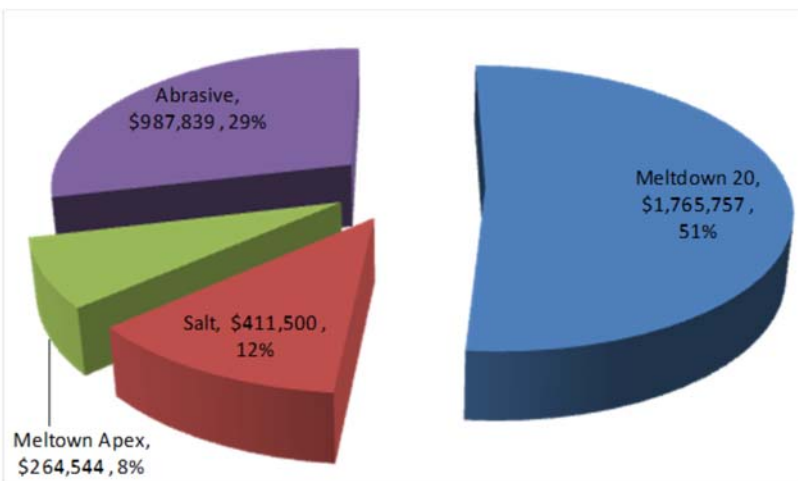

FIG 27. Annual expenditures on four snow and ice control materials by TxDOT (2008-2012)

The expenditures on Meltdown 20, Meltdown Apex, Salt, and Abrasive varied significantly by year and district. Using the data between 2008 and 2012 period, the lowest, highest and annual average expenditures were calculated to demonstrate the variation in spending patterns of 25 districts (Figure 28).

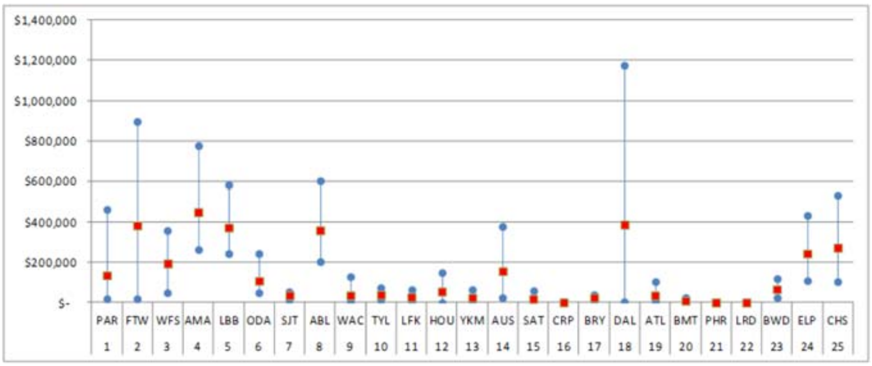

FIG 28. Expenditure on snow and ice control materials by district between 2008 and 2012 (Red squares denote mean values while blue circles denote lowest and highest annual expenditures)

The district with the most expenditure on snow and ice control materials was Amarillo ($448,753 per year), followed by Dallas ($387,527 per year) and Fort Worth ($382,757 per year). In comparison, Corpus Christi, Pharr, and Laredo spent less than $1,000 a year. It is noted that the Top 5 districts (Amarillo, Dallas, Fort Worth, Lubbock and Abilene) accounted for 57% of the total TxDOT material expenditure whereas the Top 10 districts accounted for 86% of that.

Total expenditure by districts may not reflect the degree of their vulnerability to winter weather as some Districts have many more roadways than others. The map below (Figure 29) shows the annual expenditure on snow and ice control material normalized by lane-miles maintained by each district. Material costs ranged from $0 to $50 per lane-mile. El Paso and Childress led the group by spending $50/lane-mile a year on materials, followed by Amarillo ($48/lane-mile), Abilene ($43/lane-mile), and Fort Worth ($43/lane-mile). Dallas was not in the Top 5 because of its large number of lane miles (10,847), second only to Lubbock among 25 districts.

