Optimal Snow and Ice Control for Parking Lots and Sidewalks

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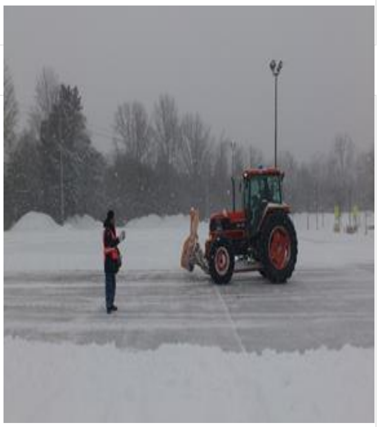

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A Summary Final Report

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January, 2015

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by

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FOREWORD

This report summarizes the results from a three year research project entitled "Snow and Ice Control for Parking Lots and Sidewalks (SICOPS)". The document highlights the important findings from the project along with a number of recommendations that can help maintenance contractors and government agencies develop a cost-effective winter maintenance program for snow and ice control of parking lots and sidewalks. The report is intentionally brief and concise so that it can be easily followed by winter maintenance personnel in the field. Detailed discussions on the test results and the underlying methodology are reported in various technical papers listed at the end of this report.

Over the project period, the project team conducted an extensive review of relevant literature, a comprehensive survey of facility users, maintenance contractors, and government agencies, and a large scale field experiment on a wide range of strategies, methods and materials. The field tests were conducted at a parking lot and several sidewalks located in the City of Waterloo, Ontario over three winter seasons. Approximately 5000 tests were conducted over nearly 100 winter snow events, covering a large number of treatment combinations in terms of material types, maintenance strategies, and treatment techniques under a wide range of winter weather conditions. The field data were then analyzed systematically using various statistics for generating quantitative information about the effects of various factors on the snow melting performance of different materials, rates and treatment methods. The major outcome of this effort is a decision support tool for the selection of the most appropriate maintenance strategies, materials and application rates to address the specific maintenance needs of any parking lots and sidewalks under any winter events.

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1. BACKGROUND

Snow and ice on pavement surfaces can create slippery conditions, causing slip-n-falls and vehicular accidents. To ensure public safety and mobility, various forms of maintenance operations such plowing and salting are performed to keep pavement surfaces free of snow and ice. The costs of winter maintenance operations are however substantial. For instance, over $1 billion is spent annually on winter maintenance of various transportation facilities in Canada, which includes the use of an average of five million tonnes of salts (Transportation Association of Canada, 2013). The release of large quantities of salts could cause significant environmental impacts, such as damage to the soil, water, vegetation and wildlife (Levelton Consultants, 2007). Salt is also a significant factor contributing to the corrosion of bridges, buildings and vehicles, increasing maintenance costs by billions of dollars. Therefore, a sensible salting strategy is necessary in order to reduce the harmful effects of salt while keeping the various transportation facilities safe.

Developing a sensible salting strategy is a multi-step process; but one of the first steps is the development of snow and ice control guidelines for the selection of the best strategies and methods, materials, and application rates for specific facility and weather conditions. It is generally understood that developing appropriate facility-specific guidelines requires a quantitative understanding of the snow melting performance of the materials being used and the effect of different application methods and rates within the usage environment of these facilities (e.g., roadways vs. parking lots vs. transit platforms). Furthermore, different facilities have different service requirements (e.g., desirable bare pavement regain time) and traffic characteristics (e.g., only vehicular traffic vs pedestrians-vehicle mix, speed differences, etc.). The goal of this three year research project is to address the need of developing guidelines for the snow and ice control of parking lots and sidewalks. This report presents the highlights and key findings from the research that will help maintenance practitioners optimally manage and clear snow and contamination from parking lots and sidewalks.

2. MAINTENANCE TECHNIQUES FOR SNOW AND ICE CONTROL

Snow and ice control methods can be generally classified into three distinct categories: mechanical, chemical and thermal (Minsk, 1998). Mechanical methods could be in the form of plowing, scraping, and blowing while thermal methods include those that control or prevent the formation of snow through the application of heat, either from above or below the pavement surface. The most effective and also costly method is however of chemical process, in which a freezing-point depressant is used to melt, or prevent the formation of, snow and ice. This section provides a brief review of three chemical based snow and ice control strategies, namely, deicing, anti-icing, and using of abrasives.

2.1. Deicing

Deicing is a method of snow and ice control in which chemical agents are applied to melt the snow and ice already accumulated on a pavement surface or prevent the bonding of snow and ice to a pavement surface (Blackburn, Bauer, Amsler, Boselly & McElory, 2004). Chemical agents work by lowering the freezing point of water or by breaking the previously formed bond between snow and pavement.

The most common type of chemical agents for deicing is rock salt. Deicing treatment can also be conducted with other alternative materials, some of which contain less or no chlorides and thus have lower environmental effects. Salt can be pre-wetted using brine or other liquids for improved performance (Fonnesbech, 2005; Fu, Omer, Hossain & Jiang, 2012; Shi et al., 2009). Pre-wetting has been shown to be an effective method to provide a higher level of service (LOS) for the following two reasons. First, wet salt can better adhere to the pavement surface, resulting in less scattering and less material usage. Secondly, salt requires moisture to activate the deicing process (Fu et al., 2012; Ketcham, Minsk, Blackburn & Fleege, 1996; Roosevelt, 1997). Road salts have become the most popular material due to their high effectiveness, easy operation, and low initial costs (Chappelow et al., 1992; Williams & Linebarger, 2000).

2.2. Anti-icing

Anti-icing is a strategy which applies snow and ice control materials before or immediately after a snow event starts. The objective of anti-icing is to prevent bonding of snow and ice to a pavement surface (Amsler, 2006; Blackburn et al., 2004; Wisconsin Transportation Bulletin, 2005). Blackburn, McGrane, Chappelow, Harwood and Fleege (1994) were among the first to conduct comprehensive research on the development of anti-icing technology in the context of North American weather and winter maintenance. To meet this end, they first conducted an in-depth literature review on research and practice on anti-icing in Europe and United States. They then conducted a two-year field study to evaluate the various anti-icing methods used in order to determine the best method available for various conditions.

The study reported that, for an anti-icing treatment, if salts are applied at an appropriate time and not during severe storm conditions or on an extremely cold pavement surface (i.e. colder than -5 ºC (23 ºF)), an application rate of 100 lb/lane-mile (28 kg/line-km) (1.57 lbs/1000sqft (8 g/m^2)) was adequate. The study also found that anti-icing operations can contribute to cost savings for both highway agencies and motorists by reducing the use of materials and by reducing the occurrence of accidents, respectively. Since then, due to the advantages inherent in an anti-icing strategy, it has become one of the most popular winter road maintenance strategies (Evans, 2008; Stidger, 2002; Wyant, 1998). Studies have also shown that, in addition to its benefits against regular winter weather, anti-icing is particularly effective in dealing with heavy frosts and freezing fogs (Evans, 2008; LRRB, 2005; Smith, 2006).

