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Development of Anti-Icing Technology

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Abstract

Limited experience (mainly of Scandinavian and other European countries) has shown that applying a chemical freezing-point depressant on a highway pavement prior to, or very quickly after, the start of frozen precipitation minimizes the formation of an ice-pavement bond. Potentially, this anti-icing practice reduces the task of clearing the highway to bare pavement conditions and requires smaller chemical amounts than are generally required under conventional deicing practices. Nine state highway agencies conducted anti-icing experiments when possible during the 1991-92 and 1992-93 winters. These tests were used to develop a better understanding of both the conditions under which anti-icing will be effective and how to conduct anti-icing efficiently to ensure the greatest success. Prewetted salt and liquid chemicals were used during the anti-icing experiments. The project also involved evaluating of specialized equipment for applying controlled quantities of solid, prewetted, or liquid chemicals at minimum application rates required for effective anti-icing treatment. Limited field tests were conducted with some Department of Transportation spreaders to determine important variables associated with evaluating spreader application rates and distribution patterns. A proposed American testing protocol for evaluating winter maintenance spreaders was developed based on foreign protocols.

A limited cost-benefit analysis was performed, comparing anti-icing effectiveness with deicing operations, considering such factors as accidents and material, equipment, and labor costs. Finally, the report contains a preliminary manual of practice for an anti-icing treatment program. The report also presents meteorological criteria and support items that are important for anti-icing operations at potential test sites.

Executive Summary

Limited experience (mainly of Scandinavian and other European countries) has shown that applying a chemical freezing-point depressant on a highway pavement prior to, or very shortly after, the start of accumulation of frozen precipitation minimizes the formation of an ice-pavement bond. This anti-icing practice reduces the task of clearing the highway to bare pavement conditions and requires smaller chemical amounts than are generally required under conventional deicing practices. State highway agencies (SHAs) in the United States generally have not adopted anti-icing practices in spite of the potentially greater effectiveness and reduced costs associated with the practice. The main reasons for the lack of acceptance concern the uncertainty about the conditions most favorable for anti-icing and how to conduct anti-icing. The imprecision with which icing events can be predicted, the uncertainty about the condition of the pavement surface, and the public's perception of wasted chemicals further complicate the situation. Some early anti-icing attempts in the United States have failed because of these uncertainties.

Technological developments in forecasting weather and in assessing pavement surface conditions now offer the potential for successfully implementing anti-icing treatments. Sensors embedded in the pavement surface are able to 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, the information provides a reasonable prediction of pavement surface conditions for a period of up to 24 hours. Improved weather forecasting targeted specifically to local or regional road conditions also provides the maintenance manager with the means to predict pavement surface state. In addition, better communications rapidly relay this information to both maintenance forces and the public.

Highway agencies need a better understanding of both the conditions under which anti-icing will be effective, and how to conduct anti-icing efficiently to ensure the greatest of success. Several hurdles standing in the way of 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; prewetted salt may also be effective in reducing the amount of material that is blown off the road by traffic. In addition, the influence of the time between an application of salt and the onset of freezing precipitation is not fully understood.

European and Scandinavian experience has shown that as little as 5 to 10 g/m^2 (65 to 130 lb/lane-mile) of salt is needed for preventive salting treatment for frost, black ice, and light snow. There appears to be no consensus among European countries regarding the rate of salt spreading during continuous snowfalls. Estimates of application rates under these conditions range from 10 to 60 g/m^2 (130 to 780 lb/lane-mile). Highway agencies in the United States have found that reducing the conventional application rate to quantities on the order of 4 or 5 g/m^2 (42 or 65 lb/lane-mile) is not generally possible with current equipment that is designed for deicing application rates of 23 to 38 g/m^2 (300 to 500 lb/lane-mile) and higher.

Liquid freezing-point depressants offer the advantage of precise and uniform application over a wide range of rates. In Scandinavia, liquid salt solution has proven successful as an anti-icing treatment under certain conditions. Scandinavian maintenance personnel have also found liquid salt is most effective when used for black ice and for preventive operations in the fall and spring. Furthermore, their experience also indicates that liquid salt should not be used when the pavement temperature is less than −5°C (23°F), nor should it be used with freezing rain or applied on compacted snow. Effective techniques for using liquid chemicals have not been developed in the United States.

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 Project H-208. The objectives were to develop a better understanding of the conditions under which anti-icing will be effective and to investigate various anti-icing techniques that will have the greatest potential for success over a range of conditions.

The research was both experimental and analytical in nature. Because traffic was expected to influence the effectiveness of anti-icing treatments various treatment programs were evaluated in field tests on in-service highways. The field tests were conducted in a number of geographic locations to include the influence of a wide number of variables. These tests were performed in cooperation with state highway agencies (SHAs) during the first part of this project, designated as H-208A. Also performed as part of this contract were analyses of the relative costs of anti-icing and deicing, considering such factors as accidents, time delays, and material, equipment, and labor costs.

The second part of this project, H-208B, involved developing of methods for measuring residual chemicals on treated pavements. This also involved a survey of the worldwide equipment market for specialized apparatus used to apply controlled quantities of liquid or solid chemicals at the minimum application rates required for effective anti-icing treatment. The effectiveness of selected equipment in achieving specified application objectives, such as precise control of the spreading or spraying pattern and of the quantities applied, was investigated during appropriate outdoor tests.

Nine SHAs participated in testing in-service highways: California, Colorado, Maryland, Minnesota, Missouri, Nevada, New York, Ohio, and Washington. A total of 14 test sites were selected in the nine states. The individual test sites consisted of a test (experimental) section and a control section. The test sections selected 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 in close proximity to each test section was also selected to serve as a control for the experiment. Each control section matched its associated test section as closely as possible, in regard to area type, pavement type, and volume of 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. A treatment strategy, consisting of the type of chemical to be used and the treatment timing, was selected for each test section in cooperation with each SHA. The types of chemicals used were prewetted solids and a liquid. Liquid chemical was used at one test site in California and one in Nevada. The treatment timing included both prior to the storm and at the beginning of the storm.

In planning 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 adverse weather conditions. The devices also had to provide meaningful results. Separate investigations were conducted in selecting techniques for measuring pavement friction and salinity.

The Coralba Friction Tester was selected for making pavement friction measurements based on a comparison of field test measurements with ASTM E274 skid trailer results. The Coralba is a Swedish instrument used to measure friction on some European and Scandinavian airport runways. The device can be installed in a pickup or passenger vehicle and is connected to the brake system. The system measures the friction between the tire and pavement by monitoring the speed reduction over time of one of the vehicle's wheels during a braking operation. The friction value obtained from a test is displayed on a dash-mounted unit.

An extensive investigation was made to determine what equipment and procedures were suitable for use by maintenance personnel to measure residual anti-icing chemicals on pavement surfaces during the field experiments. A review of information collected on potential devices indicated the SOBO-20 salinity tester, manufactured by Boschung Company of Switzerland, was the most promising candidate for a salinity tester. This device has a built-in conductivity cell and is specifically designed for the quantitative measurement of chloride solutions on roads. Laboratory experiments conducted with a borrowed unit showed the device had applicability to the study.

Some equipment and support items were provided to the participating SHAs where necessary for full participation in the anti-icing experiments:

- ground-oriented spreader controls;
- prewetting equipment for spreader trucks;
- fixed liquid spray systems and associated tanks for prewetting truck loads;
- storage tanks, pumps, and liquid deicing chemicals;
- a Road Weather Information System (RWIS);
- a system upgrade for an existing RWIS;
- local weather forecasting service;
- Coralba friction testers;
- SOBO-20 chloride measuring instruments; and
- infrared radiometers;

In general, RWIS pavement and atmospheric sensors were incorporated in each test section except for the one in Maryland. The RWIS provided information needed for informed decisions regarding pretreatment timing and application rates. Maryland was provided with a hand-held radiometer with which to measure pavement temperature.

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 Minnesota Department of Transportation (MNDOT), New York State Department of Transportation (NYDOT), and manufacturers and vendors of road weather information systems.

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, incorporating specific state requirements for winter maintenance activities, and reflecting site-specific geographic and climatic considerations and the specific 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 background on the scope of the project, basic meteorology, and snow-and-ice control chemicals; a description of the design, operation, and 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, etc. Hands-on training was also furnished for both the SOBO-20 chloride measuring instrument and the Coralba friction tester.

Operation, calibration, and maintenance instructions were also prepared 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.

State maintenance personnel were trained in the use of a series of data recording forms designed specifically for 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, in the case of Maryland, the recording of radiometer measurements.

The nine SHAs conducted anti-icing experiments when possible during the 1991-92 and 1992-93 winters. The first was run in Nevada in mid-December 1991. The official end of the anti-icing experiments for the 1991-92 winter was the end of March 1992. At that time, 57 storm events had been recorded by the nine participating states, in spite of the late start of the anti-icing experiments during the 1991-92 winter. Over 70% of the events were recorded by Maryland Department of Transportation (MDDOT), Nevada Department of Transportation (NDOT), MNDOT, and NYDOT maintenance personnel. No storm events were recorded at four sites because of the extremely mild winter after the program became operational.

One-day refresher training sessions were held at the appropriate maintenance facilities in preparation for the anti-icing experiments conducted during the 1992-93 winter. The refresher training was conducted from mid-October to early November 1992.

During the retraining, a review of the anti-icing testing procedures and reporting requirements was presented, along with the findings from the first winter's testing. Problems reporting the 1991-92 winter field data were discussed in detail, as were any particular requirements or changes the maintenance personnel wanted to make in the 1992-93 field testing procedures. Minor changes were made in some states regarding test or control section boundary limits, application mixtures, and type of deicer used.

The first anti-icing experiments of the 1992-93 winter were conducted in Minnesota at the beginning of November 1992. Data collection continued until the end of March 1993. At that time, 110 storm events had been recorded by the nine participating states. Approximately 66% of the events were recorded by MNDOT, NDOT, and NYDOT maintenance personnel. Storm events were recorded at all 14 test sites in the nine states.

Coordination with the participating SHAs continued frequently throughout both winters. Winter maintenance field data were collected to determine the effectiveness of anti-icing treatments relative to conventional deicing. Data for each storm event in the two winters were analyzed in a similar manner. The procedures provided a chronological history of the meteorological events, pavement conditions, and maintenance activities associated with the storm, including the amount of material applied to each traveled lane. Coralba friction measurements and SOBO-20 readings were identified by location. The pavement type was identified for each Coralba and SOBO-20 reading, where possible.

