Current Status of U.S. Anti-Icing Technology Development

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Limited experience has shown that application of a chemical freezing-point depressant on a highway pavement before, or very quickly after, the start of ice or snow minimizes the formation of an ice-pavement bond. State highway agencies in the United States have not adopted anti-icing practices despite the potentially greater effectiveness and reduced costs associated with the practice. The Strategic Highway Research Program (SHRP) of the National Research Council has funded a multiyear study entitled *Development of Anti-Icing Technology*. The overall objective of the research program is to develop a better understanding of the conditions under which anti-icing will be effective and to develop various anti-icing techniques that will have the greatest potential of success over the range of conditions experienced in the United States. Winter maintenance personnel in nine state departments of transportation participated in anti-icing experiments during the 1991–1992 winter. The overall aspects of the SHRP study are covered, and some preliminary research results achieved during that winter are presented.

Limited experience has shown that application of a chemical freezing-point depressant on a highway pavement before, or very quickly after, the start of ice or snow minimizes the formation of an ice-pavement bond. This reduces the task of clearing the highway to bare-pavement conditions and requires less chemical amounts than is generally required under conventional deicing practices. State highway agencies in the United States have not adopted anti-icing practices despite the potentially greater effectiveness and reduced costs associated with the practice. The main reasons for the lack of acceptance concern the uncertainty about the most favorable conditions for anti-icing and the way that anti-icing should be conducted. The imprecision with which icing events can be predicted, the lack of confidence about the condition of the pavement surface, and the public's perception of wasted chemicals further complicates the situation. Some early anti-icing attempts have failed because of these uncertainties.

Technological developments in weather forecasting and in the assessment of pavement surface conditions now offer the potential for successful implementation of anti-icing treatments. Sensors embedded in the pavement surface can measure the temperature representative of the surrounding pavement and detect the presence of water or ice and a chemical freezing-point depressant. Signal information coming from these sensors has given maintenance managers the means to observe real-time pavement surface conditions and, when used with available algorithms, to provide a reasonable prediction of pavement surface conditions for up to 12 hr. Improved weather forecasting targeted specifically to local or regional road conditions also gives the manager a way to predict the state of the pavement surface. In addition, the availability of better communications enables this information to be relayed rapidly to maintenance forces and the public.

There is a need to develop a better understanding of the conditions under which anti-icing will be effective and the ways to conduct anti-icing efficiently to ensure the greatest probability of success. Several hurdles to the successful implementation of anti-icing need to be investigated and overcome. For example, the use of chemicals in solid form for anti-icing treatments demands precise timing of the application to minimize loss from traffic action. The use of prewetted salt has reduced loss during application due to particles bouncing off the pavement. The use of prewetted salt also may be effective in reducing the amount of material that is blown off the road by traffic. In addition, the influence of time between an application of salt and the onset of freezing precipitation is not fully understood.

Limited experience has shown that anti-icing requires as little as 10 to 20 percent of the normal chemical application rate for deicing. Highway agencies have found that reducing the conventional application rate to quantities on the order of 50 lb/lane-mi is not generally possible with present-day spreading equipment that is designed for deicing application rates of 300 to 500 lb/lane-mi and higher.

Liquid freezing-point depressants have the attractive feature of enabling precise control of uniform application over a wide range of rates. However, effective techniques for using liquids remain to be developed.

In early 1991, the Strategic Highway Research Program (SHRP) of the National Research Council funded a multiyear study entitled *Development of Anti-Icing Technology* under a SHRP contract. The study was designed to identify solutions that overcome these obstacles to successful implementation of anti-icing practices in winter maintenance operations. The overall objective of the research program is to develop a better understanding of the conditions under which anti-icing will be effective and to develop anti-icing techniques that will have the greatest potential of success over the range of appropriate conditions.

To achieve this objective, the research program was divided into two parts. The first part is to determine the effectiveness of anti-icing treatments from field testing of various treatment approaches on in-service highways because of the expected

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great influence of traffic. The field tests are being conducted in different locations to evaluate the influence of a wide number of variables. These tests are being performed in cooperation with state highway agencies (SHAs). Also to be performed in this part of the study is an analysis of the relative cost of anti-icing versus deicing, considering such factors as accidents, time delays, and costs of material, equipment, and labor.

The second part of the study is to determine the optimum application rates for several anti-icing treatments over a range of environmental conditions. Also to be performed in this part of the study is a survey of the worldwide spreader equipment market. The purpose of this survey is to determine the capabilities of spreader equipment to apply controlled quantities of solid, prewetted solid, and liquid deicing chemicals at minimum application rates required for effective anti-icing treatments.

This paper describes some of the activities associated with the field testing of in-service highways during the first contract year. These activities included the development of a research design, field observations, and analysis of anti-icing effectiveness. Some preliminary results achieved during the 1991–1992 winter are also presented.

RESEARCH DESIGN

The research design consisted of several steps, including

- Selecting participating SHAs and evaluation sites;
- Determining variables to be evaluated, including anti-icing strategies and site characteristics; and
- Choosing and purchasing equipment needed by the participating SHAs to conduct the anti-icing experiment.

Nine SHAs were identified as being interested in participating in the testing of in-service highways. A liaison in each state was contacted by telephone to determine the extent of cooperation and participation in the study. Information was also obtained on the winter maintenance treatment strategies used, spreader equipment available, weather forecasting services used, and the locations of any roadway weather information systems (RWISs) used. Visits to each of the nine state agencies were made following the initial contact. During these visits, specific information was obtained on the current snow and ice control practices used by each agency, the proposed test and control sections to be used in the study, the type of material and spreader equipment typically used in the study areas, the frequency of storm events, and the meteorological support and pavement sensors available at each site. Published information was also obtained from each state on its particular snow and ice control practices, and photographs were taken of the proposed test and control locations.

The test sections selected during the visits were segments of highways that were close to a maintenance truck station and could be used for the anti-icing experiments. A segment of highway near each test section was also chosen to serve as a control for the experiment. Each control section matched its associated test section, as best as possible, in regards to area type, pavement type, and average daily traffic (ADT). The control sections were to be treated in accordance with the conventional snow and ice control policy of the particular state.

Data collected during the state visits were analyzed and assembled into a recommended research design for testing various anti-icing treatment strategies. Table 1 presents the geographical distribution of test sites used in the study. A total of 14 test sites were selected in the nine states.