2.3. Abrasives

Abrasives such as sand and sand-salt mix are commonly used to provide improved traction on ice-covered roadways, especially when it is too cold for other chemicals to work effectively (Blackburn et al., 2004; Environmental Canada, 2004; Nixon, 2001; Stidger, 2002). Amsler (2006) detailed several kinds of abrasives which can be used for snow and ice control, including natural sands, finely crushed rocks or gravels, bottom ashes, slags, ore tailings and cinders. The application rate for abrasives varies among the different winter maintenance agencies due to the diverse weather conditions. Blackburn et al. (2004) observed that most agencies apply the abrasives within a range from 500 lb/lane-mile (141 kg/line-km) (8 lbs/1000sqft (39 g/m^2)) to 1500 lb/lane-mile (423 kg/lane-km) (24 lbs/1000 sqft (117 g/m^2)) while the average application rate is 800 lb/lane-mile (225 kg/lane-km) for roadways (13 lbs/1000sqft (63 g/m^2)).

3. SNOW AND ICE CONTROL MATERIALS

Snow and ice control materials include various chemical products as well as abrasives. This section summarizes the common Deicing products used in the winter maintenance industry. Table 3-1 summarizes the characteristics of these maintenance materials.

Deicing materials can generally be classified into two types, namely, Chloride-based and non-Chloride based. The most commonly used Chloride-based materials include sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$). These materials are generally produced from the mining of surface or underground deposits, extracting and fractionating brine from wells, industrial by-products, or through solarizing saltwater.

Non-chloride based products, also called organic products, are mostly manufactured. Some are wholly synthesized (e.g., CMA and KA) while others are refined from agricultural sources (e.g., by-products from grain processing, brewing, winemaking, and similar sources). These materials are not as popular as chloride-based products, but are used as either stand-alone liquids, blended with inorganic liquids, or as stockpile treatments. In general, due to their high costs they tend to be used for special situations (e.g., for low-corrosion applications such as bridge decks). Most of these products are proprietary with little information about their actual manufacturing and refining process. These products are usually used in conjunction with chloride-based products, though stand-alone products have also been marketed. Many of these products have been claimed to have the benefits of being less corrosive and more effective in snow melting.

In addition to these products, other organic compounds are also used for snow and ice control. One group of compounds in this category is alcohols (e.g., methanol or ethanol). These are usually distilled from organic feedstock, though some can be synthesized from petroleum sources. Alcohols are volatile and flammable, which present some storage and handling concerns. Glycols are another common group of organic chemicals used for snow and ice control. The most common glycol-related compounds encountered are ethylene and propylene glycol. These are found in commercial automobile antifreeze products. These compounds are used as aircraft deicers and have seen limited roadway applications. In this study, some of the emerging products were selected and tested to investigate their snow melting performance as compared to regular rock salts. The details about these salts are provided in field test section.

Table 3-1: Properties of Some Common Deicers (Blackburn et al., 2004; Ketcham et al., 1996)

Material	Chemical Comp	Forms Used	Eutectic Temp & Eutectic Conc. °C (°F)	Atmospheric Corrosion to Metals	Corrosion to Concrete Matrix	Corrosion to Concrete Reinforcing
Sodium Chloride	NaCl	Primarily solid, but increasing use of liquid	-21 (-58) @ 23.3%	High Will initiate and accelerate corrosion.	Low/moderate Will exacerbate scaling; low risk of paste attack.	High Will initiate corrosion of rebar.
Calcium Chloride	CaCl2	Mostly liquid brine, some solid flake	-51 (-60) @ 29.8%	High Will initiate and accelerate corrosion; higher potential for corrosion related to hygroscopic properties	Low/moderate Will exacerbate scaling; low risk of paste attack.	High Will initiate corrosion of rebar.
Magnesium Chloride	MgCl2	Mostly liquid brine, some solid flake	-33 (-28) @ 21.6%	High Will initiate and accelerate corrosion; higher potential for corrosion related to hygroscopic properties	Moderate/high Will exacerbate scaling; risk of paste deterioration from magnesium reactions	High Will initiate corrosion of rebar, evidence suggests MgCl2 has highest potential for corrosion of chloride products
Calcium Magnesium Acetate	CaMgAc	Mostly liquid with some solid	-27.5 (-17.5) @ 32.5%	Low/moderate Potential to initiate and accelerate corrosion due to elevated conductivity.	Moderate/high Will exacerbate scaling; risk of paste deterioration from magnesium reactions	Low Probably (Ketcham S. A., 1996) little or no effect.

Potassium Acetate	KAc	Liquid only	-60 (-76) @ 49%	Low/moderate Potential to initiate and accelerate corrosion due to elevated conductivity.	Moderate/high Will exacerbate scaling; risk of paste deterioration from magnesium reactions.	Low Probably little or no effect.
Agricultural By-Products	NA	Liquid only	Usually blended with chloride-based products	Low Potential to initiate and accelerate corrosion due to elevated conductivity claims of mitigation of corrosion require further evaluation	Low Probably little or no effect.	Low Probably little or no effect.
Other Organic Materials	Glycols Methanol	Liquid only	Varies with product	NA	Low Probably little or no effect.	Low Probably little or no effect.

4. REVIEW OF CURRENT WINTER MAINTENANCE PRACTICES

As part of this research project, two online surveys were conducted; one on winter maintenance contractors and the other on municipalities. The main objective of the surveys was to investigate and document the current state of practice in regards to the winter maintenance of parking lots and sidewalks, with the eventual goal of using this information to develop guidelines that are easy to adopt and address common issues faced by the practitioners.

4.1. Survey of Winter Maintenance Contractors

This survey was conducted on more than 600 winter maintenance contractors who are members of Landscape Ontario. More than 100 complete responses were received.
Figure 1 shows the geographic locations of the respondents. In the survey, a number of important questions related to winter maintenance were asked including the following:

- Company's business characteristics (e.g., commercial, residential client types)
- Maintenance contract preferences
- Level of service delivered to the clients
- Maintenance methods
- Materials used for snow controls
- Application rates
- Use of technology
- Awareness on environment and sustainable practices

