Effectiveness of Pre-wetting Strategy for Snow and Ice Control on Highways

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ABSTRACT

Maintaining bare pavement conditions under winter storms is critical to the safe and expedient flow of road traffic in Canada. One of the principal snow and ice control methods is the application of salt. While salt remains to be the most cost-effective de-icer for road maintenance, its excessive use may have a detrimental effect on the environment and highway infrastructure. Improved maintenance techniques such as pre-wetting and direct liquid application (DLA) have therefore gained increasing popularity as a means of reducing the quantity of salt used. Past research has indicated that, while pre-wetted salt generally outperforms dry salt for snow removal, its effectiveness depends on the types and proportion of pre-wetting agents used and the road weather conditions under which it is applied. The primary objective of this research is therefore to investigate the effectiveness of different pre-wetting techniques under specific road weather conditions. The ultimate goal of this effort is to identify the optimal pre-wetting design (e.g. pre-wetting agent and ratio) for particular ranges of road weather conditions. Data collected by Ontario Ministry of Transportation (MTO) through a large scale field experiment called De-icing/Anti-icing Response Treatment (DART) was used in this analysis. This data consisted of measurements on snow cover, weather and pavement conditions, and treatment operations at 10-minute intervals over two winter seasons. The paper details an analysis of the snow melting trends on the test road under various road weather conditions and treatments, and summarizes the major findings related to the effects of pre-wetting chemical, pre-wetting ratio, and application rate.

INTRODUCTION

Modern highway systems play an important role in the maintenance and growth of the Canadian economy by facilitating the efficient movement of people, raw materials, components, and goods from origins to desired destinations. Thus, maintenance of bare pavement conditions on highways during or soon after winter storms is critical to maintaining the economic flow of traffic. Accumulation of winter contaminants such as frost, slush, snow and ice reduces traffic flow and increases the risk of accidents on highways by reducing the average friction level and increasing the variance of traction between the vehicle tires and the pavement [13]. Conventionally the contaminants are removed by plowing followed by the application of granular rock salt. However, by the 1970's many highway operators recognized that the application of salt had adverse effects on highway infrastructure, vehicles and the roadside environment [11], and improved application methods were developed to reduce the overall quantities of salt needed. Principal among these is the use of liquid salts, either as an additive to conventional rock salt (pre-wetting) or applied on its own in advance of snow accumulation (Direct Liquid Application) [6, 8].

Pre-wetting is a technique which coats the surface of salt particles with water or chemical agents to accelerate the process of melting snow and ice. This initial liquid coating also helps salt particles adhere better to pavements than dry salt. Pre-wetting salt has been widely accepted as an effective technique for improving the de-icing capability of salt because it accelerates the start of the melting process by directly providing the necessary initial moisture, and it also assists salt particles to adhere to the pavement. The pre-wetting of salt is a tool advocated by the Salt Institute, the Transportation Association of Canada, and Environment Canada as a recognized best management practice [4, 14, 15]. It is however largely unknown how much more effective pre-wetted salt is over regular dry salt. This analysis attempts to shed some light on this question using the data from the DART test.

While these improved methods have been widely implemented, assessment of their performance in comparison with conventional rock salt, and estimation of the overall potential for salt reduction, is an unresolved issue because their effectiveness is influenced by a large number of uncontrolled variables during winter maintenance operations. The primary objective of this research is to quantify and compare the effectiveness of rock salt with and without pre-wetting liquid and possibly identify the optimal pre-wetting design under specific road weather conditions. This research involves a statistical analysis of data collected by the Ministry of Transportation of Ontario (MTO) through a large scale field experiment called De-icing/Anti-icing Response Treatment (DART) [12]. First an overview of the test sites and the data collected from the tests is discussed and this is followed by a case by case comparison of pre-wetted salt versus dry salt used for snow control. Lastly, conclusions are summarized and future research directions are highlighted.

DESCRIPTION OF STUDY SITE AND DATA

The data used in this analysis were collected at the DART field site by MTO forces in the winter seasons of 2001-2002 and 2002-2003. The test site is a 50 kilometre maintenance route on Highway 21 located in the Great Lakes-St. Lawrence climatic region of south-western Ontario, Canada (Figure 1). Due to its proximity to Lake Huron and Georgian Bay, the route is subjected to frequent lake effect snowfall with normal winter snow accumulation of 2.8 m over 75-80 snowfall days. The mean daily temperature (MDT) at this area is below $0^{o}C$ for the period from December through March and the coldest month is January with a MDT of $-7^{o}C$. The topography of the route comprises of rolling farmlands and woodlots with a combination of open and sheltered terrain [12].