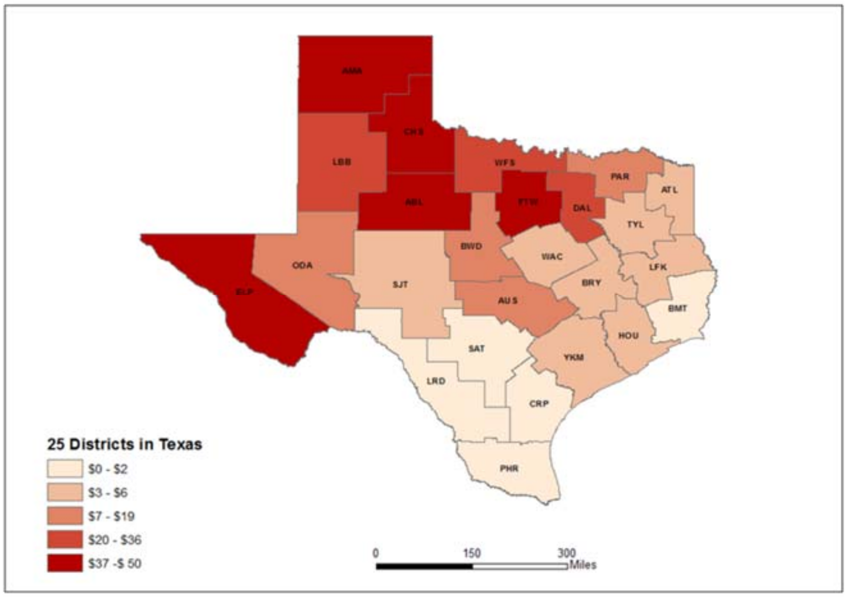

FIG. 29. Annual expenditure on snow and ice control materials of 25 districts per lane mile

Expenditures for snow and ice materials swung wildly from year to year in response to winter conditions. In 2011 – the year of the record-breaking Groundhog Day Blizzard and Superbowl XLV – Dallas' spending on snow and ice control materials reached a five-year high, at the cost of $1,176,162 while in the following year it spent the least amount - $1,911. Fort Worth had a similar pattern: its highest and lowest years were 2011 and 2012 with the spending of $894,383 and $51,159 respectively while the 5-year average was $382,757. However, the year-to-year expenditures for Amarillo were more consistent. Dispersion was measured with dimensionless coefficient of variation (CV) by dividing standard deviation with mean. Districts with the mild winter weather such as Dallas, Fort Worth and Austin had much bigger CVs (1.21, 0.89, and 0.95) than those with colder winter including Amarillo, Lubbock, and Childress (0.47, 0.40, and 0.58) as snow falls and storms in former districts were less predictable and less consistent.

MATERIAL STORAGE AND HANDLING

Proper storage of solid snow and ice control material involves adequate access to the stockpile and proper protection against escape of chemicals or leachate (Levelton Consultants Ltd., 2006). Ideally, granular (solid) snow and ice control chemicals should always be stored inside to prevent runoff of salts dissolved by precipitation (Figure 30). Storage structures should be constructed on an impermeable pad and graded away from the center of the storage area for drainage. Storage structures should be constructed to withstand the pressure from the material and the stress of loaders pushing materials against the inside walls (Levelton Consultants Ltd., 2006).

FIG 30. Granular (solid) chemicals should be stored inside to prevent runoff of salts dissolved by precipitation

Liquid storage details include adequate tank capacity, proper-sized pumps and hoses for quick loading, and recirculation capability to maintain product consistency should settling occur (Figure 31). Liquid chemical storage should include containment barriers sufficient to contain and recapture spills or the volume released from a tank rupture (Levelton Consultants Ltd., 2006).

Proper handling entails having appropriate receiving and loading equipment. When handling, the exposure effects of snow and ice control chemicals are relatively mild. Whenever there are key concerns on proprietary chemicals, these handling concerns are stated on Material Safety Data Sheets (MSDS). Most products can produce dust in their dry form and may irritate the respiratory system. Eye and skin irritation is a common concern when handling snow and ice control chemicals in liquid form. Eye, skin, and respiration protection is recommended under certain conditions (Levelton Consultants Ltd., 2006).