A number of quality control checks were imposed on the data as they were entered into a spreadsheet database. These checks identified numerous field recording errors and reporting inconsistencies which were subsequently clarified by the responsible maintenance personnel.

Graphical presentations were also generated, when possible, of the weather, pavement conditions, and air temperatures as a function of time for the test and control sections. A summary was made of the total material (chemical and abrasives) applied to the test and control sections during the storm events. Also, summaries of each storm event were developed to provide an overview of the event, the test and control section pavement conditions at the first winter maintenance treatment, and a brief history of both the test and control section pavement conditions during the storm. Finally, summary tabulations were made of the maintenance activities on the test and control sections and the savings achieved on the test sections in each state.

Of the 57 storms recorded during the 1991-92 winter, only 42 could be analyzed; there was insufficient data for the other 15 storms. The major causes for rejection were incomplete or missing operator activity data, missing weather and pavement condition information, or missing RWIS data.

During 21 out of 42 (50%) storms, less chemical and abrasive material were used on the test sections than on the control sections. The rate of chemical reduction achieved on the test sections during the 1991-92 winter was 23% in New York, 30% in Ohio, and 49% in Nevada. The other states reported increased chemical usage. Nevada also reported a 74% reduction in abrasive used over the winter on the test section as compared to the control section. Various combinations of anti-icing and deicing operations were used during these 21 storm events. Their successes resulted from better timing of the treatment applications, more sensible deicing operations, and a better awareness of the pavement conditions during the storm events on the part of maintenance personnel

Five storms during of the 1991-92 winter were analyzed in which anti-icing operations were used on the test sections while deicing operations were used on the corresponding control sections. During two of these (40%), less chemical was used on the test section than on the corresponding control section. Abrasives were used during three of these five storms. Reduced amounts of abrasives were used on the test section (as compared to the control section) during all three events. No maintenance passes were saved during the first winter through anti-icing operations.

Of the 110 storms recorded during the 1992-93 winter, 102 (or 93% of the total) could be analyzed. This percentage is much higher than that achieved for the first winter (74%). The major reasons why the other eight storms could not be analyzed are the same as were noted for the 1991-92 winter.

During 64 out of 102 (63%) storms, less chemical and abrasive material was used on the test sections than on the control sections. The rate of chemical reduction achieved on the test sections during the 1992-93 winter was 50% in Missouri, 14% in Ohio, and about 41% in New York. The other states reported increased chemical usage.

The 50% reduction in chemical use recorded by Missouri during the second winter is in contrast to a 102% increase recorded during the first winter. A possible explanation for this radical reversal was that more events were recorded in Missouri during the second winter (11) than were recorded during the first winter (3). This increased number of events provided maintenance personnel with the opportunity to successfully experiment with the testing procedures.

Reduction of chemical use in the test site, as compared with the control zone, in Ohio during the second winter (14%) was about half that achieved during the first winter (30%). No clear explanation could be found for this increased use.

The 41% reduction in chemical usage recorded by New York during the second winter was almost double that recorded during the first winter (23%). This significant reduction was due, in large part, to the increased awareness on the part the maintenance personnel of the operating conditions of the test section before and during the many storm events recorded (36).

The increased chemical use recorded by Nevada during the second winter (37%) was considerably different from the 49% reduction achieved during the first winter. The overall increased chemical use resulted primarily from activities during four storms during which much greater amounts of chemicals were used on the test section than on the control section. During three of these storms, snow and ice pack and icing conditions developed on the test pavement as a result of relatively low pavement temperatures −4.4°C (24°F) and below. The other storm involved freezing rain and sleet along with snow showers. The pavement temperature during this storm was around −1.7° to −1.1°C (29° to 30°F). These four storm events suggest that the liquid chemical used was not adequate for the lower pavement temperature −4.4°C (24°F) and for freezing rain conditions. The same temperature limitation for use of liquid chemicals has also been identified by the Finnish National Road Administration.

The success of the 64 trials during the 1992-93 winter, as was the case during the first winter of testing, resulted from better timing of the treatment applications, more sensible deicing operations, and a better awareness on the part of maintenance personnel of the pavement conditions before and during the storm events.

Combinations of anti-icing operations on the test section and deicing operations on the control section took place during 13 of the 102 storm events analyzed. Less chemical was used on the test section than on the corresponding control section during eight of the 13 (62%) storms. Abrasives were used during eight of these 13 storm events. Reduced amounts of abrasives were used on the test section (as compared to the corresponding control section) during seven of the eight events. One maintenance pass was saved through anti-icing operations during these 13 storm events.

The various states conducted successful anti-icing and sensible deicing operations during the 1991-92 and 1992-93 winters. These were accomplished by maintenance personnel closely monitoring the pavement conditions before and during the storms. Some experiments were unsuccessful. The lessons learned are given below.

Generally, the liquid chemical magnesium chloride ($MgCl_2$) was successful as an anti-icing agent when applied at the rate of about 7.7 g/m^2 (100 lb/lane-mile equivalent dry chemical) and when the pavement temperature was above −5° to −4.4°C (23° to 24°F). The liquid chemical was much less effective when applied during freezing rain or drizzle. It definitely should not be applied on compacted snow. When liquid chemical is used with falling snow, continuous visual observations are required so that refreezing of the road surface can be detected and the chemical reapplied. During prolonged snowfall, it is necessary to plow the accumulation repeatedly following each time with an application of liquid chemical. Under these conditions, it may be necessary to increase the application rate to 15 g/m^2 (200 lb/lane-mile) or higher. Extreme care should be used in applying the liquid chemical under high wind and drifting snow conditions.

The use of prewetted salt in anti-icing operations has the potential for reducing the amount of dry salt required because the prewetted salt is not blown off the traveled surface as easily as dry salt by traffic action. Prewetted salt also facilitates formation of a brine.

When prewetting was done at the spinner, the amount of liquid chemical used in the prewetting experiments ranged from 0.021 to 0.025 L/kg (5 to 6 gal/ton) of saturated salt solution. Twice this amount of liquid was used when salt was prewetted in the truck bed. It was observed that these amounts of liquid prewetting were too low and that, perhaps, 1.5 times as much liquid should have been used for better surface coating of the dry salt.

Prewetted salt appeared to be an effective anti-icing agent when applied at the rate of about 7.7 g/m^2 (100 lb/lane-mile) and when the pavement temperature was above −9.4° to −6.7°C (15° to 20°F), depending on the type of liquid used for prewetting. The use of prewetted salt during prolonged rain or freezing rain required frequent observation and sometimes increased application rates of 15 g/m^2 (200 lb/lane-mile) or higher.

The project also involved evaluating specialized equipment for applying controlled quantities of solid, prewetted, or liquid chemicals at the minimum application rates required for effective anti-icing treatment. The effectiveness of achieving specified application characteristics, such as precise control of the spreading or spraying pattern and of the amounts applied, was investigated. This involved conducting a worldwide survey of spreader equipment; selecting equipment to be tested; selecting an appropriate field test site; identifying measures of effectiveness; and finally, conducting very limited field tests of a few anti-icing application units.

U.S. and foreign manufacturers of highway spreader equipment were asked how they test their equipment's performance. This information was used to develop testing protocols for the equipment evaluation. These inquiries revealed that the highway spreader industry in the

United States does not test equipment operating characteristics. Consequently, the researchers performed field tests with some spreaders to determine important variables associated with spreader application rates and distribution patterns in order to develop their own protocol. However, European protocols do exist for testing spreader capabilities; in fact, some European governments require spreader manufacturers to demonstrate compliance with the protocols before the equipment can be accepted for use in that country. Researchers visited several European and Scandinavian manufacturing and research facilities to obtain spreader testing protocols for potential use in the United States and to review various anti-icing studies. The British, Danish, and German protocols were obtained and are given in the report, along with detailed information collected during the visits. A proposed American testing protocol for evaluating winter maintenance spreaders was developed from the foreign protocols and is also presented in the report.

A limited cost-benefit analysis was performed, comparing anti-icing effectiveness with deicing operations, considering such factors as accidents and material, equipment, and labor costs. Estimates of accident rates under dry, wet, and ice- and snow-covered pavement conditions were determined from accident, weather, and traffic volume data for several winters for selected sites in New York. The required material, equipment, and labor costs and the estimated effectiveness for anti-icing operations were based on the experience of the participating states in conducting anti-icing operations during the 1991-92 and 1992-93 winters as part of this study. These data were then combined in a cost-benefit analysis of pretreatment strategies. The results of the analysis indicate that under certain conditions anti-icing operations can result in cost savings to highway agencies and reduce accidents.

The report contains a preliminary manual of practice for an anti-icing treatment program. It also presents meteorological criteria and support items that are important for conducting anti-icing operations at potential sites.

Conclusions and Recommendations.

Some of the states conducted successful anti-icing operations during the 1991-92 and 1992-93 winters. There is clearly a learning curve associated with the use of anti-icing technology. Initial application rates of 7.7 g/m^2 (100 lb/lane-mile) of salt appear to be adequate for anti-icing operations, if applied at the appropriate time and not under severe storm conditions of extremely cold pavement temperatures and high winds. Weather forecasting specific for the highway system environs is essential to the success of anti-icing. The Coralba friction tester and the SOBO-20 salinity tester, when used correctly, have the potential of providing winter maintenance personnel with timely information needed for treatment application decisions.

Finally, no U.S. manufacturer could be found that makes highway spreaders specifically designed to distribute prewetted material or liquid deicing chemicals. Such spreader equipment is currently manufactured in European and Scandinavian countries. The equipment can dispense small amounts of salt and can control the distribution pattern of the applied material. Some of the equipment is capable of dispensing all three types of material: dry, prewetted solids, and straight liquid.

Additional winter testing of anti-icing technology should be conducted in the United States to supplement the knowledge gained from the two winters of testing. Anti-icing operations should be conducted using liquid chemicals under a variety of winter storm and traffic conditions. The role of traffic volume in these anti-icing operations needs to be assessed. Finally, anti-icing experiments should be conducted using similar salt gradations and prewetting proportions similar to those used in Europe.

1

Introduction and Research Approach

Introduction

The impact of snow and ice storms has long concerned the traveling public. Prior to the development of the automobile, travel during winter weather was somewhat limited. The automobile and all-weather roads led to in the development of improved snow-and-ice removal techniques that replaced the slow and labor-intensive use of hand tools so prevalent in the early 1900s.