Highway 21 is a Service Class 2 highway with an average daily traffic volume of 2,000~6,000 vehicles per day during a winter season, which required ploughing when snow accumulation was 20 mm and recovery of bare pavement within eight hours after a storm [12]. A 42 km segment of the 50 km test route was divided into eight sections, labelled sequentially from #1 to #8, with lengths varying between 2 to 9 kilometres as shown in Figure 1. Sections #1 to #7 are two-lane, two-way highways while section #8 is a 4-lane collector with 2 lanes in each direction. All sections are paved with asphalt concrete.

Different chemical application protocols, varying by material type, application rate and application method, were tested. The pre-wetting chemicals included near-saturation solutions of $CaCl_2$ (calcium chloride brine with corrosion inhibiting additives marketed as Corguard), and $MgCl_2$ (magnesium chloride brine with corrosion inhibiting additives marketed as Freezeguard). All tests were conducted as part of the normal winter maintenance operations while the highway was open to traffic. All test sections were plowed prior to chemical application, and chemicals or winter sand was re-applied if the surface was not cleared within the maintenance circuit time of approximately 1.5 hours. Each pass of the plow or spreader across each test section was recorded either manually or with an Automated Vehicle Location (AVL) system, providing records of the time and direction, chemical type and application rate [12].

A video surveillance camera was installed near the center of each test section to record pavement snow coverage at a pavement marking grid that divided the pavement into 3 consecutive, 1.3 m squares across each lane. Snow cover fraction, defined as the fraction of area covered by snow (0.0-1.0), was estimated visually from the recorded video and tabulated for each square at a 10-minute interval over the duration of a storm event.

Air and pavement temperature, wind speed, and precipitation were obtained from a Road Weather Information System (RWIS) station located at Allenford (Figure 1). Daily snowfall was obtained from the nearest Environment Canada observing stations and was used to estimate snowfall rate during each storm (total snowfall divided by storm duration). Storm duration was defined as the time from onset of snow accumulation until the restoration of bare pavement (<=5% snow cover).

Data from all test sections covering both winter seasons were used in this study with three exceptions due to unavailable data, including Sites #2 and #8 for 2001-2002 and Site #4 for 2002-2003. Each direction of a highway section is considered as a separate analysis unit and the snow cover measurements at all test sections were post-processed to determine the average snow cover in each direction. Preliminary analysis showed that there were significant differences in snow cover between the three observation blocks across the lanes in Sections #1 to #7, likely due to the effect of blowing snow. For example, the snow cover along the right wheel track was several times higher than the snow cover along the left wheel track. To avoid bias due to across-lane variation in snow cover, only the middle grid block of the lane was considered in calculating the average snow cover of Sections #1 to #7 while data from all three blocks were used for Section #8 (Each direction of Section #8 was divided into three observation blocks even though the highway at this section consists of two lanes in each direction).

A total of 15 and 17 storms were recorded during the winter seasons of 2001-2002 and 2002-2003, respectively, with average snowfall rate in the range of 0.01~3.53 centimetres per hour. Different chemical protocols were used, with dry rock salt and fine gradation salt applied at rates varying from 50 to 85 kilograms per lane kilometre, and the granular rates for pre-wetted salt ranged from 37 to 90 kilograms per lane kilometre. Two pre-wetting agents, namely, $CaCl_2$ and $MgCl_2$ were applied at 7 or 15% of the granular mass in 2002-2003 and $MgCl_2$ was applied at a rate of 38% in 2001-2002. The rock salt used conformed to MTO standard specification [3] which specifies at least 96% by mass sodium chloride, 100% smaller than 9.5 mm sieve and maximum 65% passing 2.36 mm sieve. The gradation is similar to coarse sand. Fine salt consisted of 100% grains smaller than 4.75 mm and at least 35% smaller than 1.18 mm.

Winter sand was applied to provide immediate traction when snow could not be removed by plowing or salting. It was pre-mixed with granular salt at a rate of 5% by mass to prevent stockpile freezing and is referred to as dry sand to distinguish it from sand that was pre-wetted with chemical agents in some tests. A sand/salt mix consisting of 20% by mass of rock salt was also used during the tests. The spreaders discharged material from the left side of the hopper between the front and rear wheels. Spreading speeds are specified by Maintenance Best Practice #702 as 32-48 km/h and during operations speed was adjusted to maintain a constant centreline windrow spreading pattern.