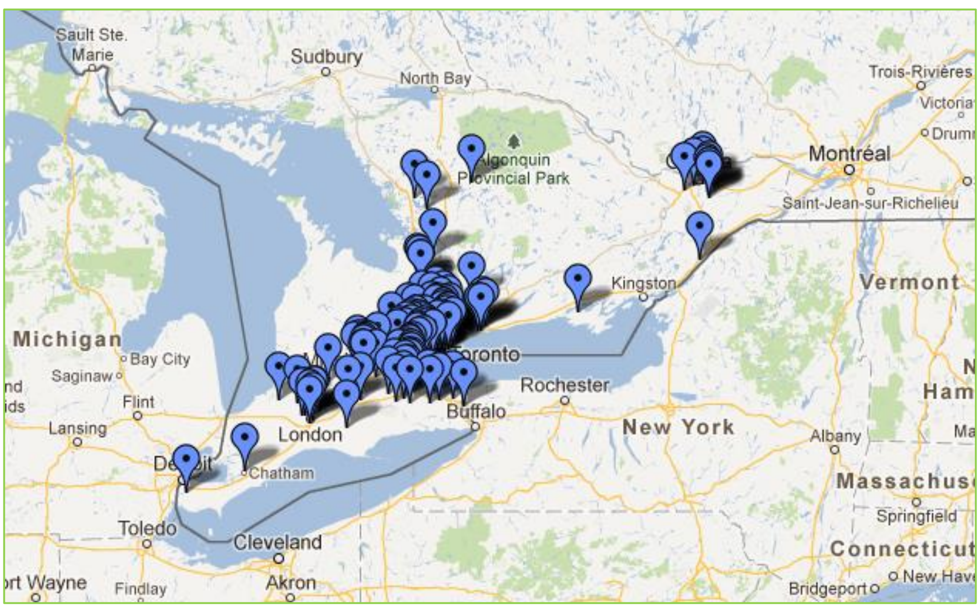

Figure 1: Geographical Location of Respondents

Summary of Major Findings

- A majority of the contractors surveyed (60%) prefer to have 'Salt Extra' contracts and this preference remains similar across contractors serving different types of clients. Given the limited guidelines and references available for this industry along with no incentive to save salt (as it is paid for by the client), it can be expected that the industry is prone to over application of salt.
- Regardless of their geographical location, a significant percent of contractors (31%) indicated they were using a salt and sand mix. Despite its proven ineffectiveness under a number of conditions (Levelton Consultants, 2007), salt and sand mixes continue to be a popular choice and thus further research towards evaluating its effectiveness for parking lots and sidewalks would be beneficial.
- Despite their proven effectiveness (Blackburn et al., 2004), pre-wetting and direct liquid application (DLA) are not used widely with only a small number of contractors indicating their prior experience (25% and 15% respectively). While high initial cost is one of the major hurdles in adopting new methods and technologies, another reason for the low adoption rate is the lack of formal studies and guidelines that explain the correct use and potential savings for parking lots and sidewalks.
- The reported application rates have a large variation, indicating that maintenance contractors are unsure of the amount of material that is needed for given conditions. Furthermore, over than 70% of the contractors surveyed currently do not have any equipment that can be used to accurately measure the amount of salt being used at different locations. Thus, if snow and ice control guidelines were to be prepared for use by field practitioners, this deficiency would have to be considered.
- From a sustainability perspective, majority of the contractors reported applying excess salt to avoid slips and falls, which often lead to litigations and increases in insurance premiums. Given the relatively low price of salt, minimal penalties for over application, and a majority of contracts being 'Salt Extra', it can be expected that this trend for over application of salt will continue. A large proportion of the respondents (75%) believe that 10% or more salt could be saved if litigations and insurance premiums were not a concern.

4.2. Survey of Municipalities

This survey investigated the current winter maintenance practices used by various municipalities that are responsible for ensuring the safety of the streets, sidewalks and parking lots of their various establishments and buildings. The online survey was sent to 222 cities and municipalities in Canada and the United Sates in the final weeks of the winter seasons of 2012-2013 and 2013-2014. Municipalities were selected based on winter severity. Of the municipalities that received the survey, over 25% of them responded, roughly half of them from Canada, and the other half from the United States. Figure 2 shows the locations of the respondents. There is a significant variation in the weather conditions for the municipalities being surveyed in terms of the number of monthly snow days, the total monthly snowfall, and the monthly average temperature, as shown in Figure 3. This suggests that winter maintenance services between municipalities would also vary.