The years between 1920 and 1929 witnessed the most rapid change in snow-removal technology on highways. The demand for complete removal of snow from the all-weather roads grew yearly, and the need for bigger, more capable equipment and better removal techniques became apparent. During these years, blade plows became bigger and heavier, truck plowing speeds increased from something less than 5 mph to 30 mph or faster as truck power and weight increased, and trucks became the most important tool in snow removal[1].

Deicing salts, primarily sodium chloride, have been applied to highways control snow and ice since early in this century. Prior to 1941, very little straight salt was applied to the roadways; most was mixed with sand or other abrasives to freeze-proof stockpiles and to treat locally hazardous highway locations such as curves, hills, and intersections. Experiments began in New England in 1941 using sodium chloride alone as a snow- and ice-control chemical. The total amount of sodium chloride applied across the country remained relatively low until the mid-1950s when usage surged dramatically to around 1 million tons annually, partially in response to the public demand for better all-weather roadway conditions. This demand eventually led to the adoption of a bare pavement policy by the highway departments in the snowbelt states[2].

Currently, the economic well-being, livelihood, and strategic defense of the United States depends to a large extent on the year-round mobility of trucks, buses, and passenger cars on the nation's highway network. Winter conditions of ice and snow still cause serious disruptions in the economies of nearly all states. Our great dependence on highway transportation for the movement of goods, services, and people has resulted in the demand for more rapid and effective clearance of ice and snow from the highways. As a result, highway agencies have increased the use of chemicals and abrasives to assist in providing a clear roadway.

Each year about $1.5 billion is spent on highway snow-and-ice control programs in the United States. Apart from plowing, the most important element of these programs is chemical deicing, which represents about one-third of winter maintenance expenditures. Since 1970, the annual salt usage by highway agencies has fluctuated from 8 million to 12 million tons; year-to-year variations depending mainly on winter conditions. The current usage of salt averages 10 million tons per year[3].

Sodium chloride has become the chemical of choice because it is effective at subfreezing temperatures (eutectic temperature of -21°C (−6°F), has low first costs, and is readily available. At temperatures not far below freezing, salt is effective for combating ice and light snow and greatly enhances the effectiveness of plowing under heavy snow conditions.

Concern has been steadily voiced over the last few years about the effects of heavy salt use on the roadside environment, water supplies, vehicles, and highway structures. The direct cost of the current national salt usage is about $500 million. However, the effective cost of its use is many times higher. A 1981 report by the National Bureau of Standards and Battelle Laboratories[4] concluded that the automobile corrosion costs attributable to salt use were about $1.2 billion per year. Estimates made by Murray and Ernst[5] in 1976 indicated that the cost of salt damage to bridges is even larger than the cost of automobile corrosion.

A recently completed study performed by a special committee of the Transportation Research Board (TRB) indicated that the annual costs for motor vehicle and infrastructure damage from continued salting could range from approximately $2 billion to $4.5 billion per year[3]. Including other cost items could increase the damage estimate to a range of $3.5 billion to $7 billion per year. These additional items include damage to roadside objects, corrosion of underground materials and structures, and costs incurred by motorists who are inconvenienced by bridge and parking garage damage and repair work. Thus, an apparently inexpensive highway deicing method is, in reality, quite expensive, possibly more than 10 times the cost of the material itself.

In addition, the extent and cost of environmental pollution are now manifesting themselves. Although there has not yet been a nationwide estimate of the costs arising from environmental pollution (particularly the salination of water supplies), the number and cost of local problems are beginning to paint an alarming picture. At a meeting of the Winter Maintenance Committee of TRB[6], presentations included reports of additional construction costs of $2.5 million for a quarter mile segment of an interstate route to avoid direct salt run-off; $1.5 million to provide city water to a small community whose water supply had been contaminated by sodium chloride; and $4 million to develop protection wells and drainage systems to safeguard another community's water wells. These are just a few of the many environmental problems which are arising from the heavy use of salt.

Removal of ice (and compacted snow) from highway surfaces has been accomplished in part by mechanical means (scraping) and in part by use of deicing chemicals or, in many locations, by a combination of these techniques. Neither the combination of these methods nor their independent use is completely satisfactory. The heavy dependence on chemical methods (salts) has the problems described above, and the mechanical method does not provide adequate ice removal.

Limited experience in Europe[7-12] and North America has shown that applying of a chemical freezing-point depressant on a highway pavement prior to, or very quickly after, the start of ice or snow minimizes the formation of an ice-pavement bond. This anti-icing practice reduces the task of clearing the highway to bare pavement conditions and requires smaller chemical amounts than is generally required under conventional deicing practices. State highway agencies (SHAs)in the United States have not adopted anti-icing practices, in spite of the potentially greater effectiveness and reduced costs associated with the practice. The main reasons for the lack of acceptance concern the uncertainty about what conditions are most favorable for anti-icing and how anti-icing should be conducted. The imprecision with which icing events can be predicted, the uncertainty about the condition of the pavement surface, and the public's perception of wasted chemicals further complicate the situation. Some early anti-icing attempts in the United States have failed because of these uncertainties. Technological developments in weather forecasting and in assessing pavement surface conditions now offer the potential for successfully implementing anti-icing treatments. Sensors embedded in the pavement surface are able to measure the temperature representative of the surrounding pavement and of detecting 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; when used with available algorithms, the information provides a reasonable prediction of pavement surface conditions for up to 24 hours Improved weather forecasting, targeted specifically to local or regional road conditions, also provides the maintenance manager with the means to predict pavement surface state. In addition, better communications rapidly relays this information to maintenance forces and the public.

Highway agencies need better understand the conditions under which anti-icing will be effective and how to conduct anti-icing efficiently to ensure the greatest success. Several hurdles standing in the way of 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. Prewetting the salt also may be effective in reducing the amount of material that is blown off the road by traffic. In addition, the influence of the time between an application of salt and the onset of freezing precipitation is not fully understood.

Limited experience has shown that as little as 10% to 20% of the normal application rate of deicing chemicals is required for anti-icing. Highway agencies have found that reducing the conventional application rate to quantities on the order of 4 g/m^2 (50 lb/lane-mile) is not generally possible with current spreading equipment that is designed for deicing application rates of 23 to 38 g/m^2 (300 to 500 lb/lane-mile) and higher.

Liquid freezing-point depressants enable precise control of uniform application over a wide range of rates. However, effective techniques for using liquids remain to be developed in this country.

In early 1991, SHRP funded a multiyear study entitled "Development of Anti-Icing Technology" under Contract SHRP-90-H208. The study was designed to identify solutions to overcome the above obstacles for successful implementation of anti-icing practices in winter maintenance operations. This report documents the methodology used in that study, along with the findings, application of findings, conclusions, and recommendations.

Research Objectives and Scope

The overall objectives of the research program were to develop a better understanding of the conditions under which anti-icing will be effective and to develop various anti-icing techniques that have the greatest potential of success over the range of expected conditions. Embedded within these overall objectives were four supplemental objectives:

- to determine the most appropriate application rates for anti-icing treatments over a range of traffic and environmental conditions and the capabilities of application equipment in achieving these rates.

- to investigate the effectiveness and cost of salt and nonchloride chemicals, in both solid and liquid form, as anti-icing treatments. The anti-icing approach includes the use of state-of-the-art technology to measure pavement surface condition and relies on improved weather prediction capabilities.

- to conduct a cost-benefit analysis of precautionary chemical application (anti-icing) versus conventional deicing in maintaining a pavement safe for traffic. The effects of the anti-icing treatments on the environment and vehicles are considered in the analysis, if possible.

- to predict the effect anti-icing treatments may have on long-term accident rates for selected road sections.

The research was both experimental and analytical in nature. Because traffic is expected to influence the effectiveness of anti-icing treatments, various treatment approaches were field tested on in-service highways. The field tests were conducted in a number of geographic locations to evaluate the influence of a wide number of variables. These tests were performed in cooperation with SHAs during the first part of this contract, designated as H-208A. Also performed as part of this contract were analyses of the relative costs of anti-icing versus deicing, considering such factors as accidents; time delays; and material, equipment, and labor costs.

A second part of this contract involved developing of methods to measure residual chemicals on treated pavements. This second part also involved a survey of the worldwide equipment market for specialized apparatus for applying controlled quantities of liquid or solid chemicals at the minimum application rates required for effective anti-icing treatment. The effectiveness of selected equipment in achieving specified application objectives, such as precise control of the spreading or spraying pattern and of the quantities applied, was investigated during outdoor tests.

The results of the multiyear research study included

- a determination of the effectiveness of anti-icing compared to deicing;
- a survey of chemical spreading equipment and an evaluation of appropriate equipment used for anti-icing treatments; and
- a manual of practice for an anti-icing treatment program, in sufficient detail to enable a SHA to implement an effective anti-icing program.

Research Approach

The research objectives were met through a two-part, multiyear, multitask effort by means of field testing on in-service highways. Part 1 of the study consisted of three tasks:

Task 1—Research Design
Task 2—Field Observations
Task 3—Analysis of Anti-Icing Effectiveness

The evaluation of anti-icing technology included evaluating the effectiveness of prestorm treatment (pretreatment or anti-icing) strategies and evaluating of the operational usefulness of existing technology for weather forecasting, pavement sensing, and thermal mapping in determining when pretreatment strategies should be applied. The evaluation of pretreatment strategies addressed their effectiveness in reducing the difficulty of clearing roads to bare pavement during the subsequent storm; reducing the total amount of chemicals needed (pounds per lane-mile for pretreatment, during-storm and poststorm treatment combined); reducing the number of passes and the amount and type of equipment needed; and reducing the duration that pavements are ice-covered and consequently reducing the frequency of ice and snow-related accidents. The evaluation of technology for determining when to apply pretreatments considered the effectiveness of approaches to minimize errors, both of applying pretreatments when they are not needed and of not applying pretreatments when they are needed. These evaluations were based on operational field data. Consequently, the results document the practical and achievable benefits of using anti-icing technology in the actual operating environment of a highway maintenance organization.

Part 1 of the research focused on the use of chemicals and equipment which the participating SHAs consider sufficiently proven technology and appropriate for application on in-service highways. Part 2 of the research involved evaluation of specialized equipment. Part 2 investigated of approaches to measuring the chemical residue on in-service pavements during winter maintenance operations and assessed innovative approaches for dispensing chemicals for anti-icing treatments. This second part consisted of two tasks:

Task 1—Residual Chemical Measurement
Task 2—Equipment Evaluation

The research approach is outlined below, together with a brief description of the activities in each step. The activities are discussed without reference to the part of the study in which they took place.