COMPARATIVE ANALYSIS

This section presents the results of a comparative analysis on the effectiveness of pre-wetted salt application protocols on snow removal versus that of a protocol using dry salt. Data obtained at the test sections described previously were used in this analysis. The performance of a treatment is measured by the fraction of pavement covered by snow (snow cover). Two measures of effectiveness were used:

- Change in snow cover over time
- Average snow cover

The first measure – change in snow cover was evaluated visually by graphing snow cover against time. Average snow cover is used as a surrogate for level of service (LOS) achieved by each particular chemical application protocol. It is calculated as the average of all snow covers measured over the snow storm, starting from the first chemical application to the end of the storm (or the end of the observation period). A lower value of average snow cover can be translated as a higher LOS experienced by drivers.

To ensure the validity of the comparative analysis, each comparison is formed with cases that had similar storm characteristics, location and traffic. For example, in comparing the effectiveness of pre-wet salt and dry salt, we should select cases in which the two types of materials are applied with similar amount (dry rates) to the similar highway sections (e.g. geographical features) under similar weather conditions. In the case that differences did exist, we provide a detailed description of these differences. Pair-wise comparisons of pre-wetted salt versus dry salt were done for both winter seasons and are detailed in the following section.

Data from the DART tests for two winter seasons, 2001-2002 and 2002-2003 were used for the intended comparison. The two winter seasons experienced a noticeable difference in daily snowfall, pavement temperature, and humidity levels as shown in Table 1. A total of twenty cases, eleven from winter season 2001-2002 and nine from winter season 2002-2003, were identified and are shown in Tables 2 and 3 respectively. The temporal variation of snow cover for two example cases is shown in Figure 2. Tables 2 and 3 also have the relative effectiveness of pre-wetted salt over dry and visual representations for both seasons are provided in Figures 3 and 4.

Based on the results shown in Tables 2 and 3, and Figures 2 to 4 we can observe that pre-wetted salt was less effective than dry salt in reducing average snow cover during the 2001-2002 winter season (eight out of eleven cases with improvements ranging from -93.5% to -8.3%), but outperformed dry salt in 2002-2003 (six out of nine cases with improvements ranging from 14.8% to 37.9%). This contradiction in the results is unexpected since most literature confirms the benefit of the pre-wetting strategy [e.g. 5, 8]. However, the differences in conditions between the two winter seasons as shown in Table 1 can be used to explain the conflicting effectiveness for pre-wetted salt with support from relevant literature [e.g. 1, 7].

The following are possible explanations why pre-wetted salt was outperformed by dry salt during the winter season of 2001-2002 and the opposite was observed in 2002-2003:

- Pavement temperatures during the snow storms of 2001-2002 were relatively high (>-6.0^oC) compared to 2002-2003 (<-6.0^oC). It is well known that dry salt is an effective de-icer up to -7.0^oC [6, 8];

- Initial moisture necessary to trigger dry salt into a solution was readily available through high total daily snowfalls (>5.0 cm) combined with high humidity levels

(>85%) during snow storms in 2001-2002. Ketcham et al. (1996) stated that dry NaCl can absorb moisture from air at a relative humidity of 76% or higher; and

- The dilution potential of pre-wetted salt under high intensity snowfalls could reduce it's effectiveness for snow removal over time. Blackburn et al. (2004) developed guidelines for snow and ice control based primarily on the dilution potential of different winter precipitation events of varying intensity. Since pre-wetting salt accelerates the solution process it theoretically has a higher potential for dilution than dry salt. As a result, the higher pre-wetting ratio used in 2001-2002, combined with high temperatures, may have contributed to high dilution.

A combination of the three points listed above is what probably influenced dry salt to outperform pre-wetted salt during 2001-2002 since an almost opposite scenario of weather and pavement conditions were experienced during 2002-2003. Random measurement errors for snow cover estimated from the surveillance video data could influence the results obtained; this effect is however expected to be minimal as the amount of data we used is sufficiently large to smooth out most of these measurement errors. Another factor which may have impacted the results is the variation in traffic intensity across the test sections. While the traffic volume along the test road is quite uniform, further research is needed to understand the combined effects of salt and traffic with detailed traffic data.