The information obtained as a result of the various surveys (telephone, site visits, and literature) is summarized in the research design in Table 2. This table gives the independent variables—geographic area, state, area type, pavement type, and ADT—and the estimated number of winter events at each site. For each unique combination (total of 23), the recommended treatment strategy, consisting of the type of chemical to be used and the treatment timing, is provided. Of the 23 experimental conditions, 8 were to take place before the storm (3 on portland cement concrete pavement and 5 on asphaltic pavement) and 15 at the beginning of the storm (5 on portland cement concrete pavement and 10 on asphaltic pavement). Because of practical restrictions and safety considerations, the research design could not be balanced with respect to pavement type and treatment strategy.

Considerable equipment and support items were provided to the participating SHAs for use in the anti-icing experiments. The items included

- Ground-oriented spreader controls;
- Prewetting equipment for trucks;
- Fixed liquid deicer spray systems and associated tanks;
- Storage tanks, pumps, and liquid deicing chemicals;
- A complete RWIS;
- A system upgrade for an existing RWIS;
- Local weather forecasting service;
- Friction testers;
- Salinity detection instruments; and
- Radiometers.

In general, each test section except the one in Maryland contained RWIS pavement and atmospheric sensors so that informed decisions could be made about pretreatment timing, application rate, and so forth. Maryland was given a handheld radiometer with which to measure pavement temperatures. The intention here was to see if decisions about the timing of anti-icing treatments could be made with a relatively inexpensive pavement-temperature sensing device.

TABLE 1 Geographic Distribution of Test Sites

Geographic Area	State	No. of Test Sites
Mountainous states	California Maryland	2 1
High plains states	Colorado Nevada	2 1
Plains states	Missouri Ohio	2 2
Lake effects states	Minnesota New York	2 1
Maritime state	Washington	1
Totals	9	14

TABLE 2 Recommended Research Design

Geographic area	State	Area type	Pavement type	ADT	Estimated number of winter events	Treatment strategy: Type of chemical to be used	Treatment timing
Mountainous	California	Rural	DGA	31,100	40	a) Liquid $MgCl_2$ b) Rock salt prewetted w/Freezgard Plus	Pre-storm
Mountainous	California	Rural	PCC	31,100	40	a) Liquid $MgCl_2$ b) Rock salt prewetted w/Freezgard Plus	Pre-storm
Mountainous	California	Rural	DGA	2,200	120	Rock salt prewetted w/liquid $MgCl_2$	Pre-storm
Mountainous	Maryland	Rural	OGA	1,600-2,000	40	Straight rock salt	Beginning of storm
High Plains	Colorado	Rural	PCC	29,500-30,100	25	Rock salt prewetted w/liquid NaCl or $MgCl_2$ after loading	Beginning of storm
High Plains	Colorado	Suburban	DGA	33,000	25	Rock salt prewetted w/liquid NaCl or $MgCl_2$ after loading	Beginning of storm
High Plains	Nevada	Suburban	DGA	39,000	6	Rock salt prewetted w/Freezgard	Beginning of storm
Plains	Missouri	Rural	DGA	39,500	15	Rock salt prewetted w/liquid $MgCl_2$ or $CaCl_2$	Beginning of storm
Plains	Missouri	Rural	DGA	11,800	15	Rock salt prewetted w/liquid $MgCl_2$ or $CaCl_2$	Pre-storm
Plains	Ohio	Suburban	DGA	34,000-45,000	30	Rock salt prewetted w/liquid NaCl	Beginning of storm
Plains	Ohio	Rural	DGA	23,000-58,000	30	Rock salt prewetted w/liquid NaCl	Beginning of storm
Lake Effects	Minnesota	Rural	DGA	5,800	18	Rock salt prewetted w/liquid $CaCl_2$	Pre-storm
Lake Effects	Minnesota	Rural	PCC	5,800	18	Rock salt prewetted w/liquid $CaCl_2$	Pre-storm
Lake Effects	Minnesota	Urban	DGA	35,000	18	Rock salt prewetted w/liquid CMA or KOAc	Beginning of storm
Lake Effects	Minnesota	Urban	PCC	35,000	18	Rock salt prewetted w/liquid CMA or KOAc	Beginning of storm
Lake Effects	New York	Suburban	DGA	19,900-45,700	40-50	Rock salt prewetted w/liquid $CaCl_2$	Beginning of storm
Lake Effects	New York	Suburban	PCC	45,700-53,500	40-50	Rock salt prewetted w/liquid $CaCl_2$	Beginning of storm
Maritime	Washington	Rural	DGA	21,000	10	a) Rock salt prewetted w/liquid NaCl b) Rock salt prewetted w/liquid NaCl + CMA	Beginning of storm
Maritime	Washington	Rural	PCC	21,000	10	a) Rock salt prewetted w/liquid NaCl b) Rock salt prewetted w/liquid NaCl + CMA	Beginning of storm

During the planning stages for the study, it was decided that pavement friction and salinity measurements should be made on the test and control sections throughout the winter testing period. It was important that the devices used to make the measurements be suitable for use by maintenance personnel during bad weather. The devices also had to provide meaningful results.

PAVEMENT FRICTION MEASUREMENT

Before the beginning of the project, the Minnesota Department of Transportation (Mn/DOT) began investigating the usefulness of the Coralba friction tester for making pavement friction measurements. The Coralba is a Swedish friction measurement device used on some European and Scandinavian airport runways. The device can be installed in a pickup truck or passenger vehicle and is connected to the brake system. It provides a measure of friction between the tire and pavement during a braking operation. The friction value obtained from a test is displayed on a dash-mounted unit.

Mn/DOT performed a limited amount of testing with the device before the study. After the study began, a protocol was developed for friction testing to determine if a correlation could be established between the Coralba friction tester measurements and ASTM E-274 skid trailer results. The testing with both systems was conducted in summer 1991 at the St. Cloud, Minnesota, test track and on I-35 and TH-53 in the Duluth, Minnesota, area. The correlation of the Coralba friction tester with ASTM E-274 skid measurements is described in the following.

A total of 106 individual measurements were made with the Coralba and 41, with the skid trailer. These were taken on three sites, including three pavement types (asphalt, concrete, and new concrete). Measurements were made at 32.2, 48.3, and 64.4 km/hr (20, 30, and 40 mph) on wet pavement (three measurements were made on dry pavement but were not included in subsequent analyses). The Coralba was used in two modes—with and without lockup—resulting in 58 and 48 measurements, respectively.

For each of the 24 unique combinations (site, pavement type, speed, and device), the mean, standard deviation, and coefficient of variation were calculated for the skid numbers and the Coralba measurements in both modes. These statistics are given in the last three columns of Table 3.