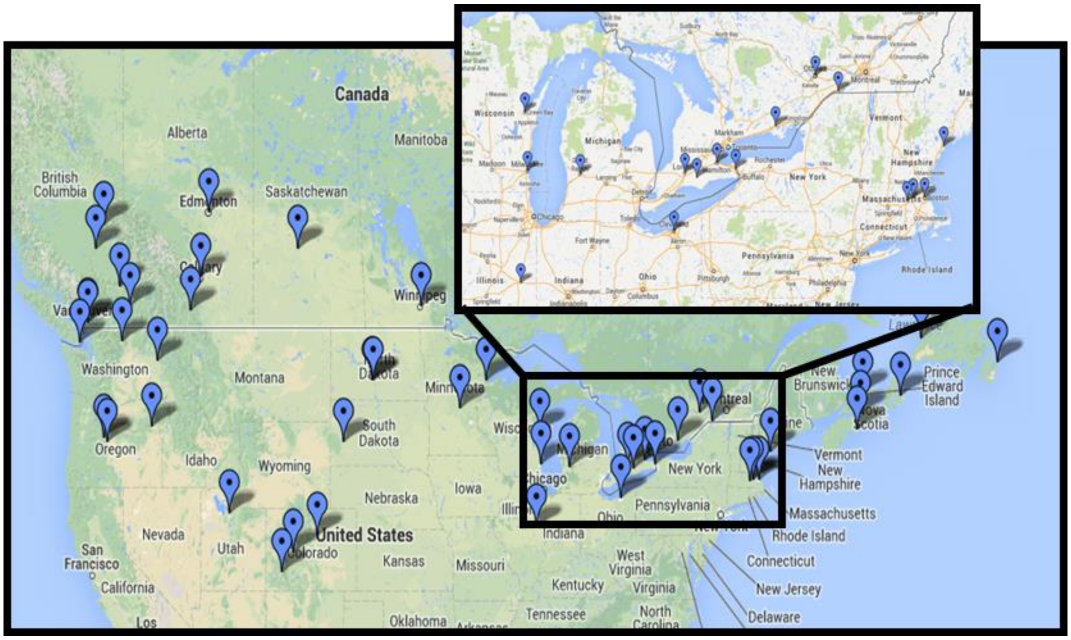

Figure 2: Locations of the Surveyed Cities

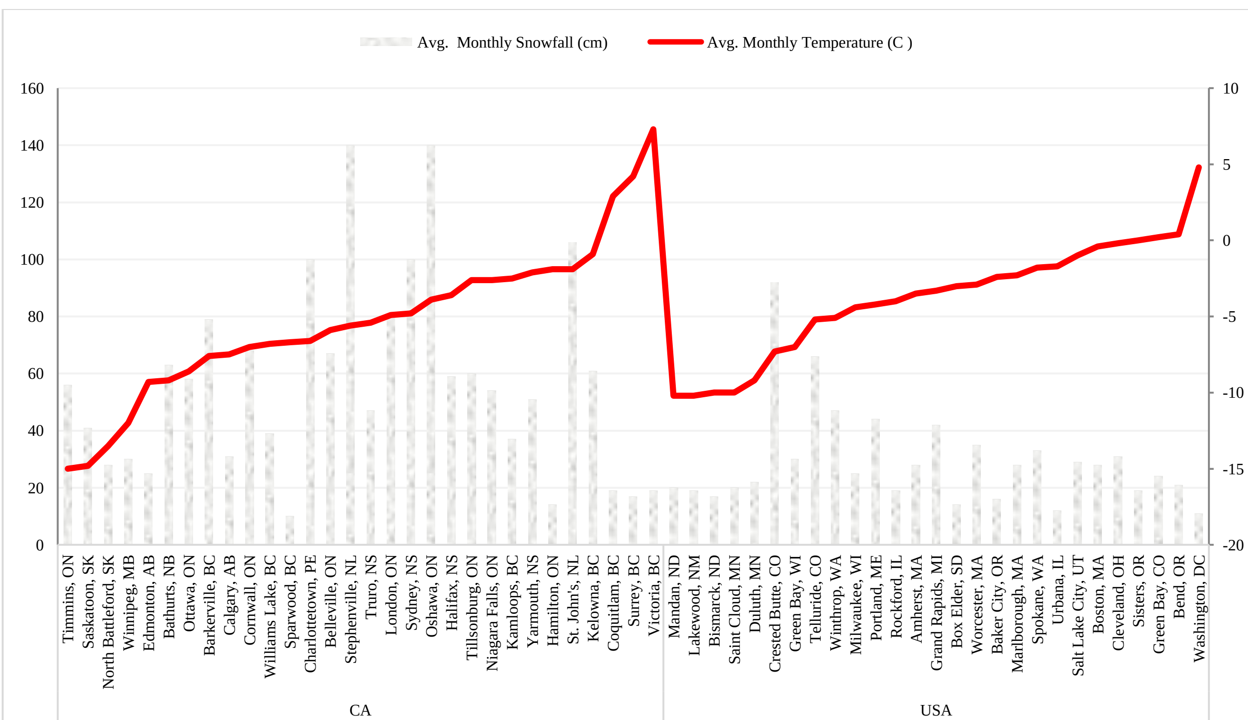

Figure 3: Average Monthly Snowfall and Air Temperatures in Respondent Cities (December, January, and February)

Summary of Major Findings:

- Approximately 65% of municipalities reported that Deicing - either plowing and salting or salting only is the main method of snow and ice control, whereas only 5% reported that they had performed anti-icing. Although anti-icing has been shown to be an effective strategy for minimising salt application rates and improving efficiency in maintenance operations, it has not been adopted widely for snow and ice control of parking lots and sidewalks.
- To prevent snow-pavement bonding, most municipalities reported that they performed plowing operations before total snow accumulation reaches 5cm (2 in).
- Despite the pressure to adopt environmentally friendly winter maintenance strategies, few municipalities had reported using materials other than ordinary road salts. No municipalities mentioned the usage of organic salts for parking lots and sidewalks. For the types of snow control chemicals being used, 65% of municipalities used regular sodium chloride, while 35% reported using other chloride based materials such as magnesium chloride. In addition, 16% of the respondents reported using abrasives (e.g., sand) for improving pavement surface friction.
- 64% of the municipalities indicated that regular dry sodium chloride was used for snow control while 36% used pre-wetted salts. 60% of the respondents who used pre-wetted salts reported using regular brine as a pre-wetting agent, while 30% used a magnesium chloride solution.
- Nearly half of the respondents indicated that they have no guidelines in determining the best application rate for parking lots during a given snow event. Some use the guidelines implemented for roadside maintenance, despite the fact that significant differences exist between roads and parking lots.

5. FIELD TESTS FOR DETERMINING OPTIMAL TREATMENT METHODS AND APPLICATION RATES

5.1. Test Site and Setup

A majority of the tests were conducted in Parking Lot C at the University of Waterloo, Ontario, Canada (Figure 4). The area of the parking lot is approximately 25,540 m^2 (6.31 acres). The parking lot contains approximately 900 parking stalls and eight driveways. Tests were conducted in multiple 10’x20’ (3m x 6m) test sections. These test sections possessed similar external conditions, such as pavement type, snow type, initial snow depth, and traffic conditions for any given snow event. During the day, this parking lot receives a large amount of traffic due to its convenient location next to the University.

A large numbers of field tests were also performed on the sidewalks and walkways around the University Waterloo. The sidewalks sections included regular concrete pavement, interlocking concrete paver, and asphalt pavement. To maintain similar weather conditions, test areas were selected such that they were within 500 m (1640’) of the parking lot. Figure 5 shows the setup of test area on a day when tests were conducted on a concrete pavement and an interlocked concrete pavement. The sidewalk test segments chosen were heavily used by pedestrians, cyclists, and maintenance vehicles. To obtain an overview of the usage of these sidewalks, pedestrian traffic was manually counted during the AM and PM peak hours for a week at the locations where most of the tests were conducted. The average AM pedestrian volume recorded was 374 pedestrians per hour across the test areas.

In addition to the field tests conducted on the University of Waterloo campus, a number of tests were completed at 50 external parking lots from around Central and Western Ontario (Figure 6) to enhance the understanding of maintenance operations of different parking lots. A total of six maintenance contractors participated in these tests; care was taken to include a large spectrum of contracting companies serving a diverse range of clientele and employing different types of maintenance equipment, and data was recorded using webcams, smart scales and a smartphone app developed by the iTSS lab.

Figure 4: Test Site – Parking Lot at the University of Waterloo

Figure 5: Test Site – Sidewalks Around the University of Waterloo

Figure 6: External Test Sites across Southern Ontario

5.2. Test Protocols

To ensure data reliability, all tests were conducted according to a common protocol. For Deicing tests, salts were applied manually on top of snow with application rates ranging from 5 to 70 lbs/1000sqft (24 to 342 g/m^2) based on the total snowfall, prevailing pavement surface temperature, and forecasted air temperature over the day, while anti-icing sections were salted before the event. A significant amount of training was conducted during the initial stage of field tests to ensure the highest possible uniformity in application. Moreover, each test section is approximately 10’x20’ (6m x 12m), a small area, to assist in achieving a high degree of uniformity. It should be noted that, in practice, the uniformity of salt spreading depends on the characteristics of the sprayer (e.g., manual rate setting vs. automatic rate control) and truck operational constraints (e.g., speed fluctuation) which remains an issue for investigation.

At the start of a test, a master event form was filled out with major information of the event, including start and end times of the snowfall, initial snow depth, snow type, density, and prevailing temperatures. To measure density, a 1m x 1m (3’ x 3’) area was sectioned off. The snow was then collected from this section and weighed to determine the snow density. An hourly data form was filled out at a fixed time interval including weather data, performance data (i.e., percentage of bare pavement over snow covered area) and contaminant type. The weather data was collected from Environment Canada’s nearest weather station and included air temperature, sky-view condition, humidity, wind speed, dew-point, and wind chill. Surface temperatures of the pavement and snow were measured on the pavement after removing patches of snow, and on top of the snow surface, respectively, using an infrared surface temperature reader. The event-based data collection form included the initial and final conditions of the tests, total snowfall over the event, as well as some processed data from the day, such as average temperatures for the event and pavement condition. Note that the data collection process was continued until every test section achieved the desired bare pavement. Figure 7 shows the major activities related to the field tests.

The tests were conducted over the winter seasons of 2011-2012, 2012-2013 and 2013-2014. In these testing seasons, there were about 100 snow events in total with pavement surface temperatures ranging from about -20 °C (-4 ºF) to 3 °C (37 ºF) and snow precipitation from about 0.2 cm to 22 cm (0.1 in to 9 in), as shown in Figure 8. Interestingly, these three winter seasons had different sets of weather conditions: the first season was very mild and contained a limited number of events (14 events in total); the second season contained average winter conditions for the region; and the last winter was extremely heavy, especially when the number of colder days is considered (over 15 events with temperatures below -15 °C (5 ºF)). Approximately 5000 tests were conducted using different salts and treatment methods, including tests with plowed and unplowed snow, with and without traffic, and in the stall areas, driveways and sidewalks. In order to closely simulate the way parking lot maintenance is performed in the real world, 60 to 70% of the test operations started between 3am and 7am. As indicated, a number of existing solid and liquid salts were tested. The key information of these salts is presented in Table 5-1 for solid salts and Table 5-2 for liquid salts.