CONCLUSIONS

Determining the relative effectiveness of the pre-wetting strategy and the conditions under which it is most effective is a challenging goal due to in the uncontrollable observational environments such as weather, traffic and location. This research has made an attempt to compare the effects of treatments involving pre-wetting of salt. A systematic statistical analysis was performed on the observational data with the goal of identifying quantitative effects of weather and maintenance operations on snow melting trend. The following is a list of major conclusions and findings obtained from this analysis:

- It was observed that the performance of pre-wetted salt appears to be dependent on the pre-wetting ratio used and the existing pavement and weather conditions. Pre-wetted salt was outperformed by dry salt in most test cases by a reduction in snow cover from -8.3% to -93.5% during 2001-2002 but in 2002-2003 pre-wetted salt was more effective with improvement in snow cover reduction from 14.8% to 37.9%. In 2001-2002 pre-wetting ratios of 15 and 38% by mass were used to treat pavements subjected to heavy snowfall (>5.0cm) at temperatures within the effective range of dry rock salt (>-7^{o}C). The opposite conditions were experienced in 2002-2003 with low temperatures (<-6^{o}C) and light to moderate snowfall (<5.0cm), and the pre-wetting ratios used were 7 and 15% by mass. This seems to suggest that pre-wetting is not necessary during heavy snowfall and at relatively high pavement temperatures and a low pre-wetting ratio is preferable if pre-wetted salt is used under these conditions.

- The identification of an optimal pre-wetting ratio was not possible for the two distinct prevailing conditions since the 7% ratio was not tested in 2001-2002 and the 38% ratio was not tested in 2002-2003.

- The potential of the comparative analysis framework used in this study is positive for quantifying the effectiveness of alternative chemical application protocols used in snow control. It provides a sound methodology for comparing the performance of alternative treatments under an environment with uncontrollable climatic and pavement conditions.

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Table 1: Summary of Observations for Winter Seasons 2001-2002 and 2002-2003

Winter Season	Number of Storms[1]	Total Snowfall (cm)	Snowfall Rate (cm/hr)	Application Protocols
2001-2002	15	0.2~30.0	0.03~3.53	- Dry Rock Salt; - Rock Salt Pre-wetted with $MgCl_2$ @ 38% - Sand, Sand/Salt Mix (20% Salt) - Pre-wetted Sand and Sand/Salt Mix with 38% $MgCl_2$
2002-2003	17	0.2~25.0	0.01~3.33	- Dry Rock and Fine Salt - Rock and Fine Salt Pre-wetted with $CaCl_2$, NaCl and $MgCl_2$ @ 7 and 15% - Sand, Sand/Salt Mix (20% Salt); - Pre-wetted Sand and Sand/Salt Mix with 7 or 15% $CaCl_2$ and $MgCl_2$

[1] Only storms with available total daily snowfall from Environment Canada’s weather stations were used in this study.

Table 2: Summary of Treatment Cases and Effectiveness: Pre-wetted Salt vs. Dry Salt for 2001-2002