Data obtained at 32.2 km/hr (20 mph) with the Coralba could not be compared with skid data because the skid trailer was not used at that speed. However, the 32.2-km/hr (20-mph) Coralba measurements were compared when using the device in either lockup or no lockup mode.

There is a direct proportional relationship between skid and Coralba measurements. However, since most of the measurements were made at higher skid numbers (over 53 SN) and only two were made at less than 18 SN, a linear regression

TABLE 3 Skid and Coralba Measurements, Statistics

Obs.	Site	Pvt type	Speed (mph)*	Device	Lockup ?	Pvt	Mean	Standard Deviation	CV*1 (100%)
1	I-35	New conc.	30	Coralba	no	wet	0.51	0.04	8.65
2	I-35	New conc.	40	Coralba	no	wet	0.55	0.03	6.08
3	I-35	New conc.	29.7	Skid	yes	wet	65.92	1.26	1.91
4	I-35	New conc.	30	Coralba	yes	wet	0.46	0.05	10.06
5	I-35	New conc.	40	Coralba	yes	wet	0.50	0.04	8.58
6	I-35	New conc.	40.4	Skid	yes	wet	62.26	1.35	2.17
7	NBL TH 53	Asphalt	30	Coralba	no	wet	0.44	0.04	8.13
8	NBL TH 53	Asphalt	40	Coralba	no	wet	0.42	0.04	9.63
9	NBL TH 53	Concrete	20	Coralba	no	wet	0.33	0.07	19.97
10	NBL TH 53	Concrete	30	Coralba	no	wet	0.36	0.06	15.78
11	NBL TH 53	Concrete	40	Coralba	no	wet	0.39	0.06	14.50
12	NBL TH 53	Asphalt	30	Coralba	yes	wet	0.45	0.03	6.29
13	NBL TH 53	Asphalt	30.3	Skid	yes	wet	57.66	2.63	4.56
14	NBL TH 53	Asphalt	39.0	Skid	yes	wet	59.32	2.33	3.94
15	NBL TH 53	Asphalt	40	Coralba	yes	wet	0.47	0.03	5.57
16	NBL TH 53	Concrete	20	Coralba	yes	wet	0.30	0.10	33.23
17	NBL TH 53	Concrete	30	Coralba	yes	wet	0.35	0.04	12.12
18	NBL TH 53	Concrete	30.3	Skid	yes	wet	58.14	1.90	3.27
19	NBL TH 53	Concrete	40	Coralba	yes	wet	0.32	0.04	13.74
20	NBL TH 53	Concrete	40.9	Skid	yes	wet	53.28	3.21	6.02
21	St. Cloud	Asphalt	30	Coralba	yes	wet	0.25	0.02	9.80
22	St. Cloud	Asphalt	30	Skid	yes	wet	17.74	0.96	5.40
23	St. Cloud	Asphalt	40	Coralba	yes	wet	0.22	0.03	11.87
24	St. Cloud	Asphalt	40	Skid	yes	wet	15.10	0.94	6.21

Note 1: CV = Coefficient of Variation = 100 * Standard Deviation/Mean
* 1 mph = 1.609 km/hr

would be misleading and therefore was not performed. Instead, the Spearman nonparametric rank correlation coefficient was calculated for each of the three possible comparisons.

The calculated correlation coefficients and their corresponding tabulated critical values (in parentheses) are

- Skid versus Coralba lockup mode ($N = 8$): $R = 0.905$ (critical $R = 0.714$)
- Skid versus Coralba no lockup mode ($N = 6$): $R = 0.657$ (critical $R = 0.886$)
- Coralba lockup versus no lockup mode ($N = 7$): $R = 0.857$ (critical $R = 0.750$)

To test whether these correlation coefficients are significantly different from zero, the calculated coefficients were compared with the corresponding tabulated coefficients with $N - 2$ degrees of freedom and a two-sided significance level of 5 percent, assuming a 95 percent confidence level. If the calculated R exceeds the tabulated R, one concludes that the correlation coefficient is significantly different from zero.

The results are summarized as follows:

- The correlation between skid and lockup Coralba measurements is significantly different from zero at the 95 percent confidence level—that is, Coralba and skid measurements increase or decrease together.
- The correlation between lockup and no-lockup Coralba measurements is significantly different from zero at the 95 percent confidence level as well.
- However, the correlation between skid and no-lockup Coralba measurements is not statistically significant.

On the basis of these results, it was decided that the SHAs would use Coralba friction testers during the winter testing. The testers were to be operated in a lockup mode at 64.4 km/hr (40 mph). However, testing could be conducted at 48.3 km/hr (30 mph) for safety considerations. It was also decided that the testers should not be operated at 32.2 km/hr (20 mph) because of the high variability in the Coralba measurements obtained at that speed (see the coefficients of variation in Table 3).

SALINITY MEASUREMENTS

A brief technical survey was made of scientific instruments that could be used for measuring residual anti-icing chemicals on pavement surfaces. The survey identified three manufacturers of conductivity meters. Boschung Company, Inc. of Switzerland was chosen for its Sobo-20 salinity tester. The primary reasons for this choice were that the Sobo-20 has a built-in conductivity cell and that the unit was specifically designed for the quantitative measurement of chloride solutions on roads. A Sobo-20 unit was purchased for evaluation.

Studies were conducted to evaluate the utility of the Sobo-20 salinity tester for the semiquantitative measurement of salt-based chemical deicer solutions. These studies consisted of evaluating the type of response and range of detection for solutions of five chemical deicers.

- Sodium chloride (NaCl)
- Magnesium chloride ($MgCl_2$)
- Calcium chloride ($CaCl_2$)
- Potassium acetate ($KOOCCH_3$)
- Calcium magnesium acetate ($Ca/MgOOCCH_3$)

When making a measurement, a precise volume of a measuring liquid is pumped into a measuring cell on the road surface. The conductivity obtained with the measuring liquid, which dissolves remaining salt on roads, gives the quantity of remaining salt in ounces per square yard. The measuring apparatus has a temperature compensation feature.

The instrument consists of two parts: (a) the measuring chamber, with built-in conductivity cell, which spreads the measuring liquid from the vessel or tank onto the road; and (b) the electronic displayer, which is a data processing device with display scale and storage of the measurements.

The liquid solution for dissolving the residual salt contains the pure liquid components distilled or demineralized water (85 percent) and technical acetone (15 percent).

The freezing point of the solution is approximately −5°C (23°F). The mixture may be prepared by the user or bought at a drug store. It should be noted that the accuracy of the measurement is guaranteed only with the aforementioned composition of the measuring liquid.