Figure 7: Test Procedure

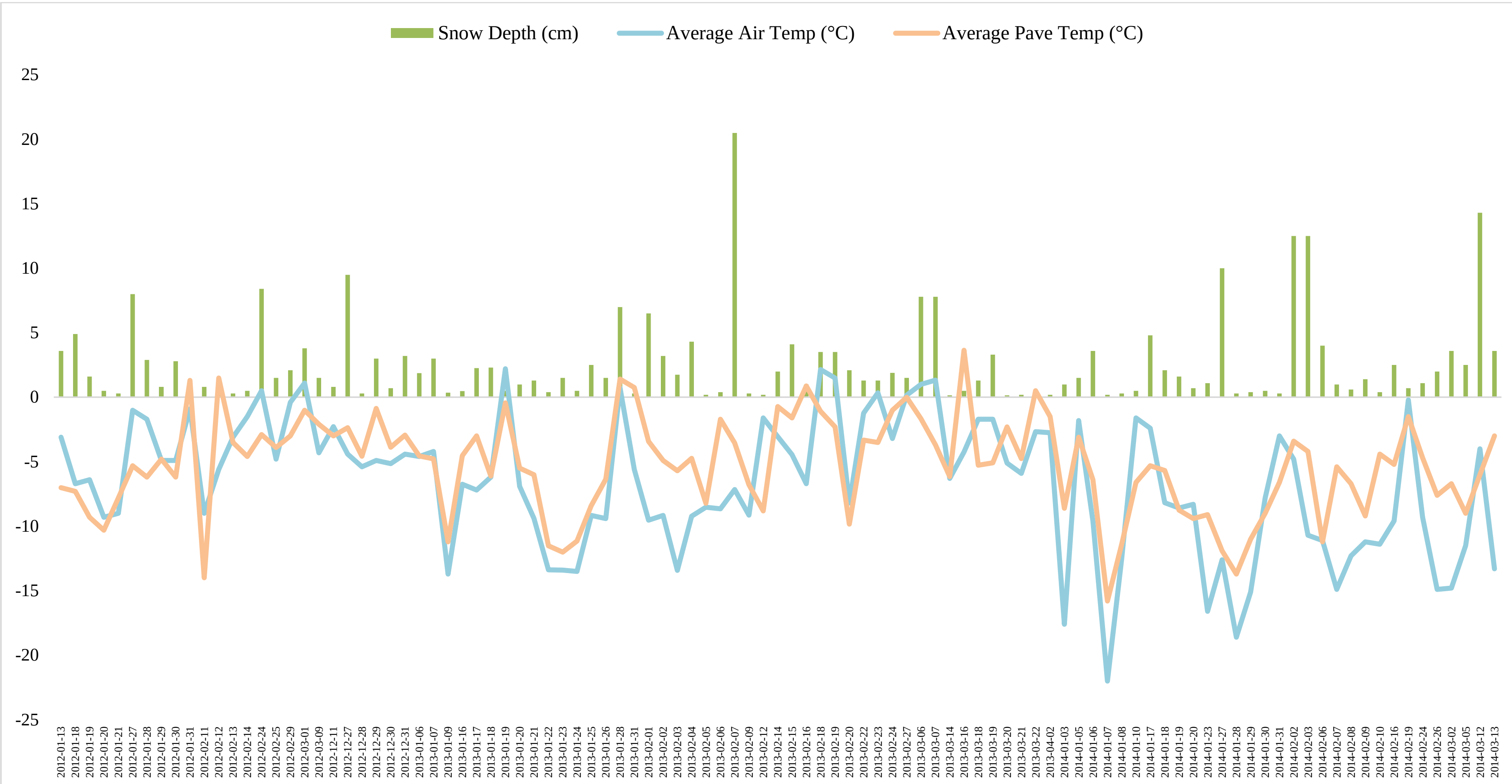

Figure 7: Winter Events Covered over 2012- 2014 Winter Seasons

Table 5-1: Solid Materials Tested				
Trade Name	**Composition***	**Effective Temp* ºC (ºF)**	**Cost ($/ton)***	**Photo**
Road Salt	Sodium Chloride	-10 (14)	80	
Blue Salt	Sodium Chloride Treated with Magnesium Chloride (Proportion not known)	-15 (5)	100	
Slicer	78% NaCl 9.4% $MgCl_2$ 2-3% and rest P/U	-25 (-13)	358	
Green Salt	Sodium Formate Treated with GEN3 runway Deicing fluid (Proportion not known)	-30 (-22)	950	
Jet Blue	Sodium Chloride Treated with proprietary polyol (Proportion not known)	-30 (-22)	495	

Table 5-2: Liquid Materials Tested

Trade Name	Composition*	Effective Temp* ºC (ºF)	Cost ($/L)*	Physical Look
Brine	23% NaCl 77% Water	-7 (19)	0.15	
Fusion 2350	12% NaCl 50% Degraded Beet Juice 38% P/U	-27 (-17)	0.30	
Snowmelt	15-20% Gylcerine 10-20% Polyether Polymer 3-8% Lactic Acid 2-4% Sorbitol 1-3% Formic Acid 1-3% Acetic Acid 1-2% 1,2-Butanediol Balanced with Water	-20 to -40 (-4 to -40)	0.29	
Caliber M1000	27% $MgCl_2$ 6% Carbohydrate 67% Water and P/U	-29.4 (-21)	0.40	

*Note: The information is based on product descriptions provided by the suppliers or found in the literature. An independent chemical analysis is being conducted by MOE at the request of TRCA and will be made available upon request. P/U stands for Propitiatory/Unknown.

6. SUMMARY OF THE FIELD TEST RESULTS

As mentioned in the previous section, a large number of tests were conducted in a real world environment covering different maintenance methods and salts under a wide range of winter conditions. Furthermore. Extensive exploratory analysis was then performed on the observational data with the goal of identifying the main factors (e.g., temperature, snow amount, application rate etc.) that affect the snow melting performance and snow melting speed (i.e., bare pavement recovery time – BPRT) of various chemical agents. The effectiveness of each individual treatment method was also assessed in the context of the friction level of the pavement surface after treatment was applied based on data collected in the field. This section highlights the important findings from our field tests.