TEXAS MATERIAL STORAGE CONSIDERATIONS

Storage of snow and ice control materials in Texas should be tailored to fit Texas' unique geography and variable winter weather conditions. For example, dedicated salt storage sheds for bulk granular salt such as are common in northern states are suitable for seasonal winter roadway material storage in Texas' snowy districts including Amarillo, Lubbock and Childress (Figure 32). However, the purchase and use of bulk granular salt is not recommended for TxDOT districts south of IH20. For the southern districts, purchase and storage of granular material in 2500 lb supersacks is more suitable (Figure 33).

Similarly, the purchase and operation of in-house salt brine manufacturing units with permanent on-site storage tanks also makes sense in the northern snowy districts (Figure 34). However, TxDOT districts south of IH20 should rely on preblended brine with permanent storage in dedicated tanks or temporary storage in frac tanks (Figure 35).

One exception to this guidance applies to strategic stockpile locations of snow and ice control materials intended for infrequent yet extreme winter weather events in the southern parts of Texas. These long-term material stockpiles (or storage tanks) can mirror the bulk storage requirements of the northern districts, but care must be exercised to ensure that materials are worked and cycled in their storage containers such that these emergency stockpiles are ready for use when needed.

FIG 31. Liquid storage includes adequate tank capacity, proper-sized pumps and hoses for loading and recirculation

FIG 32. Dedicated salt storage sheds for bulk granular salt are suitable for material storage in Texas' snowy districts

FIG 33. For TxDOT districts south of IH20, storage of granular material in 2500 lb super-sacks is recommended

FIG 34. In-house salt brine manufacturing units with permanent on-site storage tanks are used in the northern snowy districts

FIG 35. TxDOT districts south of IH20 should use pre-blended brine with temporary storage in frac tanks

SECTION 6. CORROSION, ENVIRONMENTAL IMPACTS, OPERATIONAL BEST PRACTICES

CORROSION IMPACTS

Corrosion is a significant durability issue relative to the application and use of snow and ice control chemicals. Corrosion is inevitable regardless of the snow and ice control chemical used. Corrosion is a complex process that includes many factors making it site specific and hard to predict in the field environment. Studies that have tried to compare specific snow and ice control chemicals show a wide range of conclusions, and sometimes contradict one another (Levelton Consultants Limited, 2006). Corrosion due to snow and ice materials varies between concentration of chemical, metal type, and metal alloy. Overall, chloride-based snow and ice control materials are the most corrosive. Studies attempting to rank the corrosiveness of chloride salts have not come up with definitive conclusions. The hygroscopic magnesium and calcium chlorides are generally considered the most aggressive due to the longer time of wetness, but for practical purposes all chloride salts can be considered *highly corrosive* (Levelton Consultants Limited, 2006).

The main corrosion concern to infrastructure is the corrosion of ferrous metals, specifically iron in wrought carbon steels (Figure 36). Atmospheric corrosion includes the corrosion of vehicles, roadside infrastructure, and steel bridges. Types of atmospheric corrosion include uniform (or general) corrosion, crevice, poultice, pitting, and galvanic corrosion, and filiform corrosion of aluminum and magnesium alloys (Levelton Consultants Limited, 2006).

FIG 36. The main corrosion concern to infrastructure is the corrosion of ferrous metals

Corrosion of concrete reinforcing steel and deterioration of concrete are also of concern. Chloride ions can diffuse through the concrete cover to the depth of the rebar and destroy the thin passive oxide film which protects the steel rebar from corrosion (American Society for Metals, 2005). Chloride ions break down the passive layer locally, so consequently, large cathodic areas of passive metal surround small anodes. If sufficient water and oxygen are available, corrosion will occur. When the steel corrodes the rust occupies a greater volume, creating expansion. The expansion causes tensile stresses in the concrete which lead to cracking, delamination, and spalling. This, in turn, allows more moisture to infiltrate and corrode the steel. Sulfates are a concern for the deterioration of concrete.

Sulfates can be introduced in snow and ice operations when natural brines are used. The sulfates react with hydrated compounds in the hardened cement. This results in pressure that disrupts the cement paste, causing a loss of cohesion and strength (American Society for Metals, 2005). Some pozzolans, such as fly ash meeting the requirements of ASTM C 618 Class F can increase the resistance to sulfates while other pozzolans, such as ASTM C 618 Class C fly ash can decrease sulfate resistance (American Society for Metals, 2005). Acids also cause deterioration of concrete.