Case #	Date of Event	Weather and Surface Conditions [a]	Chemicals and/or Abrasives Used [b]		LOS [c]		Relative Effectiveness of Pre-wetted Salt (%)
			Pre-wetted Salt and/or Sand with $MgCl_2$	Dry Salt and/or Sand	Pre-wetted Salt	Dry Salt	
1	1/17/2002	20.0 cm (8.0 hrs) -0.3 °C (21.9 kph)	- 5E - Rock salt 70 kg/lane-km at 15% [d] (2/2) - Rock salt 65 kg/lane-km (1/0) [e]	- 4E - Rock salt 70 kg/lane-km (2/2) - Rock salt 65 kg/lane-km (1/0) [e]	0.20	0.22	9.1%
2	1/17/2002	20.0 cm (8.0 hrs) -0.3 °C (21.9 kph)	- 6E - Rock salt 70 kg/lane-km at 15% (2/2) - Rock salt 65 kg/lane-km (1/0) [e]	- 7E - Rock salt 70 kg/lane-km (2/2) - Rock salt 65 kg/lane-km (1/0) [e]	0.20	0.27	25.9%
3	1/17/2002	20.0 cm (8.0 hrs) -0.3 °C (21.9 kph)	- 6W - Rock salt 70 kg/lane-km at 15% (2/1) - Rock salt 65 kg/lane-km (1/0)	- 7W - Rock salt 70 kg/lane-km (2/0) - Rock salt 65 kg/lane-km (1/0)	0.44	0.33	-33.3%
4	1/18/2002	10.0 cm (8.0 hrs) -3.0 °C (24.5 kph)	- 5E - Rock salt 70 kg/lane-km at 38% (1/2) - Rock salt 65 kg/lane-km (1/0) [e]	- 4E - Rock salt 70 kg/lane-km (1/2)	0.52	0.48	-8.3%
5	1/18/2002	10.0 cm (8.0 hrs) -3.0 °C (24.5 kph)	- 6E - Rock salt 70 kg/lane-km at 38% (1/2) - Rock salt 65 kg/lane-km (1/0) [e]	- 7E - Rock salt 65 kg/lane-km (1/2) - Rock salt 65 kg/lane-km (1/0) [e]	0.55	0.38	-44.7%
6	2/1/2002	10.0 cm (10.0 hrs) -2.9 °C (13.9 kph)	- 6E - Rock salt 65 kg/lane-km at 38% (3/0)	- 7E - Rock salt 65 kg/lane-km (3/0)	0.33	0.21	-57.1%