Research Review

Two literature searches were conducted at the beginning of the study, one for data on anti-icing technology, the other for information about spreader equipment and associated controls. Each is briefly described below.

Search topics included anti-icing, snow and ice detection, thermal mapping, and weather forecasting or prediction. Data bases searched included those of the U.S. Army Cold Regions Research and Engineering Laboratory (USACRREL), the National Technical Information Service (NTIS), and the Transportation Research Information Service (TRIS). Approximately 130 citations covering a period of 20 years were found. Abstracts of the citations were reviewed, and selected references were ordered for further review. Very little pertinent information on anti-icing was found.

Letters were sent highway agencies in Sweden, Finland, and Norway explaining the project and requesting copies of any pertinent information in their files. Responses were that the information needed was from ongoing studies and not published at that time, but would be available in the near future. The researchers were also encouraged to visit the Scandinavian countries to learn firsthand from local roadmasters of their experiences with anti-icing.

Requests were sent to manufacturers of road weather information systems (RWISs), pavement friction measurement devices, and salinity measurement instruments for any information on their equipment that would have applicability in the program.

A literature search was made for references to spreader equipment and associated controls. Data bases searched included USACRREL, NTIS, TRIS, and COMPENDEX. The key words used were:

- Chemicals
- Liquid salt and spreader
- Prewetting at:
  - spinner
  - load
  - pile
- Salt and spreader
- Snow and ice control
- Spreader and chloride
- Spreader and controls
- Spreader and sand
- Spreader and spinner

Approximately 190 citations were found covering a period of about 35 years. No equipment for use in anti-icing treatments was identified in the literature.

Initial efforts were made to identify worldwide sources of information concerning specialized equipment for applying controlled quantities of liquid or solid chemicals at minimum application rates required for effective anti-icing treatment. Names and addresses of equipment suppliers, material vendors, and contacts in Sweden, Finland, Denmark, and England were generated from contacts MNDOT has made over the last several years.

Manufacturers of spreader controls, aggregate (including solid deicer) spreaders, and fertilizer spreaders were for information on equipment that could be used to apply controlled quantities of solid, prewetted solid, and liquid deicing chemicals at application rates required for effective anti-icing treatments. They were also asked to identify any procedures that have been developed for evaluation of spreader controls and the spreading pattern. The only test procedure found in the United States was for evaluating the application rate and spreading pattern for agricultural spreaders of solid fertilizers.

Research Design

A research design was developed for testing anti-icing technology on in-service highways. This design consisted of these steps:

- selecting participating SHAs and evaluation sites;

- determining variables to be evaluated, including anti-icing strategies and site characteristics; and

- selecting and purchasing equipment needed by the participating SHAs to conduct the anti-icing experiment.

SHRP identified nine SHAs as interested in participating. Each agency 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 currently used, spreader equipment available, weather forecasting services used, and the locations of any RWIS's. Each of the nine state agencies was visited following the initial contact. During these visits, specific information was obtained on the current snow- and ice-control practices used by the agency, the proposed test and control sections, the type of material and spreader equipment typically used in the study area(s), the frequency of storm events, and the meteorological support and pavement sensors available at each site. Documentation was also obtained from each state on its snow- and ice-control practices, and photographs were taken of the proposed test and control location(s).

The test sections selected during the state 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 in close proximity to each test section was also selected to serve as a control. Each control section matched the test section as closely as possible in regard to area type, pavement type, and volume of average daily traffic (ADT). The control sections were to be treated in accordance with the conventional snow and ice control policy of the state.

A summary of the state visits is provided in tables A-1 through A-10 (Appendix A). The information includes the standard snow and ice-control strategy used by each agency, the location and characteristics of candidate test sites, the frequency of storm events, local meteorological support (including RWIS's), and any spreader equipment available for use in the program. Also included is an assessment of the obstacles which could hinder implementation of the study and the recommended technical approach, equipment, and associated costs.

Nineteen potential test sites located in nine different states are listed in Appendix A. Each site had an experimental section and a control section.

Data collected during the state visits were analyzed and assembled into a recommended research design for testing various anti-icing treatment strategies. This research design was presented to a SHRP advisory committee. As a result of the review and an analysis of equipment costs, it was decided to drop the US-40 site in Ohio from the study. Table 1 presents the final geographic distribution of test sites as approved by SHRP. This table does not include one of the two potential Nevada sites and the three sites in the maritime area of Maryland. These latter four sites were not recommended for use in the study for several reasons. Consequently, only 14 of the possible 19 test sites were selected in the nine participating states.

Table 1. Geographic distribution test sites.

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

The information obtained from the various surveys (telephone, site visits, and literature) is summarized in the research design in table 2. This table lists 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, (that is the type of chemical to be used and the treatment timing) is provided. Eight of the 23 were to be treated prior to the storm: 3 on portland cement concrete (PCC) pavement and 5 on dense-graded asphalt (DGA) pavement. Fifteen were to be treated at the beginning of the storm: five on PCC pavement, nine on DGA pavement, and one on open-graded asphalt (OGA) pavement. Due to practical restrictions and safety considerations, the research design could not be balanced with respect to pavement type and treatment strategy.

Table 2. Recommended research design.

Geographic area	State	Area type	Pavement type	ADT	Est. number of winter events	Treatment strategy: Type of chemical to be used	Treatment strategy: Treatment timing
Mountain	California	Rural	DGA	31,100	40	a) Liquid $MgCl_2$ b) Rock salt prewetted w/liquid $MgCl_2$ plus a corrosion inhibitor	Pre-storm
Mountain	California	Rural	PCC	31,100	40	a) Liquid $MgCl_2$ b) Rock salt prewetted w/liquid $MgCl_2$ plus a corrosion inhibitor	Pre-storm
Mountain	California	Rural	DGA	2,200	120	Rock salt prewetted w/liquid $MgCl_2$	Pre-storm
Mountain	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	Liquid $MgCl_2$	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 effect	Minnesota	Rural	DGA	5,800	18	Rock salt prewetted w/liquid $CaCl_2$	Pre-storm
Lake effect	Minnesota	Rural	PCC	5,800	18	Rock salt prewetted w/liquid $CaCl_2$	Pre-storm
Lake effect	Minnesota	Urban	DGA	35,000	18	Rock salt prewetted w/liquid CMA or KAc	Beginning of storm
Lake effect	Minnesota	Urban	PCC	35,000	18	Rock salt prewetted w/liquid CMA or KAc	Beginning of storm
Lake effect	New York	Suburban	DGA	19,900-45,700	40-50	Rock salt prewetted w/liquid $CaCl_2$	Beginning of storm
Lake effect	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

Some equipment and support items were provided to the participating SHAs where necessary for full participation in the anti-icing experiments:

- ground-oriented spreader controls;
- prewetting equipment for spreader trucks;
- fixed liquid deicer spray systems and associated tanks;
- storage tanks, pumps, and liquid deicing chemicals;
- a RWIS;
- a system upgrade for an existing RWIS;
- local weather forecasting service;
- friction testers;
- salinity detection instruments; and
- infrared radiometers.

In general, each test section (except the one in Maryland) contained RWIS pavement and atmospheric sensors so that informed decisions could be made regarding pretreatment timing, application rate, etc. Maryland was provided with a hand-held radiometer with which to measure pavement temperature. The intention here was to see if decisions regarding the timing of anti-icing treatment applications could be made with a relatively inexpensive device for sensing pavement temperature.

Vendors were quickly located and purchase orders issued for the above items, except the radiometers, after SHRP approved the allocation of funds. The radiometers were transferred from SHRP Contract No. H-207.

Most of the equipment was scheduled for delivery in mid-December 1991, about one month after it was ordered. Numerous delays were encountered in the receipt of certain equipment which were beyond the project team's control. Delivery dates promised by vendors were not met, and shipping of equipment for some items slipped considerably. Every attempt was made to follow up on these delayed shipments in order to expedite delivery to the participating SHAs.

Pavement friction and residual chemical measurements were chosen as two measures of effectiveness. It was important that the devices for measuring them be suitable for use by maintenance personnel during adverse weather conditions. The devices also had to provide meaningful results. The next two sections describe the selection of techniques for measuring pavement friction and residual chemicals.

Pavement Friction Measurement

At the beginning of the study, various means for measuring pavement friction were investigated by reviewing whatever information could be gathered on existing systems. Most systems were not suitable for the study because they required considerable support equipment, had to be specially towed or mounted, were very expensive. One system, the Coralba friction tester, was identified as having the potential for making the desired measurements.

Prior to the project, the Minnesota Department of Transportation (MNDOT) began investigating the usefulness of the Coralba friction tester for making pavement friction measurements. The Coralba is a Swedish instrument used to measure friction on some European airport runways[13]. The device can be installed in a pickup or passenger vehicle, connected to the brake system. The system measures friction between the tire and pavement by monitoring the speed reduction over time of one of the vehicle's wheels during a braking operation. The friction value obtained from the test is displayed on a dash-mounted unit.

MNDOT performed a limited amount of testing with the device prior to this 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 E274 skid trailer results. It was necessary to determine if the Coralba Friction Tester could give results equivalent or comparable to skid numbers measured with ASTM E274 for two reasons. First, the Coralba is mounted in a vehicle with conventional tires which typically have higher friction levels than skid trailer tires. Second, the system operates in a controlled braking mode rather than a locked-wheel mode. The test protocol was designed to address these concerns by specifying the need to conduct paired (Coralba/skid trailer) tests on as many different highway segments as possible, with a range of skid numbers for a given type of pavement (asphalt concrete (AC) and PCC).

The testing with both systems was conducted in the summer of 1991 at the St. Cloud, Minnesota, test track and on I-35 and TH53 in the Duluth, Minnesota, area, generally following the procedure outlined in the test protocol. Replicate tests were made at 40 mph and at other speeds (20 and 30 mph). A majority of the tests were made on wet pavement. Tests were also to be made on dry pavements. The results of these tests and the correlation of the Coralba friction tester with ASTM E274 skid measurements are given in Section 2 of this report and in Appendix B.

Salinity Measurements

An extensive investigation was made to determine if there were equipment and procedures suitable for maintenance personnel to use to measure residual anti-icing chemicals on pavement surfaces. Three manufacturers of conductivity meters were identified.