Five series of deicer surface tests were conducted to determine the Sobo-20 meter readings for selected surface concentration levels of deicer chemical. The experimental test procedures consisted of the following steps:

1. Carefully weighed amounts of a deicer solution (10 or 20 percent deicer by weight) were applied to the surface of a stainless steel pan.
2. The amounts of deicer solution applied to the test surface were selected to yield the following equivalent deicer concentration levels: 1.7, 3.4, 8.5, 17.0, 25.4, 33.9, and 50.9 g/m^2 (22, 44, 110, 220, 330, 440, and 660 lb/lane-mi).
3. The required amounts of 20 percent deicer solution by weight (20, 40, 100, 200, 300, 400 and 600 mg) were applied to attain the deicer surface concentration levels just specified.
4. After the proper amount of concentrated deicer solution is applied on the stainless test surface, the sampling/testing chamber of the Sobo-20 was placed over the deicer sample.
5. The measuring fluid was forced into the measuring chamber, and the Sobo-20 reading was recorded on its electronic meter.
6. After the measurement was completed, the solution was collected and the conductivity was measured with an ElectroMark Analyzer Model 4400 (Markson Science Inc.) conductivity meter.

The results of the Sobo-20 tests for five series of deicer solutions are presented in Figure 1. Comparative evaluations of test results revealed interesting information about the intensity and linearity of Sobo-20 response/deicer weight relationships according to deicer type and concentration range.

Sodium chloride gave the highest Sobo-20 conductivity readings per unit weight and the most linear response. In addition, the results obtained during this study were in agreement with the values reported by the manufacturer for sodium chloride.

The four other deicers ($MgCl_2$, $CaCl_2$, KOAc, and CMA) gave nonlinear Sobo-20 reading/deicer weight relationships at surface concentration levels greater than 25.4 g/m^2 (330 lb/lane-mi).

The intensity of the Sobo-20 response per unit weight varied by deicer type in the following order: NaCl > $MgCl_2$ > $CaCl_2$ > KOAc > CMA. Generally, the order of the degree of response was expected.

The analytical range of the Sobo-20 varied according to the ionic strength of the deicer electrolyte. The strong electrolyte deicers (NaCl, $MgCl_2$, and $CaCl_2$) gave Sobo-20 readings at the lowest concentration level tested (22 lb/lane-mi), but the lowest detectable concentration level, for the weak electrolyte deicers (KOAc and CMA), was 8.5 g/m^2 (110 lb/lane-mi). Because the analytical range of the standard Sobo-20 lacks the sensitivity to detect and analyze KOAc and CMA at surface concentration levels below 8.5 g/m^2 (110 lb/lane-mi), the manufacturer was contacted and asked to provide a more sensitive range. A modified electronic meter that replaces the full scale with a 1/10 scale and would provide an analytical range from 0.34 to 5.1 g of NaCl per square meter (4.4 to 66.0 lb/lane-mi) was ordered and found to detect and measure the presence of KOAc and CMA at the lower concentration levels. Accordingly, the analytical ranges of Sobo-20 for the five target deicers are as follows:

- For NaCl, $MgCl_2$, and $CaCl_2$
  - 1/2 scale: 22 to 330 lb/lane-mi
  - Full scale: 44 to 660 lb/lane-mi
- For KOAc and CMA
  - 1/2 scale: 110 to 330 lb/lane-mi
  - Full scale: 220 to 660 lb/lane-mi

On the basis of these results, the Sobo-20 salinity meter appeared to be the most promising technique for measuring residual anti-icing chemicals on pavement surfaces. Consequently, it was decided the standard Sobo-20 would be used during the winter testing by those participating SHAs that would be using NaCl, $CaCl_2$, and $MgCl_2$, or mixtures of these strong electrolytes. It was further decided that a modified electronic meter with increased sensitivity for lower concentration levels of KOAc and CMA should be obtained and provided to any SHAs that would be using KOAc and CMA.

FIELD OBSERVATIONS

It was necessary to develop training materials and to train the maintenance personnel in the nine participating SHAs before the anti-icing experiments began. Winter maintenance training materials were obtained from various sources including several departments of transportation. These materials were

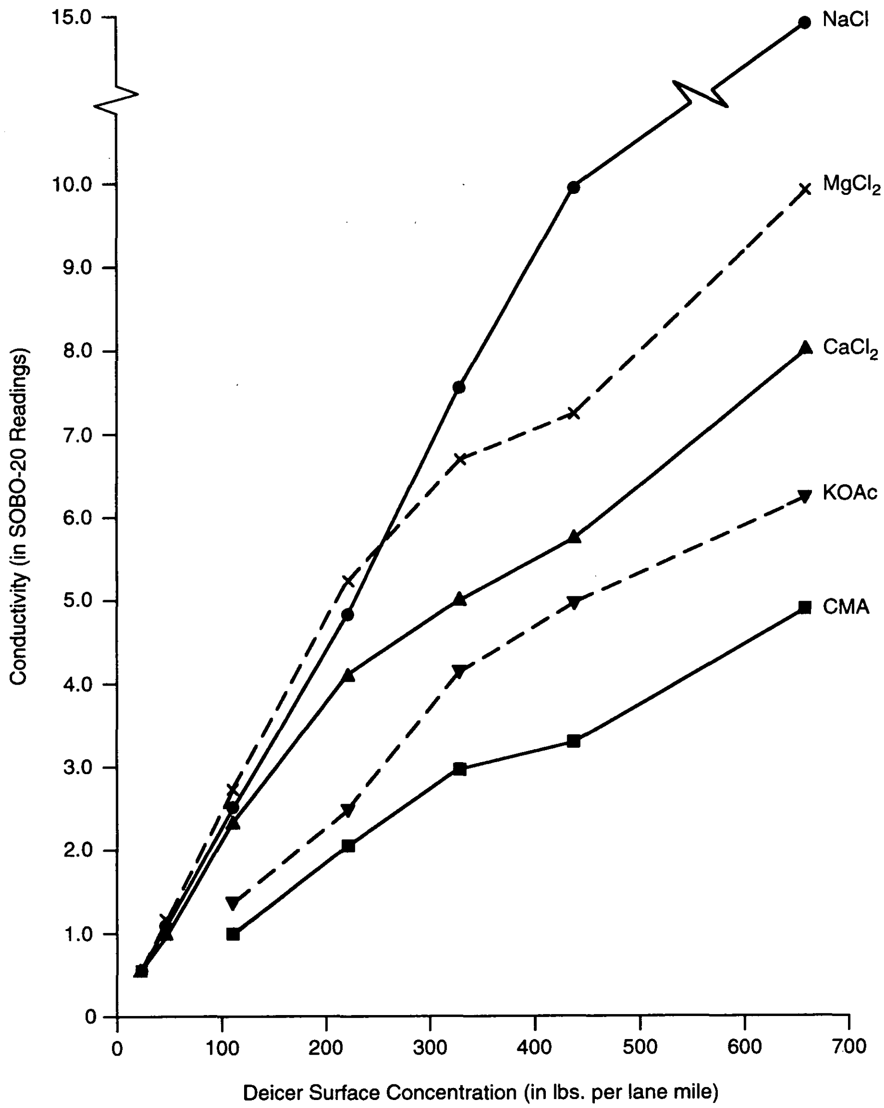

FIGURE 1 Sobo-20 reading versus deicer surface concentration.