6.1. Summary of Major Findings on Deicing Treatments

- Deicing treatments were conducted using regular rock salts, pre-wetted salts, and several semi to full organic salts such as Green Salts, Blue Salts, Jet Blue and Slicer described in the previous section. An analysis of the field data revealed that salt type, application rate, pavement temperature, snow amount and traffic volume are all statistically significant in influencing snow-melting speed/BPRT.
- It was observed that when the pavement surface temperature drops below -10 °C (14 ºF) the melting speed in sites treated with regular salts dropped substantially and took significantly longer to regain bare pavement.
- It was also observed that alternative products generally outperformed regular rock salt. The bare pavement regain time on the sections applied with these alternatives was approximately one hour shorter in average than those using rock salt.
- The alternatives tested also performed significantly better when pavement temperatures were below -5 °C (23 ºF). The BPRT reduction ranged from 1 to 5 hours, depending on application rates. One interesting characteristic of the alternative salts is that their snow-melting rate (i.e., bare pavement time reduction) differed by the application rate used.
- Pre-wetted salts were also evaluated alongside ordinary dry rock salt. In the tests conducted, same gross amounts of dry salt and pre-wetted salt were applied to the test sections. Since the pre-wetted salt mixture contains brine, its use means a reduction in the use of sodium chloride by approximately 20%. Despite this reduction, the pre-wetted salt and ordinary dry rock salt had similar performances and BPRTs in the tests conducted. Accordingly, the use of pre-wetted salt has the potential to reduce salt usage directly while still maintaining a comparable LOS.
- The effect of traffic was clearly observed in the field experiment with the test sections located in the driveways being more effective than those in the parking stalls. Quantitative evidence on the relative effect of traffic was subsequently obtained under various simulated traffic loads. The study concluded that to reduce salt usage while still achieving a desired level of service, different application rates should be applied for stall areas and driveways.
- From the tests conducted, it was also found that snow melting performance varied by pavement type. The tests conducted on asphalt concrete and Portland cement concrete revealed that snow melting speed is higher on asphalt concrete sections. A substantial amount of comparable tests were conducted on the two pavement types. From these sample tests, it was found mean snow melting speed on asphalt

concrete was 10% faster than Portland cement concrete. This difference was found to be statistically significant at a 95% confidence level.

- Between Portland cement concrete and interlocked concrete, the difference in melting speed was not found to be statistically significant.
- Snow melting performance models were developed and used to determine the minimum application rates and adjustments factors. Recommended application rates and adjustment factors are presented in the next section.

6.2. Summary of Major Findings on Anti-icing Treatments

- Anti-icing treatment tests were conducted using conventional chloride salts and some emerging organic products. These include regular salt, brine, Fusion, Snowmelt and Caliber M1000. It was found that all materials were highly effective in preventing the bonding of snow, i.e., improving friction levels. The average friction gain on the anti-icing sites over the control sites (without anti-icing treatments) varied from 10% to 70% depending on event conditions.
- The test results did not indicate statistically significant differences between the performance of organic products and chloride based salts. This finding has confirmed that the organic products are at least as effective as the regular products for anti-icing operations in addition to the advantage of being environmentally friendly.
- A relatively low application rate, for example, 5 lbs/1000sqft (24 g/m^2) for solid salts and 3 L/1000sqft (0.033 L/m^2) for regular brine, was found to be sufficient to achieve the main purpose of anti-icing operations.
- When comparing the performance of regular dry salt and brine, it was found that brine treated sites outperformed sites treated with regular salts when the total mass of sodium chloride applied was the same.
- The performance of anti-icing operations also depended on the characteristics of the snow event. For long and intense events, anti-icing operations were found to be ineffective in preventing the snow from bonding with the pavement. Anti-icing operations, when used as pre-application, were found to perform much better than after-application (Deicing) for light snow events.
- It was also observed that the effectiveness of anti-icing became much lower when the pavement temperature dropped below -10 ºC (14 ºF). This trend was observed for all the tested anti-icers.

7. QUICK GUIDE FOR OPTIMAL SNOW AND ICE CONTROLS

This section summarizes the major recommendations and guidelines that have been developed on the basis of an extensive literature review, two large-scale surveys, and a large number of field tests. These guidelines can help the maintenance industry responsible for snow and ice control of parking lots, sidewalks and transit platforms to optimize maintenance operations and minimize salt usage.

7.1. Set Appropriate Level of Service (LOS) Targets

Any maintenance program for a transportation facility starts with establishing the desired level of service (LOS) that should be delivered during winter events or the winter season. The desired LOS must be realistic and cost-effective due to the random nature of winter events. As a result, it is preferable that each LOS standard includes a probability quantifier. For example, MTO's Maintenance Quality Standards (MQS) designates that all Class I highways must reach bare pavement within 8 hours for 90% of the events over a season, i.e., the LOS requirement for Class I highway is 8 hrs. Standards of this type also make sense from the users' point of view, as it would understandably be too cost prohibitive to maintain a facility in a bare pavement condition at all times and under all types of events. Another consideration in setting LOS targets is the need to strike a balance between costs and benefits. An ideal LOS policy for a parking lot should take into account the types of snow events that are to be expected in the area where the site is located as well as the service demand of the parking lot/establishment type (e.g., shopping plaza, restaurants, emergency buildings etc.). As a result, it may make sense to have different LOS standards for different types of parking lots/sidewalk sections.

7.2. Select the Right Treatments and Application Rates

In responding to any upcoming event, maintenance operators must choose the right maintenance strategy such as anti-icing or deicing and the application rate for each treatment. If an anti-icing operation is to be implemented, solid or liquid salt should be selected on the basis of a business strategy and the expected event conditions. The recommended application rate should then be applied before the event begins. Because the purpose of anti-icing is to prevent bonding between the pavement and surface contaminant and to ease the plowing operations, it is not necessary to apply different application rates for different weather conditions. It should however be noted that anti-icing may not be effective and thus should not be recommended for some event conditions. Table 7-1 summarizes the key information required in anti-icing treatments.

For deicing operations, a number of weather conditions should be determined at the time of treatment. First, the average representative pavement surface temperature should be either measured using a portable infrared (IR) thermometer or estimated on the basis of air temperature and site conditions. Secondly, the type of snow and the total amount of the snow (depth) that is expected to accumulate during the event should be determined. The snow accumulation should include snow already present on ground in addition to the forecasted precipitation. Finally, the desired level of service should be determined in terms of bare pavement regain time, based on the LOS requirements of the facility. Table 7-2 provides the recommended base application rates derived on the basis of snow melting models developed using the field test data. It is important to note that these rates are highly aggregated, representing the average amount of salt needed for a given range of conditions as defined by these factors. They should therefore be adjusted according to actual conditions and requirements (as discussed in the following section - Section 7.3). More accurate application rates are provided in Appendix A. Note that when snow accumulation is more than 2 cm (0.8 in), snow need to be first plowed for best results in deicing treatment.

Table 7-1: Anti-icing Treatment Matrix for Best Results		
	With Liquid Salts[1]	**With Regular Solid Salt**
Lowest Practical Temperature	-7 °C (-19 °F)	-9 °C (-16 °F)
Event Conditions	Less effective for wet snow and heavy event	Less effective for dry snow and heavy event
Recommended Application Rate	3 L/1000sqft (0.032 L/m^2)	5 lbs/1000sqft (24 g/m^2)
Additional Treatments	To make most of the anti-icing operation, snow should be plowed timely. After the site is plowed, a low amount of salt could be applied subsequently to melt the remaining snow.	
Other Notes	Liquid salts are typically more effective than solid salt for anti-icing	

[1]Liquid salts tested were Brine, Caliber M1000, Snowmelt, and Fusion.