- Presto-Tek Corporation manufactures two types of conductivity meters: a portable battery-powered laboratory unit (Model SM-10) and a hand-held salt analyzer for field use (Model SM-8). Although both units have desirable features, neither model has a field-sampling capability.

- Cole-Parmer Instrument Company manufactures has a pocket-size conductivity tester with automatic temperature compensation over the range 32° to 122°F. However, the instrument does not provide field sampling.

- Boschung Company manufactures the SOBO-20. This instrument is specifically designed for the quantitative measurement of chloride solutions on roads. The instrument has a sampling head, a built-in conductivity cell, and electronic display.

The SOBO-20 was selected as the most promising candidate for testing salinity. 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 obtained from MNDOT for evaluation.

The SOBO-20 was evaluated for the semiquantitative measurement of several ice control chemical solutions. The type of response and range of detection for solutions of five different chemicals were determined:

- Sodium chloride ($NaCl$)
- Magnesium chloride ($MgCl_2$)
- Calcium chloride ($CaCl_2$)
- Potassium acetate ($KOOCCH_3$; more simply KAc)
- Calcium magnesium acetate ($Ca/MgOOCCH_3$; more simply CMA)

To make a measurement, a precise volume of a solvent (liquid for dissolving the residual chemical) is pumped into a measuring cell in contact with the road surface. The conductivity measures the quantity of salt, expressed in ounces per square yard. The apparatus is calibrated for measurements of sodium chloride and calcium chloride at all temperatures.

The instrument consists of three parts: a storage chamber for the solvent; the measuring chamber, with built-in conductivity cell, which confines the solvent to a fixed area on the road; and the electronic processor, which displays and stores the measurements.

The solvent is 85% distilled or demineralized water, plus 15% technical acetone. Its freezing point is approximately −5°C (23°F). This mixture, required for accurate measurements, may be prepared by the user or purchased at a drug store. The experimental work and a discussion of the results are presented in Section 2 of this report.

Field Observations

Field observations of the anti-icing operations were made at the selected test sites in the nine states. Both the experiments and observations were conducted by the state maintenance personnel during the winters of 1991-92 and 1992-93. A number of activities were performed in preparation for, and in support of, the field observations:

- developing training materials;
- training maintenance personnel;
- establishing meteorological criteria and support for the test sites;
- documenting the test conditions, treatments, and results; and
- coordinating with participating SHAs.

Each of these activities is described below.

Procedural manuals were prepared for training the maintenance personnel in the nine participating SHAs before the anti-icing experiments began. Portions of winter maintenance training materials obtained from various sources, including MNDOT, New York Department of Transportation (NYDOT), and manufacturers and vendors of RWISs were incorporated.

Appropriate materials assembled from the various sources were combined into the manuals. Portions of the training manuals varied from state to state, incorporating specific state requirements for winter maintenance activities, site-specific geographic and climatic considerations, and specific 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 background on the scope of the project, basic meteorology, and snow and ice-control chemicals; a description of the design, operation, and use of RWIS; and information specifically related to implementing the study in each jurisdiction, including the role of supervisory and operating personnel, data collection, etc. Hands-on training was also furnished for both the SOBO-20 chloride measuring instrument and the Coralba friction tester. An outline of the training materials provided to the maintenance personnel for all participating state agencies is shown in figure 1. The training material developed for Maryland was different from the other eight states because that state did not have a RWIS.

Operation, calibration, and maintenance instructions were prepared for the SOBO-20 and Coralba instruments. Also, operating instructions for several types of spreader control equipment were obtained during the state visits. These documents were 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 forms and procedures incorporated many of the features found in the materials collected.

The data recording forms designed specifically for use in the research program were also included in the training. These forms provided the proper format in which to record weather and pavement conditions, spreader equipment operation, and SOBO-20 and Coralba readings. Forms were also prepared for instrument calibration and, in the case of Maryland, the recording of radiometer measurements. Examples of each form are shown in Appendix C.

On-site training was provided to all state agencies participating in the project. Although modified in certain cases, the training was originally designed for a 1.5-day period with classroom work on the first day and hands-on training on the second day. Figures 2 and 3 show a typical agenda for each training course given.

Outline of H-208 Training Course

Section	Title
1	Introduction to Project
2	Benefits to Agency and Public
3	Overview of Course
4	Basic Meteorology
5	Characteristics of Snow- and Ice-Control Chemicals
6	RWIS Components and Functions
7	Pavement Temperature Forecasts: Their Uses and Implications
8	Decision-making Process in Snow and Ice Control Using RWIS Information
9	Overview of Anti-Icing Study
10	Role of Supervisory Personnel in Study
11	Role of Operators in Study
12	Spreader Equipment Operation
13	Documentation of Anti-Icing Test Conditions, Treatments, and Results

Figure 1. Outline for H-208 training course.

Course Outline for SHRP Project H-208: First Day of Training

8:30 AM	Introduction to Project and Course Overview
9:00 AM	Basic Meteorology
9:30 AM	Break
10:00 AM	Characteristics of Snow-and Ice-Control Chemicals
10:30 AM	RWIS Components and Functions
11:00 AM	Pavement Temperature Forecasts: Their Uses and Implications
11:30 AM	Decision-making Process in Snow- and Ice-Control Using RWIS Information
12:00 PM	Lunch
1:00 PM	Overview of Anti-Icing Study
1:30 PM	Role of Supervisory Personnel in Study
2:00 PM	Role of Operators in Study
2:30 PM	Break
3:00 PM	Spreader Equipment Operation
3:30 PM	Documentation of Anti-Icing Conditions, Treatments, and Results
4:00 PM	Adjourn

Figure 2. Typical agenda for first day of training course.

Course Outline for SHRP Project H-208: Second Day of Training

8:30 AM	Hands-on Training on Use of SOBO-20 Salinity Tester and Coralba Friction Tester
9:30 AM	Break
10:00 AM	Demonstration of RWIS Computer System and Data Outputs
10:30 AM	Review of Supervisor and Operator Roles
11:00 AM	Review of Documentation and Data Submittal to MRI
12:00 PM	Adjourn

Figure 3. Typical agenda for second day of training course.

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

During the first training provided to state winter maintenance personnel, some adjustment of the test and control sections was necessary to conform more closely to their routine treatment practices. A "first cut" was made during the initial state visits to select appropriate test and control sections. The boundaries of these sections were further refined during the training session. Also, discussions were held with supervisory personnel to identify the specific equipment to be used for anti-icing on the test section and deicing on the control section. In general, each test section (except in Maryland) contained RWIS pavement and atmospheric sensors to help make informed decisions regarding pretreatment timing, application rate, etc.

Table 3 provides an overall summary of the test and control sections used during the study, the application parameters employed, and the types of data collected during the first winter testing.

The first anti-icing experiment was run in Nevada in mid-December 1991. Data collection for the 1991-92 winter continued to the end of March 1992. At that time, 57 storm events had been recorded by the nine participating states, in spite of the late start of the anti-icing experiments. Data on 52 storm events were received for review within a relatively short time after the events. Data on five storm events were not received until almost one year after they took place. Over 70% of the events were recorded by Maryland Department of Transportation (MDDOT), Nevada Department of Transportation (NDOT), MNDOT, and NYDOT maintenance personnel. No storm events were recorded at four sites because of the extremely mild winter after the program started.

The coordination with the SHAs continued on a regular basis during the winter. The main thrust was to encourage each state to conduct the anti-icing experiment for each storm event and to resolve any operational problems. Offers were made to be on-site during a forecasted storm event, if possible. One on-site visit took place during an extended storm event on I-80 in California. No other on-site visits took place during storm events because of scheduling difficulty.

Although at the time of the contract award SHRP had specified completion of a draft final report by November 1992, the project team was notified in June 1992 that the SHRP Executive Committee approved a no-cost extension to the end of July 1993. This extension was granted to allow continued anti-icing experiments during a second winter (1992-93).

Table 3. Test matrix for anti-icing experiments.

State	Geographic area	Location of test section	Test section application parameters	Location of control section	Control section application parameters	Measurements and observations
CA	Mountain state	Eastbound I-80 from Kingvale to the Donner Lake Interchange	First application: 35 gal/lane-mile liquid $MgCl_2$; subsequent applications: 100 lb/lane-mile rock salt prewetted at the spinner with 5 gal/ton liquid $MgCl_2$	Westbound I-80 from Donner Lake Interchange to Cisco Grove then Eastbound to Kingvale	1,000 lb/lane-mile sand or 50:50 sand/rock salt mixture	Time; weather conditions; roadway conditions; applications; salinity; and friction
CA	Mountain state	SR 88 between the north junction with SR 89 and the south junction with SR 89	100 lb/lane-mile rock salt prewetted at the spinner with 5 gal/ton liquid $MgCl_2$	SR 88 westward from the north junction with SR 89 to the Blue Lakes turnoff	1,000 lb/lane-mile 80:20 cinder/rock salt mixture	Time; weather conditions; roadway conditions; applications; and friction
MD	Mountain state	MD 495 from Maple Grove Road to New Germany Road	100 lb/lane-mile rock salt	MD 495 from New Germany Road to junction with MD 135	400-500 lb/lane-mile of sand/rock salt mixture (exact mix depends on conditions)	Time; weather conditions; roadway conditions; applications; salinity; friction; and pavement temperature by radiometer
CO	High plains state	Westbound CO 470 from US 85 to West Bowles Avenue	500 lb/lane-mile of a 18:82 salt/sand mix prewetted at the load with 10 to 12 gal/ton liquid $CaCl_2$	Eastbound CO 470 from West Bowles Avenue to US 85	Sand mixed with 18% rock salt (application rate not specified but estimated at 800 lb/lane-mile)	Time; weather conditions; roadway conditions; applications; and friction

Table 3 (Continued)