reviewed for application to the study, and parts were found to be of direct value. Operating instructions on several types of spreader control equipment were obtained during the state visits. These documents were also reviewed for their applicability to the study. Finally, various forms and procedures for documenting winter maintenance activities and pavement sensor readings were obtained and reviewed. The development of the needed forms and procedures was greatly enhanced by incorporating many of the features found in the materials collected.

Appropriate materials assembled from the various sources were combined into manuals for training the winter maintenance personnel. Portions of the training manuals varied from state to state. The variations incorporated specific state requirements for winter maintenance activities, reflected site-specific geographic and climate considerations, and pertained to the type of chemical (solid, prewetted, or liquid) spreaders to be used in the testing.

The training materials covered all aspects of the H-208 program, including a background on the scope of the project, basic meteorology, and snow and ice control chemicals; a description of the design, operation, and the use of RWISs; and information specifically related to the implementation of the study in each jurisdiction including the role of supervisory and operating personnel, data collection, and so on. Hands-on training was also furnished for both the Sobo-20 and the Coralba friction tester. The training material developed for Maryland was different from the other eight states because of the absence of a RWIS in that state.

Itemized operating, calibration, and maintenance instructions were prepared also for the Sobo-20 and Coralba instruments. These instructions were intended to simplify the data collection during winter storm events and to ensure the quality of the information collected.

Also included in the training was a series of data recording forms designed specifically for use in the research program. These forms provided the proper format in which to record weather and pavement conditions, spreader equipment operation, and Sobo-20 and Coralba readings. Suitable forms were also prepared for instrument calibration and, for Maryland, the recording of measurements collected using the radiometer.

Using these materials, on-site training was provided to all SHAs participating in the project. Although modified in certain cases, the training was originally designed for 1½ days, with classroom work held on the first day and hands-on training provided during the morning of the second day.

Finally, during the training provided to state winter maintenance personnel, some adjustment of the test and control sections were necessary to more closely conform to their routine treatment practices. A first cut was made during the initial state visit to select an appropriate test and control section. The boundaries of these sections were further refined during the training session. Also, discussions were held with supervisory personnel to identify the specific equipment (e.g., truck or trucks) to be used for anti-icing on the test section and deicing on the control section.

The training of the winter maintenance personnel in the nine SHAs began near the end of November 1991 and was completed during the early part of January 1992.

The first anti-icing experiment was run in Maryland near the end of January 1992. The official end of the anti-icing experiments for the 1991–1992 winter was the end of March 1992. At that time, 57 storm events had been recorded by the participating states, despite the late start of the anti-icing experiments during the 1991–1992 winter. More than 70 percent of the events were recorded by maintenance personnel from the departments of transportation in Maryland, Minnesota, Nevada, and New York. No storm events were recorded at four sites because of the extremely mild winter after the program became operational.

ANALYSIS OF MAINTENANCE FIELD DATA

A complete analysis of the maintenance field data collected by the states was begun at the end of the 1991–1992 winter. The analysis is intended to determine a preliminary estimate of the cost-effectiveness of anti-icing treatments relative to conventional deicing.

Examples of the analyses being conducted of the maintenance field data are given in Figures 2 through 5. These figures pertain to Storm 8 recorded on February 16, 1992, for US-395 in Nevada. Figures 2 and 3 provide a chronological history of the meteorological events, pavement conditions, and maintenance activities associated with the storm, including the amount of material applied to the driving lane (DL) and passing lane (PL). Figure 2 pertains to conditions related to the test section, and Figure 3 contains similar data for the control section. Figures 4 and 5 are graphical presentations of the

DATE: FEBRUARY 16, 1992

TEST

DATE	TIME	TRK I.D.	PVMT TEMP (°F)	AIR TEMP (°F)	ROAD COND	WTHR COND	APPLICATION: MATERIAL APPLIED	RATE (lbs/ ln-mi)	LANES TREATD: DL	PL	AMOUNT APPLIED (lbs): DL	PL	TRMT	CORALBA FRICTION VALUE @40 mph	SOBO: READNG: WT	CL	EQUIVALENT (lbs/ln-mi): WT	CL
Feb 16	05:00		31	31	15	5								NONE*				
Feb 16	05:05		31	31	15	5												
Feb 16	05:10	2769	31	31	15	5	Lq. MgCl2	102	1		682		C					
Feb 16	05:15		31	30	15	5												
Feb 16	05:25		31	30	15	5												
Feb 16	05:35	2769	31	30	15	5	Lq. MgCl2	102		1		682	C					
Feb 16	05:45		32	30	25	5												
Feb 16	05:55		32	30	25	5												
Feb 16	06:15		31	30	25	4												
Feb 16	06:25		31	29	25	4												
Feb 16	07:10	2769	31	29	10	5	Lq. MgCl2	102	1		682		C					
Feb 16	07:15		31	28	10	5												
Feb 16	07:30		31	28	10	5												
Feb 16	07:45	2769	31	29	25	5	Lq. MgCl2	102		1		682	C					
Feb 16	07:55		31	29	25	5												
Feb 16	08:00		31	30	25	5												
Feb 16	08:15		31	31	25	5												
Feb 16	08:25		32	31	25	7												
Feb 16	08:30		33	31	25	7												

Codes:

WEATHER	ROAD CONDITION
1 – DRIZZLE	30 – DRY
2 – RAIN	25 – WET
3 – FR. RAIN/SLEET	20 – SLUSH
4 – LT. SNOW	15 – SNOW
5 – SNOW	10 – SNOW/ICE PACK
6 – BLOWING SNOW	5 – ICE
7 – NONE	45 – OTHER

TOTAL LBS MgCl2 TO PL: 1,364

TOTAL LBS MgCl2 TO DL: 1,364

TOTAL LBS MgCl2 APPLD: 2,727

* No friction values taken for test.