7	2/2/2002	10.0 cm (7.5 hrs) -3.1 °C (2.3 kph)	- 5E - Rock salt 65 kg/lane-km at 38% (1/2)	- 3E - Rock salt 65 kg/lane-km (1/2)	0.27	0.14	-92.8%
8	2/2/2002	10.0 cm (7.5 hrs) -3.1 °C (2.3 kph)	- 5W - Rock salt 65 kg/lane-km at 38% (1/1) - Sand/Salt Mix 270 kg/lane-km at 38% [d] (1/0)	- 3W - Rock salt 65 kg/lane-km (1/1) - Sand/Salt Mix 270 kg/lane-km (1/0)	0.19	0.30	36.7%
9	2/3/2002	30.0 cm (8.5 hrs) -1.2 °C (25.1 kph)	- 5W - Rock salt 65 kg/lane-km at 38% (1/1) - Sand/Salt Mix 270 kg/lane-km at 38% (1/0)	- 3W - Rock salt 65 kg/lane-km (1/0) - Sand/Salt Mix 270 kg/lane-km (1/0)	0.60	0.31	-93.5%
10	2/4/2002	10.0 cm (8.0 hrs) -5.1 °C (27.4 kph)	- 6W - Rock salt 65 kg/lane-km at 38% (1/0) - Sand/Salt Mix 270 kg/lane-km at 38% (2/0)	- 7W - Rock salt 65 kg/lane-km (1/0) - Sand/Salt Mix 270 kg/lane-km (2/0)	0.51	0.44	-15.9%
11	2/26/2002	15.0 cm (8.5 hrs) 0.3 °C (14.4 kph)	- 6W - Rock salt 50 kg/lane-km at 38% (2/0) - Sand/Salt Mix 148 kg/lane-km at 38% (1/0)	- 7W - Rock salt 50 kg/lane-km (2/0) - Sand/Salt Mix 148 kg/lane-km (1/0)	0.19	0.13	-46.1%

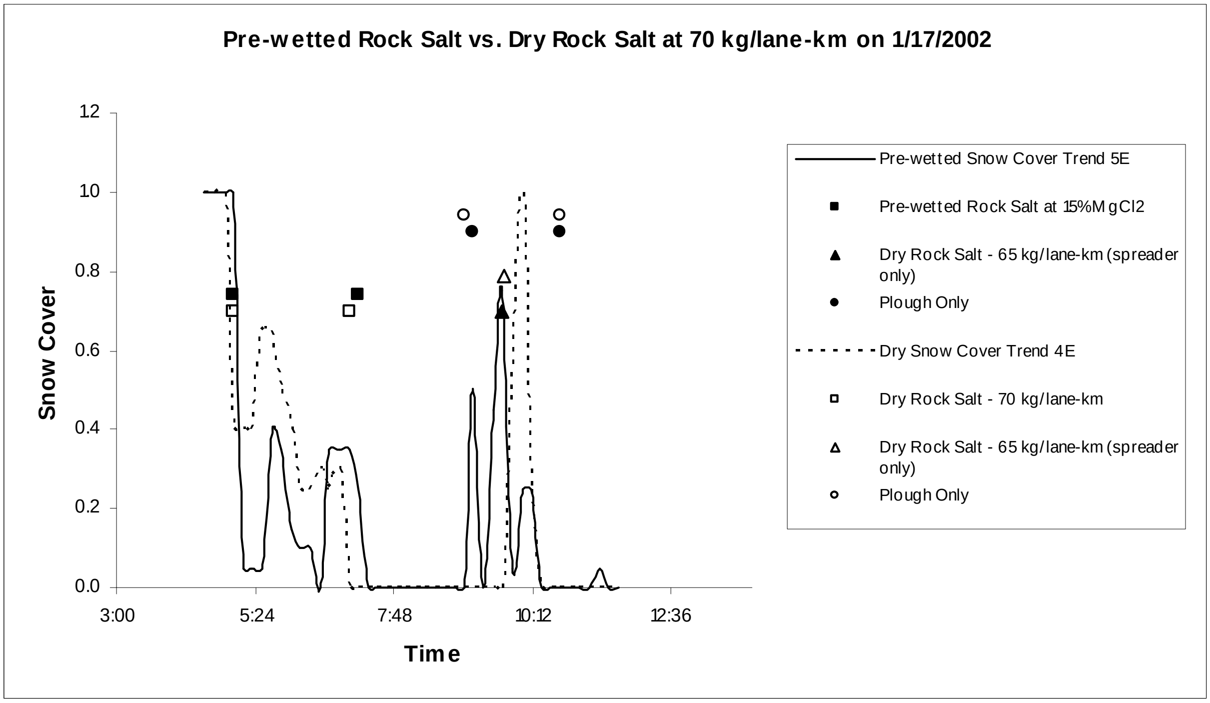
[a] total daily snowfall (storm duration)/average pavement temperature (average wind speed); [b] site/material/granular application rate in kg/lane-km (number of applications runs plus plow/plow only runs); [c] average snow cover; [d] percentage of $MgCl_2$ added to granular mass; [e] Application broadcasted from opposite lane.