State	Geo-graphic area	Location of test section	Test section application parameters	Location of control section	Control section application parameters	Measurements and observations
CO	High plains state	Southbound I-25 from CO 402 to interchange with CO 56	500 lb/lane-mile of a 8:92 salt/sand mix prewetted at the load with 10 to 12 gal/ton liquid $CaCl_2$	Northbound I-25 from CO 56 to interchange with CO 402	Sand mixed with 8% rock salt (application rate not specified but estimated at 800 lb/lane-mile)	Time; weather conditions; roadway conditions; applications; and friction
NV	High plains state	Northbound US 395 from the Glendale interchange to Golden Valley Drive	First application: 35 gal/lane-mile liquid $MgCl_2$; subsequent applications: 35 gal/lane-mile liquid $MgCl_2$ or 800 lb/lane-mile of a 6:1 sand/salt mix prewetted at the spinner with 5 gal/ton liquid $MgCl_2$	Southbound US 395 from Golden Valley Drive to the Glendale interchange	1,100 lb/lane-mile of a 83:17 sand/rock salt mixture	Time; weather conditions; roadway conditions; applications; and friction
MO	Plains state	Northbound I-29 from 112th Street to Mexico City Avenue interchange	100 lb/lane-mile rock salt prewetted either at the load or at the spinner with 6 gal/yd^3 liquid $CaCl_2$	Southbound I-29 from Mexico City Avenue interchange to 112th Street	400-500 lb/lane-mile straight rock salt	Time; weather conditions; roadway conditions; applications; and friction
MO	Plains state	Northbound US 71 from Bates county line to the "Half Way Crossover"	200 lb/lane-mile of a 50:50 abrasive/salt mix prewetted either at the load or at the spinner with 6 gal/yd^3 liquid $MgCl_2$	Southbound US 71 from the "Half Way Crossover" to the Bates county line	400-500 lb/lane-mile of a 50:50 cinder/rock salt mix	Time; weather conditions; roadway conditions; applications; salinity; and friction

Table 3 (Continued)

State	Geo-graphic area	Location of test section	Test section application parameters	Location of control section	Control section application parameters	Measurements and observations
OH	Plains state	Westbound I-70 from crossover at MP 80 (just past Franklin-Madison county line) to crossover located between SR 29 and US 42	100 lb/lane-mile rock salt prewetted at the spinner with 5 gal/ton liquid $CaCl_2$	Eastbound I-70 from crossover located between US 42 and SR 29 to crossover at MP 80 (just past Franklin-Madison county line)	First application: 250-300 lb/lane-mile straight rock salt; subsequent applications: 250-300 lb/lane-mile of a 50:50 limestone/ rock salt mix	Time; weather conditions; roadway conditions; applications; salinity; and friction
OH	Plains state	Southbound I-71 from crossover at MP 101 to crossover at Franklin-Pickaway county line (MP 91)	100 lb/lane-mile rock salt prewetted at the spinner with 5 gal/ton liquid $CaCl_2$	Northbound I-71 from crossover just East of Franklin-Pickaway county line (MP 91) to crossover at MP 101	First application: 250-300 lb/lane-mile straight rock salt; subsequent applications: 250-300 lb/lane-mile of a 50:50 limestone/ rock salt mix	Time; weather conditions; roadway conditions; applications; and friction
MN	Lake effect state	Southbound SR 53 from Canyon to Four Corners (near Duluth)	100 lb/lane-mile rock salt prewetted at the spinner with 6 gal/ton liquid $CaCl_2$	Northbound SR 53 from Four Corners to Canyon	400-600 lb/lane-mile of a 75:25 sand/salt mix	Time; weather conditions; roadway conditions; applications; salinity; and friction

Table 3 (Continued)

State	Geographic area	Location of test section	Test section application parameters	Location of control section	Control section application parameters	Measurements and observations
MN	Lake effect state	Northbound I-35 from Mesaba Avenue interchange to 12th Avenue East in Duluth	106 lb/lane-mile rock salt/CMA mixture prewetted at the spinner with 24 gal/ton liquid CMA	Northbound I-35 from 27th Avenue West interchange to Mesaba Avenue	First application: 150 lb/lane-mile rock salt; subsequent applications: 300 lb/lane-mile of a 50:50 sand/salt mix	Time; weather conditions; roadway conditions; applications; and friction
NY	Lake effect state	Eastbound SH 104 from Bay Road to Monroe-Wayne county line	100 lb/lane-mile of rock salt prewetted at the spinner with 5 gal/ton liquid $CaCl_2$	Westbound SH 104 from Monroe-Wayne county line to Bay Road	First application: 225 lb/lane-mile of straight rock salt; subsequent applications: 115 lb/lane-mile of a 80:20 sand/salt mix	Time; weather conditions; roadway conditions; applications; salinity; and friction
WA	Maritime state	Eastbound I-90 from Issaquah (MP 17) to the interchange with SR 202 (MP 30.9)	100 lb/lane-mile of a mixture of rock salt and solid CMA prewetted at the spinner with a liquid mix of NaCl and CMA	Westbound I-90 from SR 202 to Issaquah (MP 17)	Sand mixed with 5% rock salt (application rate determined by operator)	Time; weather conditions; roadway conditions; applications; salinity; and friction

Each of the nine cooperating SHAs was contacted by telephone to ascertain the state's interest in participating in a second winter of anti-icing experiments. Each state reiterated its continued support for the study and agreed to participate in the data collection during the 1992-93 winter. A follow-up letter was sent to each of the nine states thanking them for their past and continued support for the program. The letter stated the same study sites and equipment used during the 1991-92 winter would be used during the second winter,and that the project team would hold a one-day refresher training session at the appropriate maintenance facility.

Material for the refresher training included an overview of the project; a summary of the overall findings from the first winter's testing; a review of the specific anti-icing study developed for each jurisdiction; a review of the role of the supervisory and operating personnel for each jurisdiction; a review of the documentation needed of the anti-icing test conditions, treatments, and results; and a review of the recording problems noted with the maintenance data collected during the 1991-92 winter anti-icing operations. Material was also assembled for the refresher training associated with the operation of the SOBO-20 chloride measuring instrument, the Coralba friction tester, and the radiometer.

The refresher training was conducted from mid-October to early November 1992. Reporting problems with the 1991-92 winter field data were discussed in detail. Participants also discussed any particular requirements or changes the maintenance personnel wanted to make in the 1992-93 field testing procedures. Minor changes were made in some states regarding test or control section boundary limits, application mixtures, and type of deicer used.

A major enhancement was made at test and control sections used on New York SR 104 in Monroe County. A manufacturer installed prototype pavement sensors at two locations on the test section and at two locations on the control section. Traffic loops were installed at all four locations. Thermocouples were also installed near the pavement surface at two locations on the test section and two locations on the control section. An instrumentation trailer was located in the median close to the four prototype sensors, and a new meteorology tower was built for instruments to sense air temperature, relative humidity, wind speed and direction, precipitation type and amount, and visibility range. Specific locations on both the test and control sections also were established for SOBO-20 and Coralba measurement observations and for photographing the pavement condition throughout storm events.

The first anti-icing experiments of the 1992-93 winter were conducted in Minnesota at the beginning of November 1992. Data collection ceased at the end of March 1993. At that time, 110 storm events had been recorded by the nine participating states. Approximately 66% of the events were recorded by MNDOT, NDOT, and NYDOT maintenance personnel. Storm events were recorded at all 14 test sites in the nine states.

Coordination with the participating SHAs continued frequently throughout the 1992-93 winter after the refresher training.

Weather forecasting specific for highway segment areas is important to the success of anti-icing trials. One final activity in connection with the field observations was establishment of the requirements for meteorological criteria and support for the test sites. Tailored weather and pavement forecasts were available for all test sites except MD 495 in Maryland and SR 88 in California. The forecasts were furnished either by contract with a RWIS vendor or, in the case of MNDOT, through a private weather forecasting service. The availability of weather and/or pavement forecasts for a majority of the test sites at or before the beginning of the anti-icing experiments made it unnecessary to establish the meteorological criteria and support at that time. Instead, the meteorological support for potential test sites was established after the start of the first winter testing, from a review of the work performed under SHRP Contract H-207 and from practical experience in working with state Department of Transportation (DOT) operational maintenance personnel. The meteorological support developed for potential test sites is given in Appendix D and discusses six areas:

- meteorological service to DOT maintenance personnel;
- road-weather meteorology;
- procedures for selecting a private meteorological service provider for road-weather forecasts;
- specific criteria for a road-weather forecast service;
- specific forecast requirements; and
- utilization of road-weather forecasts and other meteorological information by maintenance decision makers.

No attempt was made to apply these criteria in the study. The results are presented to guide state and local DOTs in future implementation of anti-icing strategies.

Analysis of Anti-Icing Effectiveness

The objective of this part of the research was to analyze the effectiveness and the cost-effectiveness of anti-icing treatments. Activities directed toward this particular objective included

- analyzing the maintenance field data on anti-icing treatments (and conventional deicing treatments) collected by the nine cooperating SHAs;
- collecting and analyzing accident data for one site;
- collecting and analyzing of weather information related to the accident data;
- analyzing cost-effectiveness of anti-icing treatments in comparison to conventional deicing.

These activities are discussed in two categories: the analysis of maintenance field data and the accident and cost-effectiveness study.

Analysis of Maintenance Field Data

The maintenance field data from the participating states were reviewed as they were received. The main purpose of this review was to monitor the completeness of the data reported and to call any deficiencies to the attention of the participating maintenance personnel. In addition, the monitoring process provided both an opportunity to discuss and correct any operational problems, and a preliminary indication of how well the anti-icing was working.

A complete analysis of the maintenance field data was begun at the end of the 1991-92 winter. This analysis was completed before the refresher training was given to maintenance personnel for the second winter testing. The 1992-93 winter data analysis continued throughout that winter as the Midwest Research Institute (MRI) received data. The purpose of the analysis was to estimate the effectiveness of anti-icing treatments compared to conventional deicing.

The analysis of the field data for each storm in the two winters was conducted in the same manner. This provides for each test and control section a chronological history of the meteorological events, pavement conditions, and maintenance activities associated with the storm, including the amount of material applied to each traveled lane. Graphs were created, showing the weather, pavement conditions, and air temperatures as a function of time. (See figure 20 in section 2 for an example of these graphs.) A summary was made of the total material (chemical and abrasives) applied to the test and control sections during the storm events. Also, summaries of each storm provide an overview of the event, the test and control section pavement conditions at the first winter maintenance treatment, and a brief history of both the test and control pavement conditions during the storm. Another summary records the maintenance activities on the test and control sections and the savings achieved on the test sections in each state.

Accident and Cost-Effectiveness Study

A limited analysis was performed, comparing the effectiveness of anti-icing and deicing, considering such factors as accidents and material, equipment, and labor costs. This analysis included the collection of accident data for several winters at selected sites in New York, pavement sensor data, weather data for several winters for New York SR 104 in Monroe County, and selected traffic and winter maintenance data for SR 104 during the 1992-93 winter. These data were combined in an accident analysis of the effectiveness of anti-icing treatments. Winter maintenance cost information was then combined with various factors in a cost-effectiveness analysis of pretreatment strategies.