Table 7-2: Recommended Base Rates lbs/1000 sqft (g/m^2) for Deicing Treatment for upto 2 cm (0.8 in) snow			
Average Pavement Temp of the Event, ˚C (ºF)	**Bare Pavement Regain Time (hours)**		
	1 ~ 2	**3 ~ 4**	**5 ~ 6**
-1 to -3 (30 to 27)	15 (73)	6 (29)	4 (20)
-4 to -6 (25 to 21)	45 (220)	15 (73)	10 (49)
-7 to -9 (19 to 16)	85 (415)	35 (171)	20 (98)

7.3. Adjusting Salt Application Rates for Other Factors

The application rates provided in Table 7-2 are appropriate only for the base conditions and therefore must be adjusted when the actual conditions deviate from these base conditions. This section summarizes the adjustment factors developed on the basis of the field testing results.

1) Snow Type Adjustment Factor

The base application rates listed in Table 7-2 were determined for new snow with an average density in the range of 100 kg/m^3 (6 lb/ft^3). The base rates must therefore be adjusted according to snow density, which is captured by the snow-melting model (Hossian, Fu & Lu, 2014). For convenience of application, Table 7-3 gives the adjustment factor for some typical types of snow.

2) Traffic Adjustment Factor

Vehicular traffic is known to have a positive effect on the snow melting performance of salts. Our field tests under a wide range of controlled settings have provided quantitative evidence on the relative benefit of traffic. This means that lower amounts of salt are needed for parking lots with higher traffic volumes or areas of higher traffic in a given parking lot (e.g., driveways versus parking stalls). Table 7-4 shows the adjustment factors that were developed on the basis of the field test results (Hossain, Fu & Li, 2015). In combination with the base application rates presented in the Table 7-2, these traffic adjustment factor values can be used to determine the appropriate application rate for a specific facility of known traffic level. For example, under the same LOS requirement, a high traffic parking lot such as shopping plaza requires only 30% of the application rate of a facility with no vehicular traffic (e.g., sidewalk).

3) Pavement Type Adjustment Factor

Pavement type also affects the snow melting performance of salt, due to thermodynamic properties. Our field tests indicated that Portland cement concrete (PCC) and interlocked concrete requires approximately 20% more salt to achieve the same LOS as compared to an asphalt concrete pavement (Hossain, Fu, Li & Kabir, 2015). An adjustment factor is therefore recommended for a PCC or interlocked concreted pavement facility, as shown in Table 7-5.

4) Adjustment Factors for Pre-wetting

Pre-wetted salt has been shown to be more effective than regular dry salt in the road maintenance sector. This performance advantage of pre-wetting was also confirmed in our field study (Hossain, Fu, Li & Lamb, 2015). Based on our field test results, the application rates could be reduced by 20% if pre-wetted salt is applied, as shown in Table 7-6. It should be noted that the relative advantage of pre-wetting decreases as the precipitation intensity or the amount of snow to be melt increases.

5) Adjustment Factors for Alternative Salts

In this research, several alternative products were also tested for their relative performance as compared to regular rock salt. It was found that most of these alternatives had better snow melting performance than regular salt although their relative advantage varied widely (Hossain, Fu & Lake, 2014). Table 7-7 summarizes the recommended adjustment values for four different alternatives under three ranges of pavement temperatures.

Table 7-3: Adjustment for Snow Type	
Snow Type	**Adjustment Factor**
Loose snow (Density = ~75 kg/m^3) (5 lb/ft^3)	0.75
Regular fresh snow (Density = ~100 kg/m^3) (6 lb/ft^3)	1.00
Packed snow (Density = ~150 kg/m^3) (9 lb/ft^3)	1.50
Freezing rain and ice (Density = ~800 kg/m^3) (50 lb/ft^3)	8.00

Table 7-4: Adjustment for Different Traffic Loads	
Traffic Volume	**Adjustment Factor**
No vehicular traffic (e.g., stalls, sidewalks and platforms)	1.00
Low to Medium Traffic (10-50 veh/hr) (e.g., staff parking lots, restaurants)	0.45
High Traffic (50-70 veh/hr) (e.g., shopping plaza)	0.30

Table 7-5: Adjustment for Different Pavement Types	
Pavement Type	**Adjustment Factor**
Asphalt Concrete	1.00
Portland Cement Concrete (PCC)	1.20
Interlocked Concrete (IC)	1.20

Table 7-6: Adjustment Factor for Pre-wetting	
Salt Form	**Adjustment Factor**
Regular dry salt	1.00
Pre-wetted salt (with a recommended pre-wetting ratio of 20~30 % brine by weight)	0.80

Table 7-7: Adjustment Factors for Alternative Salts				
Average Pavement Temperature °C (ºF)	**Slicer**	**Blue**	**Green**	**Jet Blue**
-1 to -3 (30 to 27)	0.74	N/A	0.53	0.64
-4 to -6 (25 to 21)	0.79	N/A	0.52	0.68
-7 to -9 (19 to 16)	0.83	0.84	0.65	0.72

7.4. Guideline Application Example

This section provides a hypothetical example to illustrate how the recommended guidelines described in the previous section can be applied by the users to select the most appropriate snow and ice control methods and to determine the appropriate application rates under the specific site and event conditions.

Site and Event Description

A contractor is hired to provide winter maintenance service for an 8000 sqft (743 m^2) parking lot at a shopping plaza. The parking lot has an asphalt pavement and its required level of service is essentially bare pavement with a maximum bare pavement regain time of 2 hours for majority of the events. A snow storm is forecasted with the following event characteristics:

- Total snowfall = 4 cm (1.6 in)
- Average air temperature = -4 ºC ~ -6 ºC (25 ºF ~ 21 ºF)
- Expected start and end time: 3am~11am

The following is a sequence of decisions that could be made following the proposed guidelines:

Step 1: Decide on whether or not to perform anti-icing or pre-application and if so what should be the application form, rate and time.

Because of the high LOS requirement of the parking lot, anti-icing is recommended for facilitating the subsequent plowing and deicing operations. Based on the anticipated air temperature, regular rock salt with the recommended application rate of 5 lbs/1000sqft (24 g/m^2) should be applied. The total amount of salt needed to cover the whole parking lot is 40 lbs (18 kg) (8000 sqft x 5 lbs/1000sqft) (743 m^2 x 24 g/m^2). The salt can be applied at any time before the event starts (3am).

Step 2: Decide on plowing and deicing operations

The event is expected to start around 3am and continue until 11am, which means that there will be noticeable accumulation by the time when the shopping plaza opens (9am). Assume that, to meet the service requirements, the contractor would decide to start plowing operation at 7am and then treat the site with salt, which should be done by 8am. The question is: how much salt should be applied, or what should the appropriate application rate? To determine the optimal application rate, the following information is collected:

- Pavement temperature: ~-6 (~21 ºF) measured by a portable IR thermometer
- Snow/ice remaining on the pavement surface after plowing: 0.5 cm (0.2 in)
- Anticipated future snow fall: 1.5 cm (0.6 in)
- Bare pavement regain time: 2 hour
- The contractor will not return to the site, which means all accumulated snow must be melted off by salt

From Table 7-2, we can obtain the base application rate of 15 lbs/1000sqft (73 g/m^2). The base rate needs to be adjusted to account for the busy traffic with $f_{traffic}$ = 0.30. The final application rate for the driveways is therefore 4.5 lbs/1000sqft (22 g/m^2). The total amount of salt needed for the whole parking can be decided on the basis of the arear of the total driveways.