Concrete scaling, flaking, peeling, or pitting of the concrete surface has been caused by snow and ice chemicals in concrete without sufficient strength or air entrainment. However, scaling has not been an issue on DOT system roads built and maintained under strict standards for design and construction.

CORROSION INHIBITORS

Corrosion inhibitors are added to many of the manufactured blended, snow and ice control products. These corrosion inhibitors are almost always proprietary, so little is known about the chemical makeup. In the past, agricultural by-products have been popular additives. Though the corrosion inhibitors could have some corrosion inhibiting effect on vehicles, these agricultural products biodegrade, and are thought to have little long term effects for inhibiting corrosion for infrastructure. There are three basic types of corrosion inhibitors: anodic inhibitors, cathodic inhibitors and mixed inhibitors (Levelton Consultants Limited, 2006)

For practical purposes, all chloride salts can be considered highly corrosive, with the main factor being time of wetness. These hygroscopic materials suggest that roadway infrastructure will stay wet longer, causing higher corrosion. Corrosion inhibited snow and ice control chemicals, which are tested in the laboratory, show reductions in corrosion rates of the metals being tested, but they may show little or no inhibiting effect on other metals (Levelton Consultants Limited, 2006). Also, corrosion inhibited snow and ice control chemicals can show significant reductions in corrosion rates in the laboratory, but under field conditions show much lower inhibiting effects.

When one considers that corrosion impacts directly relate to the quantity of chemical used, and the quantity of chemical is driven by climate severity, it can be observed that because Texas winters are relatively mild, most portions of the State see only a few winter storms per year, and some see no storms at all. Further, even the coldest and snowiest portions of Texas have less severe winters than northern states with active, chemical-based winter roadway maintenance programs. Figure 19 indicates that Texas' winter maintenance activities are an order of magnitude lower – one-tenth to one-fiftieth – compared to states such as Iowa, Ohio, and Massachusetts. Quantitatively, it is reasonable to infer that TxDOT winter maintenance operations apply an order of magnitude (or lower) of chemical to Texas bridges and roads. While this does not eliminate corrosion concerns associated with winter roadway maintenance in Texas, it does put these issues in perspective.

ENVIRONMENTAL IMPACTS

The Federal Highway Administration states that highway runoff is appreciably cleaner than other non point runoff sources such as agricultural and industrial sources (FHWA 1997). The United States Geologic Survey in Ohio reported that deicing chemicals, including road salt, did not affect the environment in the long term (Kunze and Sroka 2004). The Salt Institute encourages cities and municipalities to plant salt tolerant vegetation along roadways (Salt Institute 2004).

The Texas Commission on Environmental Quality (TCEQ) has no implicit rules about snow and ice control on their website or in the Texas Administrative Code. Overall, the literature suggests that there is minimal added risk to the environment when using snow and ice control chemicals, certainly less that the risk of a fuel leak in an accident caused by winter weather (Thompson et al. 2009). This claim, however, needs additional, site -specific research to be valid. Because there is a lack of research on natural brines, assumptions about their impact must be made. The brine in question should be tested for constituents and toxicity and if it passes the criteria for a deicer, the brine should be safe for use on highways.

FIG 37. When applied at recommended rates, TxDOT de-icing chemicals will not pose a threat to the environment

Much of the environmental risk involved with putting a deicer on the roadway is negated by the amount of dilution when the deicer leaves the roadway (Figure 37). De-icing chemicals typically used in Texas include MeltDown® Apex, MeltDown® 20, and road salt. Based on the literature reviewed and information from the material safety data sheets, when applied at recommended rates, these chemicals will not pose a threat to the environment. MeltDown® Apex contains 25-35 percent magnesium chloride and MeltDown® 20 contains 90 to 98 percent sodium chloride. Excluding the proprietary parts of the deicers, they seem to be safe to use in the environment.

Further, in a manner similar to the discussion of corrosion impacts, even the coldest and snowiest portions of Texas have less severe winters than northern states with active, chemical-based winter roadway maintenance programs. The inference is that environmental impacts from Texas snow and ice control operations will therefore be less than those from winter maintenance operations in the northern states.