Notes:
1 Pavement and Air Temperature data from Sensor #5 located at US 395 and Business 395 junction.
2 Nevada DOT did not have a SOBO unit for test or control sections.
3 Treatment methods are P, C, A, P+C, P+A, C+A. P = Plowing; C = Chemical; A = Abrasives.
4 Under SOBO Heading, WT=Wheel Track, CL=Center Lane
5 Section length is 6.68 miles.
6 Pavement type is Portland Cement Concrete (PCC).

FIGURE 2 Chronological history of Nevada Storm 8 for test section.

DATE: FEBRUARY 16, 1992

TEST

DATE	TIME	TRK I.D.	PVMT TEMP (°F)	AIR TEMP (°F)	ROAD COND	WTHR COND	APPLICATION MATERIAL APPLIED	RATE (lbs/ ln-mi)	LANES TREATD DL	LANES TREATD PL	AMOUNT APPLIED (lbs) DL	AMOUNT APPLIED (lbs) PL	TRMT	CORALBA FRICTION VALUE @40 mph	SOBO READNG WT	SOBO READNG CL	SOBO EQUIVALENT (lbs/ln-mi) WT	SOBO EQUIVALENT (lbs/ln-mi) CL
Feb 16	05:00	2286	31	31	15	5	Sand/Salt*	1,385		1		9,252	C+A	NONE**				
Feb 16	05:05		31	31	15	5												
Feb 16	05:15		31	31	15	5												
Feb 16	05:25		31	30	15	5												
Feb 16	05:35		31	30	15	5												
Feb 16	05:45		32	30	15	5												
Feb 16	05:55		32	30	15	5												
Feb 16	06:00	2286	31	30	15	5	Sand/Salt*	1,385		1		9,252	C+A					
Feb 16	06:15		31	30	15	4												
Feb 16	06:25		31	29	20	4												
Feb 16	07:15		31	28	15	5												
Feb 16	07:20	1821	31	28	15	5	Sand/Salt*	2,126	1		14,199		C+A					
Feb 16	07:30	2286	31	28	15	5	Sand/Salt*	1,385		1		9,252	C+A					
Feb 16	07:45		31	29	15	5												
Feb 16	07:55		31	29	15	5												
Feb 16	08:00		31	30	15	5												
Feb 16	08:15		31	31	25	5												
Feb 16	08:25		32	31	25	7												
Feb 16	08:30		33	31	25	7												

Codes:

WEATHER	ROAD CONDITION
1 – DRIZZLE	30 – DRY
2 – RAIN	25 – WET
3 – FR. RAIN/SLEET	20 – SLUSH
4 – LT. SNOW	15 – SNOW
5 – SNOW	10 – SNOW/ICE PACK
6 – BLOWING SNOW	5 – ICE
7 – NONE	45 – OTHER

TOTAL LBS SAND/SALT MIX TO PL:	27,757
TOTAL LBS SAND/SALT MIX TO DL:	14,199
TOTAL LBS SAND/SALT MIX APPLIED:	41,956

TOTAL LBS SAND–PL:	23,039
TOTAL LBS SALT–PL:	4,719
TOTAL LBS SAND–DL:	11,785
TOTAL LBS SALT–DL:	2,414
TOTAL LBS SAND APPLIED:	34,823
TOTAL LBS SALT APPLIED:	7,133

Notes:
1 Pavement and Air Temperature data from Sensor #5 located at US 395 and Business 395 junction.
2 Nevada DOT did not have a SOBO unit for test or control sections.
3 Treatment methods are P, C, A, P+C, P+A, C+A. P = Plowing; C = Chemical; A = Abrasives.
4 Under SOBO Heading, WT=Wheel Track, CL=Center Lane
5 Section length is 6.68 miles.
6 Pavement type is Portland Cement Concrete (PCC).

* Salt/Sand mix is 83% Sand; 17% Salt
** No friction value taken for test.

FIGURE 3 Chronological history of Nevada Storm 8 for control section.

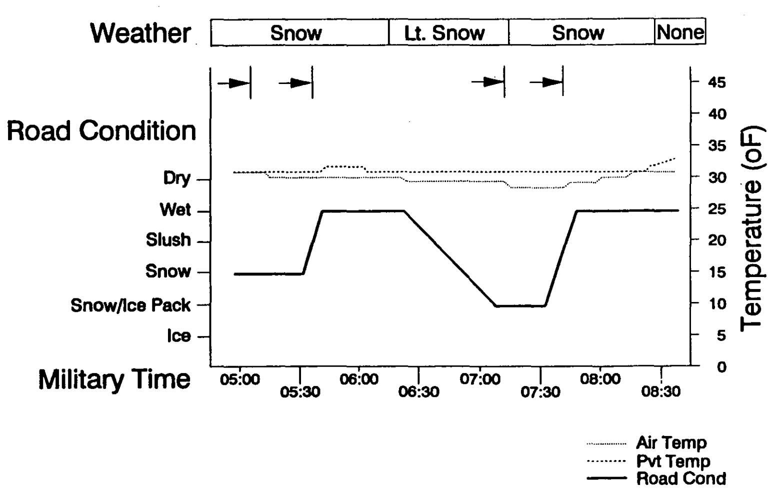

FIGURE 4 Time history of weather, pavement, and air temperature conditions for test section on US-395 in Nevada, Storm 8; arrows denote liquid Freezegard applications (application rate = 102 lb/min, total application = 2,727 lb).

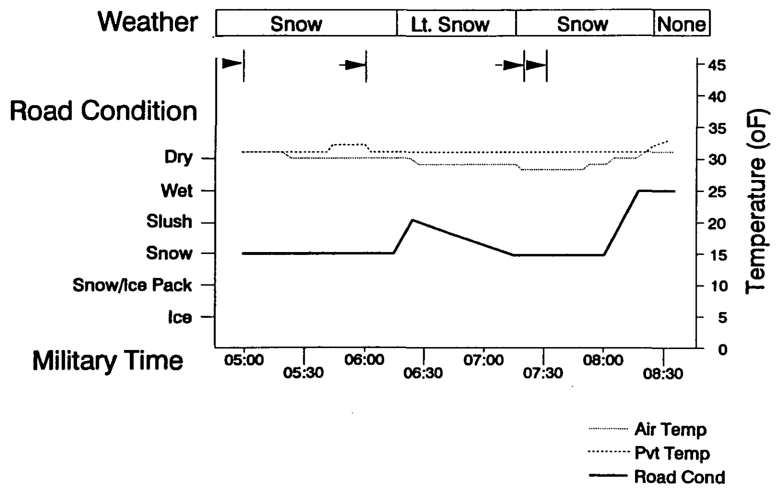

FIGURE 5 Time history of weather, pavement, and air temperature conditions for control section on US-395 in Nevada, Storm 8; arrows denote sand/salt applications (mix is 83 percent sand, 17 percent salt; total application = 41,956 lb).

weather, pavement conditions, and air temperature as a function of time for the test and control sections, respectively. For Nevada Storm 8, more than 2.6 times as much deicer was applied to the control section as was applied to the test section [3236 kg NaCl versus 1237 kg $MgCl_2$ (7,133 lb versus 2,727 lb)]. On a total material basis, more than 15 times as much material was applied to the control section as was applied to the test section [19 031 kg versus 1237 kg (41,956 lb versus 2,727 lb)].