Equipment Evaluation

The objective of the equipment evaluation was to evaluate specialized apparatus for applying controlled quantities of solid, prewetted, or liquid chemicals at the minimum application rates required for effective anti-icing treatment. The effectiveness of spreader equipment in achieving specified application characteristics, such as precise control of the spreading or spraying pattern and of the amounts applied, was also investigated. This involved a worldwide survey of spreader equipment; selection of the types of equipment to be tested; selection of an appropriate field test site and of the measures of effectiveness; and, finally, limited field tests of some anti-icing application equipment.

U.S. and foreign manufacturers of highway spreader equipment were asked how they test equipment performance. This information was needed to develop testing protocols for the equipment evaluation. These inquiries revealed that highway spreader manufacturers in the United States do not test their equipment's operating characteristics.

The Salt Institute has a procedure for measuring the application rates of a salt or abrasive spreader in a stationary mode[14] . Although suitable for obtaining general calibration information, this was not useful in the equipment evaluation because of the need to operate the spreader equipment while in motion, not while stationary.

The only standard test method found in the literature for evaluating spreaders was that developed by the American Society of Agricultural Engineers under ASAE Standard §341.2 entitled "Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders." This procedure also is not applicable because it is used for fertilizers which have a density and gradation band different from that of salt. In addition, the standard does not apply to material application on a hard surface, such as a highway pavement.

These results made it necessary to develop a protocol which could be used to test and evaluate spreader equipment. A number of variables and concepts were investigated in the development process, as described in section 2.

2

Findings

Summary of Foreign Experience with Anti-Icing Operations

In recent years, a number of highway authorities in the Scandinavian and other European countries have been warned of the dangers inherent in the overuse of deicing chemicals. These dangers include damage to the environment as well as to vehicles, roads, and bridges. Historically, Scandinavian and other Northern European countries have applied a substantial amount of salt to their roadways to combat the frequent occurrences of black ice, frost, and roadway freezing after precipitation. A number of these countries have been experimenting with new and highly promising techniques and systems, which could lead to substantial savings in deicing chemicals without sacrificing the level of roadway service during wintertime.

It has been demonstrated in some countries that salt usage can be reduced and the level of service maintained by applying small quantities (5 to 10 g/m^2, 65 to 130 lb/lane-mile) of salt to the roadway surface prior to the formation of a strong ice-pavement bond. Once a bond has developed, it is very difficult to remove. If a road is presalted, snow will not bond strongly to the surface. Typically, the brine formed at the beginning of a snowfall is absorbed as snow continues and produces very little free moisture. The snow can be removed by plowing, leaving a slush that traffic may disperse, rather than a compacted snow-ice layer.

Salt should usually be applied immediately before snow begins for optimum effect and economy. The amount of chemical required prior to snowfall depends on the anticipated amount of snow and the temperature, but it is generally a smaller amount than is necessary for treatment during or after a storm. European highway maintenance workers have not determined the amount of salt application, the timeliness of the applications, and the form of the salt (dry, prewetted, or liquid required during prolonged snowfall or snow that requires repeated plowing. Changes in their winter maintenance practices relative to these issues have been made as a result of research findings. The changes have improved the efficiency of winter maintenance operations and reduced the amount of salt needed to keep the highways free of ice.

United Kingdom

The Transport Research Laboratory (TRL) in Crowthorne, England, has calculated theoretical rates of salt application based on the concentration of aqueous solutions. TRL has observed that the thickness of a water film may typically vary between 0.08 and 0.5 mm (0.003 and 0.02 in.) on a well-drained roadway during and after rain. Thin films of ice formed by the freezing of water on the road surface are usually less than 0.25 mm (0.01 in.) thick, which is equivalent to approximately 0.25 kg/m^2 (0.5 lb/yd^3) of ice. An application of 10 g/m^2 (130 lb/lane-mile) of salt is sufficient to completely melt an ice film less than 0.25 mm (0.01 in) thick at temperatures above −2.4°C (28°F). Applying this quantity before the onset of freezing will prevent the formation of ice.

TRL has tabulated the freezing point depression for a range of water film thicknesses and for different applied quantities of salt. This information is presented below.

- The freezing point of a water film with 10 g/m^2 (130 lb/lane-mile) of salt added:

Film Thickness		Freezing temperature	
mm	in.	°C	°F
0.08	.003	-8.6	16.5
0.10	.004	-6.5	20.3
0.20	.008	-3.0	26.6
0.25	.010	-2.4	27.7
0.30	.012	-2.0	28.4
0.50	.020	-1.2	29.8

- The amount of salt required to prevent a specified water film thickness from freezing at −5°C (23°F) is

Film thickness		Amount of salt required	
mm	in.	g/m^2	lb/lane-mile
0.08	.003	7	91
0.10	.004	8	104
0.20	.008	16	208
0.25	.010	20	260

- Crossfall and super elevation on motorways usually ensure that the road is well drained. Once rain has ceased to fall, traffic quickly reduces the water film on the road. Assuming, therefore, that the water film thickness will generally not be greater than 0.25 mm when precautionary salting is being considered, it is possible to specify application rates for temperature bands:

Forecast temperature		Amount of salt required	
°C	°F	g/m^2	lb/lane-mile
-2.5	27.5	10	130
-4.0	24.8	16	208
-5.0	23.0	20	260

When ice has formed, an application rate of 10 g/m^2 (130 lb/lane-mile) is not sufficient to achieve the required increase in skid resistance in a reasonable time. Under this condition, a deicing application rate of 40 g/m^2 (520 lb/lane-mile) of salt is required.

The density of fresh untrafficked snow is about one-tenth that of ice so that a 10-mm depth of snow over a 1-m^2 area is roughly equivalent to 1 kg/m^2 of ice. In practice, one-half the quantity of salt required for complete melting will reduce the snow so that it can be dispersed by traffic, and about 6 g/m^2 (78 lb/lane-mile) of salt is required per 10 mm of fresh snow for each degree Celsius that the air temperature is below the freezing point. When snowfalls of 10 mm or more occur, the temperature is usually higher than −3.0°C (27°F). Note that this calculation assumes no plowing.

The current UK Department of Transport's "Code of Practice for Winter Maintenance on Motorways and Trunk Roads"[15] recommends that salt be spread before ice forms or snow settles on the road for maximum efficiency. The Code specifies application rates for a range of conditions:

- For frost and light snow, salt shall be spread at 10 g/m^2 (130 lb/lane-mile).

- If freezing conditions are expected after rain, salt shall be spread at 20 to 40 g/m^2 (260 to 520 lb/lane-mile), according to the amount of moisture present and the temperature expected. Unless freezing conditions coincide with rainfall, salting shall be delayed as long as possible to reduce loss of salt by run-off.

- If continuous snow is forecast, salt shall be spread at 20 to 40 g/m^2 (260 to 520 lb/lane-mile), according to the anticipated severity of the snowfall. It is essential that enough salt is applied *before* snow bonds with the pavement so the salt will melt the initial snowfall, providing a wet surface beneath subsequent snow. This wet layer makes plowing much easier.

- If ice has formed, salt shall be spread up to 40 g/m^2 (520 lb/lane-mile), depending on the amount of ice present and the air temperature to ensure a rapid melt. (The Code of Practice does not specify the amount of ice or air temperature.)

- The best way of removing moderate accumulations of snow after precautionary salting is by plowing. This shall take place when snow depths exceed 30 to 50 mm (1.2 to 2.0 in). Each pass of the plow shall be supplemented by salt spread at 10 g/m^2 (130 lb/lane-mile), as this will prevent snow from compacting and ease subsequent plowing.

- If the temperature drops and the need for plowing continues, it is important to monitor the air temperature and to increase the salt spread up to 40 g/m^2 (520 lb/lane-mile), if necessary.

- During prolonged snowfall, it is useful to plow continuously from the onset to prevent buildup and compaction by traffic. This can be supplemented by simultaneous salting at 20 to 40 g/m^2 (260 to 520 lb/lane-mile).

- Plowing or snowblowing is not always possible in all areas, such as high traffic volume urban areas. In these cases, the maximum salt spread for melting up to 40 mm (1.6 in) of fresh snow at 0°C (32°F) shall be 40 g/m^2 (520 lb/lane-mile). Repeated applications can remove a heavy accumulation of snow; this method is useful where plowing or snowblowing is impractical, but heavy salting is not otherwise recommended.

If the recommendations are followed, hard-packed snow and ice should be rare. But if snow is heavy, provided it is no more than about 20 mm (0.8 in) thick and the air temperature is not below −5°C (23°F), then removal is possible by using successive salt spreads at 20 to 40 g/m² (260 to 520 lb/lane-mile). Below −10°C (14°F), or where the snow or ice is more than 22 mm (0.9 in) thick, salt use alone can result in an uneven and slippery surface. In those exceptional circumstances, a single-sized abrasive aggregate of particle size up to 6 mm (0.24 in) or a 5-mm (0.2-in) sharp sand having a low fine content, should be added as necessary to the salt.

Sustained low temperatures are rare in the United Kingdom. For each degree below −5°C (23°F), the amount of salt needed to maintain the equivalent melting effect increases by about 14 g/m² (182 lb/lane-mile). But where traffic is reasonably heavy, little or no increase is needed until sustained temperatures fall below −10°C (14°F). It should be noted that due to the atmospheric conditions in the United Kingdom, British salt has a normal moisture content of 5% or greater. As a result, the British road administrators do not prewet their salt during spreading operations. Also, the gradation of the salt is much finer than that used in the United States (see Appendix E).

European and American Studies

Various studies have been conducted to determine the amount of dry versus prewetted salt that remains on the road after a given amount of traffic has passed. Studies conducted in Switzerland at the end of the 1960s[16] with vehicles passing the test section at 65 km/hr (40 mph) found the following:

Amount of traffic	Percent material retained on road during tests in Switzerland	
	Dry salt(%)	Prewetted salt (%)
After 5 vehicles	30	93
After 100 vehicles	15	80

Studies conducted in Germany with vehicles passing the test section at 90 km/hr (56 mph) found the following:

Amount of traffic	Percent material retained on roadway during tests in Germany		
	Dry salt (%)	Prewetted salt with NaCl (%)	Prewetted salt with $CaCl_2$ (%)
After 100 vehicles	20	80	80
After 1000 vehicles	10	40	60

A study was conducted in Michigan in 1962[17] to determine the amount of salt retained on a 7.3-m (24-ft) wide portland cement concrete pavement during spreading operations. The study found that 70% of the salt spread was retained on the roadway when the salt was dry. However, 95% of the salt spread was retained on the roadway when the salt was prewetted. The study did not identify the moisture content of the prewetted salt nor how the salt residue was determined.