OPERATIONAL BEST PRACTICES

Snow and ice control chemicals – especially sodium chloride and magnesium chloride salts – are highly corrosive, and if improperly managed they can be harmful to equipment, infrastructure and the environment. Maintenance supervisors must therefore employ operational best practices so as to minimize impacts. Here are a few best practices:

- Safety first. Maintenance section personnel must be trained to safely perform all aspects of snow and ice control operations.
- Tailor your snow and ice control material strategy to your particular district with due consideration to the winter weather maintenance zone for your area.
- Properly store and safely handle all snow and ice chemicals.
- Calibrate granular material spreaders so that the amount of material applied corresponds to the target application rate (Figure 38).
- Use anti-icing where appropriate to minimize the amount of chemical needed for snow and ice control.
- Calibrate liquid spray application rig so that the amount of brine ap-

plied corresponds to the target application rate.

- Thoroughly and completely power wash your snow and ice application equipment after storm events, and in particular, following the winter storm season (Figure 39).

- Protect equipment using chloride neutralizers where appropriate. Paint or treat any bare metal parts. Clean, apply silicon, and cover electrical connections.

In addition, maintenance section personnel should be trained in operational aspects of snow and ice control including application of the correct amount of snow and ice control chemical and proper clean-up when the job is done.

FIG 38. Calibrate granular material spreaders so that the material applied corresponds to the target application rate

FIG 39. Thoroughly and completely power wash snow and ice application equipment after storm events

SECTION 7. SELECTION OF SNOW AND ICE CONTROL MATERIALS

SNOW AND ICE CONTROL MATERIALS BY ZONE

The winter weather maintenance strategy recommended herein (Figure 9) recognizes the inherent variability of Texas climate and therefore supports variability in the selection of snow and ice control materials for winter weather maintenance.

Because most of Texas does not typically experience severe winter weather, the use of abrasives makes sense for Zone 2, Zone 3, and Zone 4.

For Zone 4, abrasives will be the primary if not the only snow and ice control material used.

However, for Zone 1, Zone 2, and Zone 3, given the benefits of a chemical-based approach to winter weather roadway maintenance, using chemicals is both appropriate and is recommended.

In Zone 1, chemicals would be the primary snow and ice control material. In Zone 2 and Zone 3, chemicals would be used to leverage maintenance efforts and improve the level of service that can be achieved for a given maintenance dollar.

OBSERVATIONS ABOUT TEXAS SNOW AND ICE CONTROL MATERIALS

In answer to the question of which snow and ice control chemicals should be used, the previous discussions about cost, effectiveness, application, corrosion, environmental impacts, and related factors come into play. Some observations are:

- All snow and ice control chemicals currently used by TxDOT are effective for Texas climate conditions. Texas climate does not experience temperatures that drop below the effectiveness-limits of these chemicals.

- A national trend exists relative to moving from "traditional" strategies involving dry abrasives, dry salt, and abrasive/salt mixes to techniques that involve using various combinations of chemicals and application methods such as anti-icing and pre-wetting of salt and/or abrasives to address specific storm events (Levelton Consultants Limited, 2006).

- The proactive approach of pre-treatment in advance of the storm (anti-icing), whenever possible, is the recommend strategy, especially for the northern areas of the State. This is consistent with the evolving strategies of other State Department of Transportation. The pre-treatment approach requires the heavy use of specifically anti-icing chemicals, or brines.

- The low cost option of in-house brine manufacturing is recommended for anti-icing.

- Several potential vendors for natural brines are available in Texas.

- Over half of the current chemical placed by TxDOT does not include any type of corrosion inhibitor, so in very low quantity applications it may be acceptable practice to use chemicals without corrosion inhibitor additives.

- It is an option to purchase and introduce corrosion inhibiting additives for natural brines and in-house manufactured brines. More information on additives can be obtained from the PNS Qualified Products List.

- Relative to granular road salt, the use of salt deposits within the borders of Texas is currently underutilized by TxDOT.