Similar tabulations and plots for Maryland Storm 6 are given in Figures 6 through 9. During this storm, 1.6 times as much deicer was applied to the test section as was applied to the control section when the deicer amounts were normalized with section length [35.5 g/m^2 NaCl versus 21.7 g/m^2 NaCl (461 lb/mi versus 282 lb/mi)]. However, on a total material weight basis, about 2.0 times as much material was applied to the control section as was applied to the test section when the material amounts were normalized with section length (731 g/m^2 versus 35.5 g/m^2 [9,490 lb/mi versus 461 lb/mi]).

Some interesting comparisons can be drawn between the Maryland test and control sections even though more salt was used on the test section than on the control section. For instance, a maintenance truck had to make five passes on the control section but only three passes on the test section. Also, the pavement condition of the test section only deteriorated to a slush state while the pavement condition of the control section deteriorated to a snowy condition. The salt application rate of 5.9 g/m^2 (77 lb/lane-mi) applied to the test section was

DATE: FEBRUARY 4, 1992

TEST

DATE	TIME	TRK I.D.	PVMT TEMP (°F)	AIR TEMP (°F)	ROAD COND	WTHR COND	APPLICATION: MAT'L APPLIED	APPLICATION: RATE (lbs/ ln mi)	APPLICATION: LANE TRTD SB	APPLICATION: LANE TRTD NB	APPLICATION: AMOUNT APPLIED (lbs) SB	APPLICATION: AMOUNT APPLIED (lbs) NB	TRMT	CORALBA FRICTION VALUE @40 mph	SOBO READING WT	SOBO READING CL	SOBO EQUIVALENT lbs/ln−mi WT	SOBO EQUIVALENT lbs/ln−mi CL
Feb 4	14:00		42	40	30	7								0.51	0	0.5	0	22
Feb 4	16:30	86068	35	33	25	2	Rock Salt	77	1	1	845	845	C	0.20	0.5	5	22	220
Feb 4	22:00	86068		27	20	3	Rock Salt	77	1	1	845	845	C					
Feb 4	22:30	86068		26	25	4	Rock Salt	77	1	1	845	845	C					
Feb 4	23:00			27	30	7												
Feb 5	08:00		22	20	30	7								0.30	2	2.5	85	110
Feb 5	08:30			20	30	7												

Codes: WEATHER
1 – DRIZZLE
2 – RAIN
3 – FR. RAIN/SLEET
4 – LT. SNOW
5 – SNOW
6 – BLOWING SNOW
7 – NONE

ROAD CONDITION
30 – DRY
25 – WET
20 – SLUSH
15 – SNOW
10 – SNOW/ICE PACK
5 – ICE
45 – OTHER

TOTAL LBS ROCK SALT TO NB: 2,534

TOTAL LBS ROCK SALT TO SB: 2,534

TOTAL LBS ROCK SALT APPLIED: 5,069

Notes:
1 Length of section is 11 miles.
2 Pavement type is DGA (Dense Graded Asphalt).
3 Air and Pavement temperature were obtained from Raytek Raynger PM–4 forms and MD Highway Administration Weather Condition Reports.
4 Treatment methods are P, C, A, P+C, P+A, C+A. P=Plowing; C=Chemical; A=Abrasives.
5 Under SOBO Heading, WT=Wheel Track, CL=Center Lane.

FIGURE 6 Chronological history of Maryland Storm 6 for test section.

DATE: FEBRUARY 4, 1992

CONTROL							APPLICATION							CORALBA	SOBO			
		TRK	PVM TEMP	AIR TEMP	ROAD	WTHR	MAT'L	RATE (lbs/	LANE TRTD		AMOUNT APPLIED (lbs)			FRICTION VALUE	READING		EQUIVALENT lbs/ln-mi	
DATE	TIME	I.D.	(°F)	(°F)	COND	COND	APPLIED	ln-mi)	NB	SB	NB	SB	TRMT	@40 mph	WT	CL	WT	CL
Feb 4	14:30		41	39	30	7								0.50	0	0	0	0
Feb 4	16:30				25	2												
Feb 4	17:00	86218	35	32	25	2	Sand/Salt*	188	1		1,880		P+A+C	0.26	0.5	3	22	135
Feb 4	17:30	86218		30	20	3	Sand/Salt*	188		1		1,880	P+A+C					
Feb 4	20:00	86218		27	15	7	Sand/Salt*	188	1		1,880		P+A+C					
Feb 4	21:30	86218		30			Sand/Salt*	188		1		1,880	P+A+C					
Feb 4	22:30	86218		29			Sand/Salt*	188	1		1,880		P+A+C					
Feb 5	08:30		20	18	30	7								0.26	3	4	135	180

TOTAL LBS MAT'L TO SB:	3,760
TOTAL LBS MAT'L TO NB:	5,640
TOTAL LBS MAT'L APPLD:	9,400

*Sand/Salt Mix is 70% Sand, 30% Salt

TOTAL LBS SAND TO SB:	2,632
TOTAL LBS SALT TO SB:	1,128
TOTAL LBS SAND TO NB:	3,948
TOTAL LBS SALT TO NB:	1,692
TOTAL LBS SAND APPLIED:	6,580
TOTAL LBS SALT APPLIED:	2,820

Codes:

WEATHER	ROAD CONDITION
1 - DRIZZLE	30 - DRY
2 - RAIN	25 - WET
3 - FR. RAIN/SLEET	20 - SLUSH
4 - LT. SNOW	15 - SNOW
5 - SNOW	10 - SNOW/ICE PACK
6 - BLOWING SNOW	5 - ICE
7 - NONE	45 - OTHER

Notes:
1 Length of section is 10 mi
2 Pavement type is DGA (Dense Graded Asphalt).
3 Air and Pavement temperature were obtained from Raytek Raynger PM-4 forms and MD Highway Administration Weather Condition Reports.
4 Treatment methods are P, C, A, P+C, P+A, C+A. P=Plowing; C=Chemical; A=Abrasives.
5 Under SOBO Heading, WT=Wheel Track, CL=Center Lane.