Table 3: Summary of Treatment Cases and Effectiveness: Pre-wetted Salt vs. Dry Salt for 2002-2003

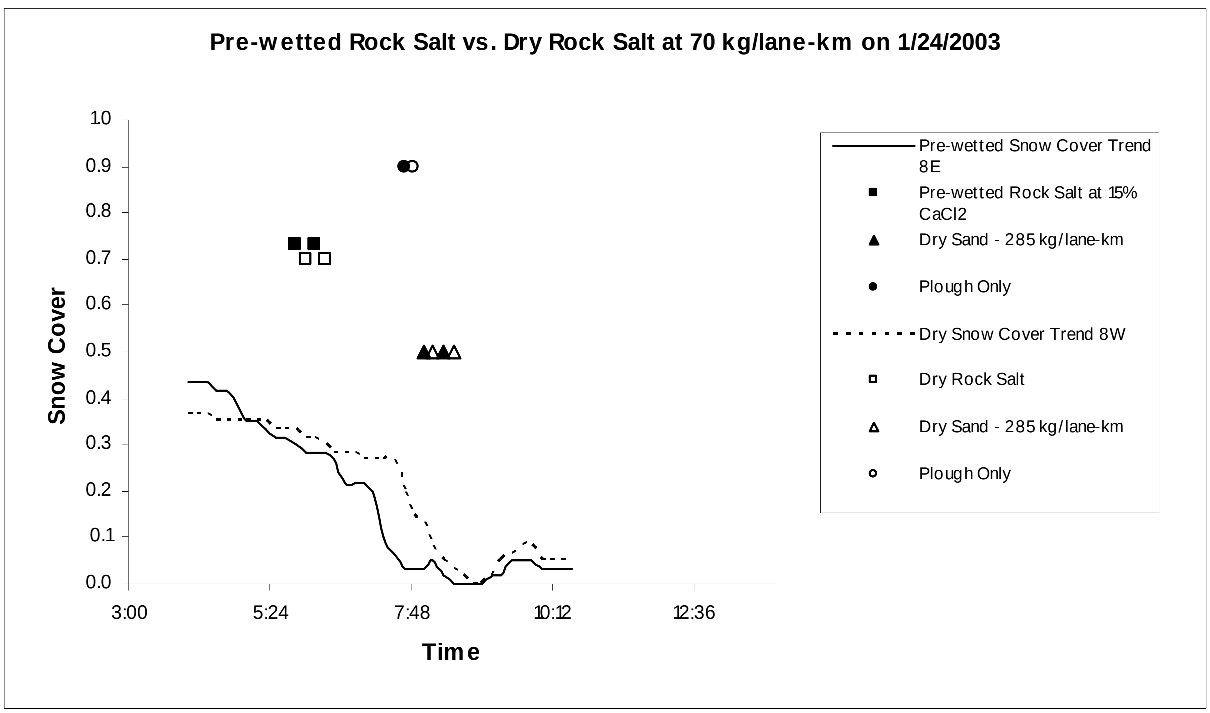
Case #	Date of Event	Weather and Surface Conditions [a]	Chemicals and/or Abrasives Used [b]		LOS [c]		Relative Effectiveness of Pre-wetted Salt (%)
			Pre-wetted Salt and/or Sand with $CaCl_2$	Dry Salt and/or Sand	Pre-wetted Salt	Dry Salt	
1	1/24/2003	2.2 cm (6.5 hrs) -14.1 °C (0.6 kph)	- 1E - Rock salt 70 kg/lane-km at 15% [d] (1/1) - Sand 279 kg/lane-km at 15% [d] (1/0)	- 2E - Rock salt 70 kg/lane-km (1/0) - Sand 279 kg/lane-km (1/0)	0.54	0.41	-31.7%
2	1/24/2003	2.2 cm (6.5 hrs) -14.1 °C (0.6 kph)	- 1W - Rock salt 70 kg/lane-km at 15% (1/1) - Sand 279 kg/lane-km at 15% (1/0)	- 2W - Rock salt 70 kg/lane-km (1/0) - Sand 279 kg/lane-km (1/0)	0.58	0.87	33.3%
3	1/24/2003	1.0 cm (6.5 hrs) -14.1 °C (0.6 kph)	- 8E - Rock salt 70 kg/lane-km at 15% (2/1) - Dry Sand 285 kg/lane-km (2/0)	- 8W - Rock salt 70 kg/lane-km (2/1) - Sand 285 kg/lane-km (2/0)	0.13	0.18	27.8%
4	1/25/2003	25.0 cm (8.0 hrs) -6.1 °C (27.9 kph)	- 8E - Rock salt 70 kg/lane-km at 7% (5/3) - Dry Sand 285 kg/lane-km (2/0)	- 8W - Rock salt 70 kg/lane-km (5/3) - Sand 285 kg/lane-km (2/0)	0.18	0.29	37.9%
5	1/25/2003	25.0 cm (8.0 hrs) -6.1 °C (27.9 kph)	- 7W - Rock salt 70 kg/lane-km at 7% (2/0) - Dry Sand/Salt Mix 285 kg/lane-km (1/0)	- 6W - Rock salt 70 kg/lane-km (2/0) - Sand 285 kg/lane-km (1/0)	0.22	0.30	26.7%
6	1/25/2003	25.0 cm (8.0 hrs) -6.1 °C (27.9 kph)	- 7E - Rock salt 70 kg/lane-km at 7% (2/0) - Dry Sand/Salt Mix 285 kg/lane-km (1/0)	- 6E - Rock salt 70 kg/lane-km (2/0) - Sand 285 kg/lane-km (1/0)	0.22	0.17	-29.4%
7	1/27/2003	4.5 cm (7.0 hrs) -18.8 °C (2.8 kph)	- 8E - Fine salt 56 kg/lane-km at 7% (4/2)	- 8W - Fine salt 66 kg/lane-km (6/0)	0.23	0.27	14.8%
8	2/14/2003	0.2 cm (8.5 hrs) -9.4 °C (0.8 kph)	- 7E - Fine salt 56 kg/lane-km at 15% (3/0)	- 6E - Fine salt 66 kg/lane-km (3/0)	0.42	0.60	30.0%
9	2/14/2003	0.2 cm (8.5 hrs) -9.4 °C (0.8 kph)	- 7W - Fine salt 56 kg/lane-km at 15% (3/0)	- 6W - Fine salt 66 kg/lane-km (3/0)	0.63	0.56	-12.5%