MOST OF WHAT YOU NEED TO KNOW

After all has been said, the basics of selection for snow and ice control chemicals in Texas are as follows:

For <u>northern (snowy)</u> districts (Zone 1):

- A chemical-based strategy using anti-icing is recommended

- Both types of granular chemicals --- Meltdown 20 and road salt – perform adequately, with road salt being less expensive per lane mile

- Both types of liquid chemicals – Meltdown Apex and salt brine – perform adequately, with salt brine being less expensive per lane mile *and* less susceptible to causing slippery pavement

- Use bulk storage sheds for granular road salt and home-made salt brine with dedicated storage tanks

For southern (snow-free) districts (Zone 4):

- Abrasives for traction improvement is the recommended strategy.

For in-between (snow-ice) districts (Zone 2, Zone 3):

- Abrasives for traction improvement may be used
- The use of a chemical-based strategy including anti-icing is also recommended
- Both types of granular chemicals --- Meltdown 20 and road salt – perform adequately, with road salt being less expensive per lane mile
- Both types of liquid chemicals – Meltdown Apex and salt brine – perform adequately, with salt brine being less expensive per lane mile *and* less susceptible to causing slippery pavement
- Use supersacks for storage of granular road salt
- Purchase pre-made salt brine which may be stored in dedicated or temporary storage tanks

SECTION 8. CONCLUSIONS FROM THE RESEARCH REPORT

Project 0-6793 considered all major aspects of TxDOT's typical snow and ice control materials including their effectiveness, availability, impact on infrastructure durability (corrosion), environmental concerns and regulations, field performance, and cost. The reader is directed to the individual report chapters for details. The following statements are the key conclusions from this study, presented by research task.

Task 1. Review of technical literature on snow and ice control materials used in the United States and in Texas, including the effectiveness of these materials in relation to type of application, shows the following:

1.1 Texas snow and ice control material historical usage has relied heavily on Meltdown® products (51% granular, 8% liquid), but national usage focuses even more strongly on road salt and road salt brine.

1.2 A widespread belief exists among TxDOT personnel that MeltDown® products are comprised of magnesium chloride. Liquid MeltDown Apex™ is truly $MgCl_2$ in water, but granular MeltDown 20® is almost pure sodium chloride. *Manufacturer's* data for MeltDown 20® shows this product consists of 90 to 98% NaCl (road salt) and 0.06 to 0.2% $MgCl_2$ plus other elements and a proprietary corrosion inhibitor.

1.3 Texas ranks 30th nationally in terms of snow and ice control expenditures, and 42nd nationally in terms of percent maintenance effort *and* cost of treatment per lane mile.

1.4 Texas winter weather is very challenging for snow and ice control in that it is unpredictable (varying number and frequency of storms), diverse (both snow *and* ice), and presents with a wide range of severity (from climate normals to extreme winter storm events).

1.5 Weather directly influences winter roadway maintenance strategy and operational issues including the type, application, quantity, and effectiveness of snow and ice control materials, as well as equipment selection and personnel training.

Task 2. Review of technical literature and other data on the usability of brines for snow and ice control shows the following findings.

2.1 Texas historical usage of brines includes Meltdown Apex™ and more recently, homemade salt brine in the Childress District.

2.2 Many pre-approved brine products with known properties are available for purchase.

2.3 Three types of "geologic" brines are available for consideration in snow and ice control: natural brine, manufactured brine, and oilfield brine (produced water).

2.4 All of the geologic brines should be tested and approved prior to widespread use; concentrations of trace metals could be highly variable.

Task 3. Review of technical literature and a limited experimental program on durability impacts of snow and ice chemicals on infrastructure show the following facts.

3.1 TxDOT's historical usage of chemicals includes both inhibited chlorides (Meltdown Apex™, Meltdown 20®) and uninhibited chlorides (road salt, salt brine).

3.2 These are all chloride salts and all chloride salts are highly corrosive.

3.3 Atmospheric corrosion tests indicate

- No difference in corrosion rate observed between sodium chloride products, and
- Inhibited chlorides are 36% to 55% less corrosive than uninhibited road salt.

3.4 Chloride diffusion tests indicate

- Magnesium chloride achieves the highest chloride concentrations during diffusion, and
- No chemicals diffused beyond Level 2 (0.75" to 1.25").

3.5 The literature demonstrates that studies that have tried to compare specific snow and ice control chemicals show a wide range of conclusions, and sometimes contradict one another.