8. TECHNICAL PAPERS FROM THIS RESEARCH

Fu, L., Omer, R., Hossain, S. M. K. & Jiang, C. (2012). Experimental Study of Snow-Melting Performance of Salt for Snow and Ice Control of Parking Lots. *Paper no 13-1507, Proceedings of the 92nd Annual General Meeting of the Transportation Research Board, Washington D.C., January 2013.*

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Hossain, S. M. K., Fu, L. & Law, B. (2014). Parking Lots and Sidewalks under Winter Snow Events: Classification, Friction Characteristics, and Slipping Risk. *Paper no-14-4909, Proceedings of the 93rd Annual General Meeting of the Transportation Research Board, Washington D.C., January 2014.*

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Hossain, S. M. K., Fu, L., Li, D. T. & Kabir, S. (2015). Snow Melting Performance of Salt: Effect of Pavement Types. *Paper accepted for presentation at the 94th Annual Meeting of the Transportation Research Board, Washington D.C., January 2015.*

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Work-in-Progress Papers

Hossain, S. M. K. & Fu, L. (2014). Modeling Active Mode Choice for Making Short Trip in Winter Months. *iTSS lab, University of Waterloo, Ontario, January 2015.*

Hossain, S. M. K., Fu, L. & Johnson, M. (2014). A Simplistic Way to Predict Winter Pavement Temperature. *iTSS lab, University of Waterloo, Ontario, January 2015.*

Hossain, S. M. K., Fu, L. & Johnson, M. (2014). How Salt Particle Size Matters in Snow Melting. *iTSS lab, University of Waterloo, Ontario, January 2015.*

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APPENDIX A

This appendix provides the optimal application rates for specific site and event conditions. Compared to Table 7-2, these rates are of a much higher granularity and thus should be used when accurate information on site and weather conditions is available.

Table A-1: Application Rates for Stall Areas lbs/1000 sqft (g/m^2)

Stall		**Application Rate for Desired LOS in BPRT (hr)**					
Snow depth cm (in)	Avg Tp ˚C (ºF)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	6 (29)	3 (15)	2 (10)	1 (5)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	17 (83)	9 (44)	6 (29)	4 (20)	3 (15)	3 (15)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	35 (171)	18 (88)	12 (59)	9 (44)	7 (34)	6 (29)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	19 (93)	9 (44)	6 (29)	5 (24)	4 (20)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	58 (283)	29 (142)	19 (93)	14 (68)	12 (59)	10 (49)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	117 (571)	59 (288)	39 (190)	29 (142)	23 (112)	20 (98)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	38 (186)	19 (93)	13 (64)	9 (44)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	115 (562)	58 (283)	38 (186)	29 (142)	23 (112)	19 (93)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	235 (1147)	117 (571)	78 (381)	59 (288)	47 (230)	39 (190)

Table A-2: Application Rate for Driveways (Low Traffic-Parking Lot) lbs/1000 sqft (g/m^2)

Driveway (Low)		**Application Rate for Desired LOS in BPRT (hr)**					
Snow depth cm (in)	Avg Tp ˚C (ºF)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	3 (15)	1 (5)	1 (5)	1 (5)	1 (5)	0 (0)

0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	8 (39)	4 (20)	3 (15)	2 (10)	2 (10)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	16 (78)	8 (39)	5 (24)	4 (20)	3 (15)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	8 (39)	4 (20)	3 (15)	2 (10)	2 (10)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	26 (127)	13 (64)	9 (44)	6 (29)	5 (24)	4 (20)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	52 (254)	26 (127)	17 (83)	13 (64)	10 (49)	9 (44)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	17 (83)	8 (39)	6 (29)	4 (20)	3 (15)	3 (15)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	51 (249)	26 (127)	17 (83)	13 (64)	10 (49)	9 (44)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	104 (508)	52 (254)	35 (171)	26 (127)	21 (103)	17 (83)

Table A-3: Application Rate for Driveways (Medium Traffic-Parking Lot) lbs/1000 sqft (g/m^2)

Driveway (Medium)		**Application Rate for Desired LOS in BPRT (hr)**					
Snow depth cm (in)	Avg Tp ˚C (ºF)	1	2	3	4	5	6
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	2 (10)	1 (5)	1 (5)	1 (5)	0 (0)	0 (0)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	7 (34)	3 (15)	2 (10)	2 (10)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	13 (64)	7 (34)	4 (20)	3 (15)	3 (15)	2 (10)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	7 (34)	4 (20)	2 (10)	2 (10)	1 (5)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	22 (107)	11 (54)	7 (34)	5 (24)	4 (20)	4 (20)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	45 (220)	22 (107)	15 (73)	11 (54)	9 (44)	7 (34)

1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	14 (68)	7 (34)	5 (24)	4 (20)	3 (15)	2 (10)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	44 (215)	22 (107)	15 (73)	11 (54)	9 (44)	7 (34)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	89 (235)	45 (220)	30 (147)	22 (107)	18 (88)	15 (73)

Table A-4: Application Rate for Driveways (High Traffic-Parking Lot) lbs/1000 sqft (g/m^2)

Driveway (High)		**Application Rate for Desired LOS in BPRT (hr)**					
Snow depth cm (in)	**Avg Tp ˚C (ºF)**	**1**	**2**	**3**	**4**	**5**	**6**
0.1 to 0.5 (0.04 to 0.2)	-1 to -3 (30 to 27)	2 (10)	1 (5)	1 (5)	0 (0)	0 (0)	0 (0)
0.1 to 0.5 (0.04 to 0.2)	-4 to -6 (25 to 21)	6 (29)	3 (15)	2 (10)	1 (5)	1 (5)	1 (5)
0.1 to 0.5 (0.04 to 0.2)	-7 to -9 (19 to 16)	12 (59)	6 (29)	4 (20)	3 (15)	2 (10)	2 (10)
0.5 to 1.5 (0.2 to 0.6)	-1 to -3 (30 to 27)	6 (29)	3 (15)	2 (10)	2 (10)	1 (5)	1 (5)
0.5 to 1.5 (0.2 to 0.6)	-4 to -6 (25 to 21)	19 (93)	10 (49)	6 (29)	5 (24)	4 (20)	3 (15)
0.5 to 1.5 (0.2 to 0.6)	-7 to -9 (19 to 16)	39 (190)	19 (93)	13 (64)	10 (49)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-1 to -3 (30 to 27)	12 (59)	6 (29)	4 (20)	3 (15)	2 (10)	2 (10)
1.5 to 2.5 (0.6 to 1)	-4 to -6 (25 to 21)	38 (186)	19 (93)	13 (64)	10 (49)	8 (39)	6 (29)
1.5 to 2.5 (0.6 to 1)	-7 to -9 (19 to 16)	78 (381)	39 (191)	26 (127)	19 (93)	16 (78)	13 (64)