[a] total daily snowfall (storm duration)/average pavement temperature (average wind speed); [b] site/material/granular application rate in kg/lane-km (number of applications runs plus plow/plow only runs); [c] average snow cover; [d] percentage of $CaCl_2$ added to granular mass.

Figure 1: Study Site, Test Sections, and Road Weather Information System (RWIS) Station



(a) Case #1 (1/17/2002)



(b) Case #3 (1/24/2003)

Figure 2: Temporal Variation of Snow Cover – Pre-wetted Salt vs. Dry Salt

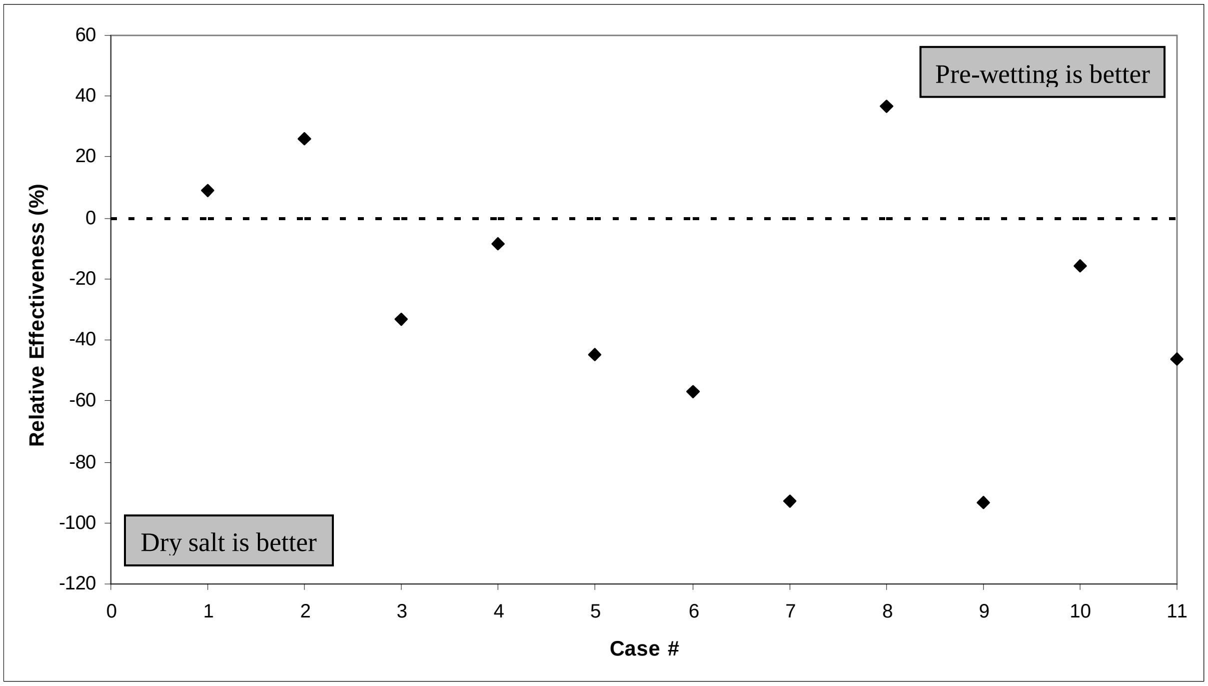


Figure 3: Relative Effectiveness of Pre-wetted Salt versus Dry Salt for 2001-2002

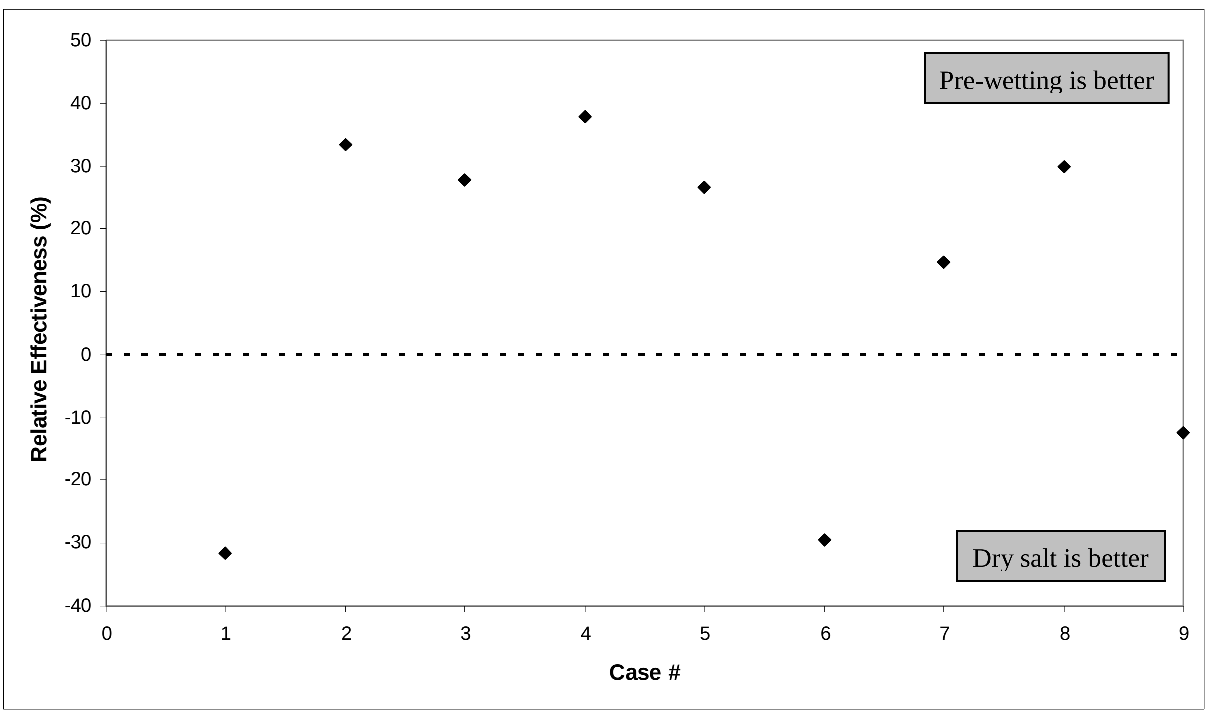


Figure 4: Relative Effectiveness of Pre-wetted Salt versus Dry Salt for 2002-2003