FIGURE 7 Chronological history of Maryland Storm 6 for control section.

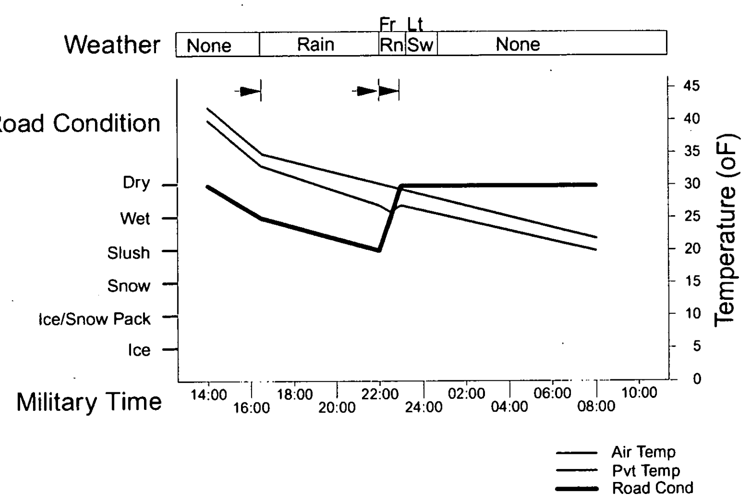

FIGURE 8 Time history of weather, pavement, and air temperature conditions for the test section on Maryland Route 495, Storm 6; arrows denote rock salt applications (application rate = 77 lb/min, total application = 5,069 lb).

apparently enough to prevent the pavement from reaching a snowy state. However, the 25.4 kg (56 lb) of salt plus 59.9 kg (132 lb) of abrasives applied per lane mile on the control section was not enough to prevent the pavement from reaching a snowy state.

The first treatment application for each storm event made by the maintenance forces on the test and control sections was classified as either an anti-icing or a deicing operation. A general definition of an anti-icing operation is one in which a maintenance treatment involving a deicer is applied to the highway before a bond is established between frozen precipitation, or frost, and the pavement surface. Conversely, a deicing operation is one in which a treatment of a deicer is applied to the top of an accumulation of snow, ice, or frost that is bonded to the pavement surface. The exact point at which frozen precipitation is either bonded, or not bonded, is very difficult to establish. In practice, a friction measurement (or Coralba reading) could help define that point in the development of the storm. The Coralba measurements, in general, were not made in the field at the appropriate time or were not reliable enough to assist in this determination for all storms. It appears that the friction measurements were

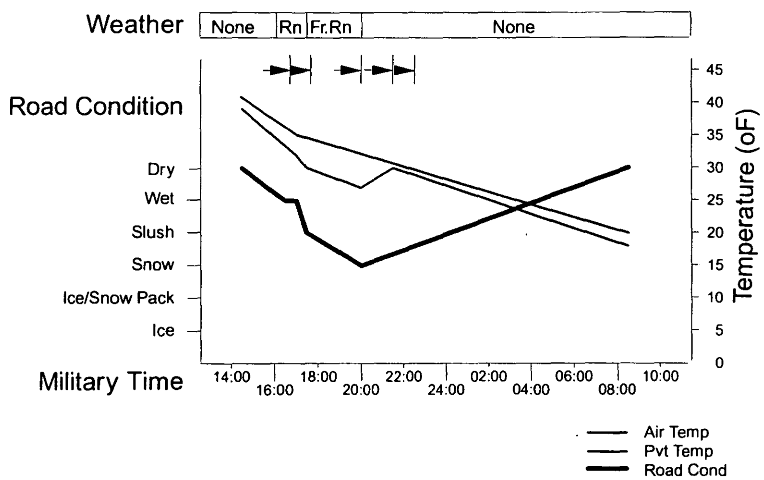

FIGURE 9 Time history of weather, pavement, and air temperature conditions for the control section on Maryland Route 495, Storm 6; arrows denote sand/salt applications (mix is 70 percent sand, 30 percent salt; application rate = 190 lb/min, total application = 9,400 lb).

made as part of the storm documentation and not as part of a decision making process concerning the reapplication for deicing/abrasive materials.

Consequently, it was necessary to develop criteria to help decide the classification of the first maintenance treatment. As developed, this classification of the first maintenance operation depends on the pavement temperature, the pavement condition, and the type of precipitation. Air temperature is not directly included in the criteria but is implicitly assumed to be below 40°C. The pavement conditions identified as appropriate for anti-icing operations are dry, wet, and one with very minor accumulation of snow or sleet on the pavement shoulder or roadway. The pavement conditions identified as appropriate during deicing operations include slush, snow and ice pack, and ice. These criteria, along with ancillary information (such as Coralba readings, Sobo-20 readings, and maintenance personnel observations), were used in classifying the first maintenance treatment of each storm.

Tabulations and plots similar to those displayed in Figures 2 through 9 are being developed for the other storm events recorded during the 1991–1992 winter.

Coralba friction measurements and Sobo-20 salinity measurements were made by some of the states during the 1991–1992 winter in an attempt to better define the pavement conditions before and during selected storm events. Coralba friction measurements were made by five states during 27 storm events; Sobo-20 measurements were made by four states during 24 storm events.

During several storms, some of the states made salinity measurements using the Sobo-20 device before the first (anti-icing) application treatment. Most of the time these pretreatment measurements resulted in zero salinity values. However, in a few storms, the pretreatment measurements indicated that there was a minor salinity level, possibly a carryover from previous storm treatments.

Cases were noted in which a low salinity measurement value was followed by an application treatment. In other cases, a low salinity measurement value was not followed by an application treatment. The same application treatment combinations were noted also for high salinity measurement values. Thus, it appears that the Sobo-20 measurement value levels were not used consistently to make decisions about reapplication treatments.

CONCLUDING REMARKS

The activities conducted so far under the program have suggested methods that can be used by winter maintenance personnel for measuring pavement friction and residual chemicals before, during, and after storm events. Such tools can provide maintenance supervisors with added knowledge of the pavement conditions for their decision making.

The analysis of the 1991–1992 winter maintenance field data is starting to reveal some interesting results concerning anti-icing operations in the United States. The balance of the analysis results will be used to help guide the continued anti-icing experiments planned for the 1992–1993 winter.

ACKNOWLEDGMENTS

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