3.6 Laboratory corrosion results often differ from observed field impacts.

3.7 Texas' annual chemical applications are generally an order of magnitude lower than applications in northern states.

Task 4. Review of literature on environmental impacts and regulations associated with application of snow and ice chemicals, nationally and in Texas, shows the following results.

4.1 Overall, the literature suggests there is minimal added risk to the environment when using Na, Mg, Ca, and Cl salts for snow and ice control.

4.2 Any product (solids or brines) should be tested for constituents and toxicity prior to use, with particular attention to geologic brines that can be spatially and temporally variable.

4.3 De-icing chemicals commonly used in Texas include road salt (both liquid and granular), liquid MeltDown Apex™, and granular MeltDown 20®, all of which are approved products on the PNS Qualified Products List.

4.4 Dilution by snowmelt greatly decreases potential impacts (~500X).

4.5 The coldest and snowiest portions of Texas have less severe winters than northern states with more active, chemical-based winter roadway maintenance programs.

Task 5 (field trials). The field trials performed in Winter 2012/13, Winter 2013/14, and Winter 2014/15 showed the following findings.

5.1 Photo and video datasets for anti-icing applications typically showed

- No statistically-significant difference in the amount of visible bare pavement for sections treated with Salt Brine vs. sections treated with MeltDown Apex™, and
- No statistically-significant difference in the amount of visible bare pavement for sections treated with Salt Brine or MeltDown Apex™ compared to untreated control sections.

5.2 Decelerometer tests for anti-icing applications indicated

- MeltDown Apex™ -treated sections could be 10 to 20 percent slicker (lower deceleration) than the Salt Brine-treated sections, and
- MeltDown Apex™ -treated test sections could be slicker (lower deceleration) than untreated sections.

5.3 Photo and video datasets for de-icing applications typically showed

- A statistically-significant improvement in the amount of visible bare pavement for sections treated with road salt (at the TxDOT rate of 300 lb/lane mile) vs. sections treated with MeltDown 20® (at the TxDOT rate of 150 lb/lane mile),
- No statistically-significant difference in the amount of visible bare pavement for and sections treated with road salt or MeltDown 20® de-icing chemical compared to untreated control sections.

5.4. Decelerometer tests for de-icing applications indicated

- No statistically-significant difference in pavement friction between sections treated with road salt vs. sections treated with MeltDown 20®, and
- Both MeltDown 20®-treated test sections and road salt -treated sections were less slippery (better deceleration) than untreated sections.

Task 5 (laboratory testing). The laboratory testing program shows the following:

5.5 With respect to ice melting and undercutting

- MeltDown 20® and Salt Brine de-icing solutions are comparable with regard to their ability to melt ice or undercut ice under laboratory conditions at temperatures above 15°F,
- Neither Salt Brine nor MeltDown 20® was particularly effective at 0°F (which is near the freezing temperature of a 23% salt mixture),
- MeltDown Apex™ was substantially more effective at ice melting, even at 0°F, and was generally more effective at undercutting although this effect was much more variable, and
- The melting process rapidly dilutes the salt solutions, reducing their effectiveness.

5.6 With respect to surface friction

- MeltDown Apex™ was much "slicker" than either MeltDown 20® or Salt Brine, and
- Friction data for MeltDown 20® and Salt Brine were similar to distilled water.

Task 6. Detailed cost analyses established the baseline of TxDOT's snow and ice control expenditures and show the following results.

6.1 Opportunities to improve efficiency in snow and ice material procurement include

- Standardize selection of materials,
- Develop a uniform standard for selecting snow and ice control materials, and
- Leverage TxDOT's purchasing power to lower prices.

6.2 Opportunities to improve efficiency of winter maintenance operations include

- Reduce Operation to Material (O-M) ratios,
- Capture data on cleanup and anti-icing maintenance functions, and
- Manage risk for low-frequency, high-impact events.

6.3 Opportunities to improve efficiency of winter maintenance policy include

- Apply performance-based models for snow and ice control,
- The current cost analysis focuses on input factors, and
- A significant question remains unanswered, namely: "Is the current level of winter maintenance spending adequate in maintaining snow and ice free roadways in Texas?"

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