Liquid salt solutions have been used for a number of years to prevent slippery roads. The method is probably most common in Italy, where road maintenance personnel have used liquids on roads for several years. The Italians have primarily used a 27% calcium chloride ($CaCl_2$) solution. When the solution is used as a preventive treatment, 18 to 37 g/m^2 (234 to 481 lb/lane-mile) of brine is spread, which corresponds to 5 to 10 g/m^2 (65 to 130 lb/lane-mile) of dry $CaCl_2$. When liquid material is spread to melt a thin layer of ice or snow, 74 to 92 g/m^2 (962 to 1196 lb/lane-mile) of brine is applied, which corresponds to 20 to 25 g/m^2 (260 to 325 lb/lane-mile) of dry material. These quantities are known "norms," which are found in reports dating back to 1985.[18]

Scandinavia

The practices in the Scandinavian countries differ substantially from those in Italy in that Scandinavians use a 23% solution of sodium chloride (NaCl). A liquid salt solution has proven successful as a preventive treatment against slippery roads. However, spreading salt brine on compacted snow of variable thicknesses, results in different degrees of success.

For example, using liquid salt in Norway during the past two winters has produced conflicting results.[12] In 470 snow occurrences, 51% of the results were reported as good, 10% were not acceptable, and 14% were poor; the remaining 25% were unknown. Friction measurements were made to evaluate road condition, however, no information was provided on how or when friction measurements were conducted. The friction values used for reporting acceptance were 40 for good, 30 to 40 for not acceptable, and less than 30 for poor.

Some possibilities for the negative results may include unfamiliarity by personnel with how much brine should be spread. Therefore, underdosage applications may account for some of the poor results. This was demonstrated during the winter of 1992-93 in Tromsö, when 1,400 m^3 (370,000 gal) of liquid were spread. Positive results of using salt brine on snow were reported only after the maintenance personnel had shortened their application routes in order to make the liquid suffice. This indicates that in previous tests too little material was being applied.[18]

The use of liquid or dry salt affects the freezing point of material on the roadway, as seen in the following examples. These data were obtained from reports gathered from Vägverket, Sweden, and Statens Vegvesen, Norway.

In Example 1, there were 15 g/m^2 (195 lb/lane-mile) of water on the roadway surface, which makes the road appear moist but not wet. It is assumed that when liquid salt is spread, it all remains on the road. When 5 g/m^2 (65 lb/lane-mile) of dry salt are spread, the freezing point is lowered to −21°C (5.8°F). When 5 g/m^2 (65 lb/lane-mile) of saturated liquid salt solution are spread, the freezing point is lowered only to -11°C (12.2°F).

Example 2 features the same elements in Example 1 except that there are 60 g/m^2 (780 lb/lane-mile) of water on the road surface, which makes the surface appear wet. The freezing point for dry salt usage is lowered to −6°C (21.2°F) and for liquid salt to −5°C (23°F).

Example 3 features the same elements in Example 1, but because of the influence of traffic, the quantity of salt is reduced. After 500 vehicle axles passed, the quantity of dry salt is reduced to 0.5 g/m^2 (6.5 lb/lane-mile) and the quantity of liquid to 4 g/m^2 (52 lb/lane-mile). With this reduction, the freezing point for dry salt is lowered to −3°C (26.6°F) and for the liquid salt to −10°C (14°F).

The Finnish National Road Administration has conducted a number of studies throughout Finland using liquid salt as an anti-icing method. Based on these findings and the experience of Finnish road masters, liquid salt appears to be the material of choice for roads in Finland. The liquid salt is manufactured at each roadmaster station. Water is mixed with dry salt until a 23% salt concentration is obtained. The brine is stored in tanks inside buildings and is used either as an anti-icing treatment or for prewetting dry salt. Liquid salt is most effective when used for black ice and for preventive treatments in the fall and spring. It is also most effective as a preventive treatment when the pavement temperature is between 0° and −3°C (32° and 26.6°F). It was emphasized that it is important to apply only small amounts of liquids (most often 10 g/m^2 [130 lb/lane-mile]) and then to allow traffic action to dry the pavement. If the road surface remains wet during periods of low traffic, such as at night, the risk of refreezing increases. If traffic can dry the road surface, it is possible to use liquid salt even at temperatures as low as −7° to −10°C (19.4° to 14°F). However, use at these low temperatures is not normally recommended. Generally, liquid salt should not be used when the pavement temperature is less than −3°C (26.6°F), nor should it be applied on compacted snow.

Normally, liquid salt is not a good material to use with freezing rain, but at times it has been used with application rates increased to 40 to 60 g/m^2 (520 to 780 lb/lane-mile). It was reported that liquid salt does not appear to be effective on roads with low traffic volume (less than 2,000 average daily traffic, ADT). Traffic action is required to dry the pavement after the application of the liquid. Finnish roadmasters do not recommend liquid salt application for snowfall. However, if liquid salt is used, the suggested application rate is 25 g/m^2 (325 lb/lane-mile) per each 10 mm (0.4 in.) of snow. Finnish roadmasters state that one major drawback of using liquid salt is that continuous visual observations are required to anticipate refreezing of the road surface. Also, salt brine corrodes spreading equipment more than granular salt does, especially electrical connections. Another concern expressed when working with liquid salt is the attitude of the equipment operator. Operators may be reluctant to accept reduced application rates and to reapply liquid salt after dilution.

The advantage of liquid salt is that it can be applied up to 3 hours before the beginning of freezing precipitation. Thus, small quantities of salt can be applied under controlled conditions, and the material is not blown off by traffic. Use of liquid salt decreases the total amount of salt used, and provides instant melting action when precipitation falls. Furthermore, a small amount of liquid salt used does not splash onto car windshields and it remains on the roadway and does not spread to the road shoulders. The material can be applied at a higher rate of speed (60 to 70 km/hr [37.2 to 43.4 mph]) than dry or even prewetted salt. Also, the equipment cost of liquid spreaders is less than that of solid spreaders.

When the pavement temperature is −3° or −5°C (26.6° to 23°F) and −7° to −10°C (19° to 14°F), it is recommended that prewetted salt be used. The salt is prewetted with 23% salt brine at the spinner at the rate of 30% by weight. This mixture has the consistency of oatmeal, which helps the material stay in place on the road surface. Again, when using prewetted salt for preventive treatment, traffic action is required. Using prewetted salt reduces the amount of salt required because it does not blow away, and it starts to work more quickly than dry salt.

In Finland, no chemicals are generally applied to the roadway when the pavement temperature reaches −7°C (19°F). The snow and ice operations consist of snow plowing and at the most critical spots. The Finnish National Road Administration had 80 liquid salt spreaders in 1992 and is purchasing more each year. Two types are used. One is a spray bar with nozzles to be used for the driving lane, and three nozzles for applying chemical to the left lane; either one or both lanes can be treated using this type of spreader. The other type features two spinners. The Finnish fleet has approximately equal numbers of each type of spreader. The salt used in Finland is much finer (all smaller than 5 mm [0.2 in]) than that used in the United States (see Appendix E). This provides for more uniformity of material and is easier to prewet.

The Swedish National Road Administration (SNRA) conducted its MINSALT project[9] to find out if the harmful effects of salt from winter road maintenance could be reduced without a deterioration of traffic safety. The study indicated that the harm caused by salt can be reduced by methods and materials, both chemical and mechanical, which more effectively counteract existing or probable slippery conditions.

Swedish preventive salting operations use either salt brine or prewetted salt. Salt brine is optimally used to prevent black ice and on highways with large traffic volumes, such as those over 6,000 ADT. For safety, night applications are generally recommended, when traffic volume is diminished. The Swedes also recommended not using salt brine during precipitation. The SNRA has 100 salt brine units.

When a storm is approaching, the SNRA recommends using prewetted instead of liquid salt. It can be prewetted at the spinner at the rate of 30% of the amount of dry salt, or water can be applied after loading in the truck at a rate of 80 to 100 L per metric ton of salt. The recommended maximum volume of salt prewetted is 2 to 3 m^3 (2.6 to 3.9 yd^3). The application rate for preventive salting is 10 to 20 g/m_2 (130 to 260 lb/lane mile) of liquid, corresponding to 2.5 to 5 g/m_2 (33 to 65 lb/lane-mile) dry material, depending on pavement temperature and humidity. The same quantity is also used to remove a thin layer of ice or rime. Prior to or during snowfall, 40 to 60 g/m_2 (520 to 780 lb/lane-mile) of liquid is spread, which corresponds to 12.5 to 15 g/m_2 (163 to 195 lb/lane-mile) dry material.

With a few exceptions, preventive salting on dry or wet roads in Sweden has shown positive results. On rime (frost) or thin ice layers, the results are generally good, and "full friction" can be obtained in less than 1 minute. The results varied during snowfall when the roads were covered by slush or loose snow. Liquid salt worked well during short snowfalls, but during long or intense snowfalls, several reapplications were necessary to obtain good results. On hard-packed snow, liquid salt was unsuitable and showed poor results. Therefore, it is important to clear snow with a plow and/or sweeper before spreading liquids.

Table 4 displays the liquid quantities recommended by the SNRA.

The SNRA has determined that application rates above 60 g/m^2 (780 lb/lane-mile) are not effective and waste salt. The effective minimum temperature for prewetted salt is between −8°C and −10°C (17.6° to 14°F). At times, the prewetted salt has worked at temperatures as low as −12°C (10.4°F). Various gradations of salt have been tested in Sweden. It was found that a maximum size of 3 mm (0.12 in.) is the optimum. A gradation with a maximum size of 2 mm (0.08 in) was tried, but without much success.

Table 4 Application rate of liquid NaCl recommended by the Swedish National Road Administration.

Weather and road conditions	Liquid quantity*	
	g/m^2	lb/lane-mile
Preventive against ice:		
Dry road, humidity below 85%	10 to 15	130 to 195
Dry road, humidity above 85%	15 to 20	195 to 260
Wet road	15 to 20	195 to 260
Preventive against snow:		
On dry road	40	520
On frost	15 to 20	195 to 260
On snow and during snowfall	40 to 60	520 to 780

* 1 g/m^2 = 13 lb/lane-mile

In Denmark, the roadmaster determines the application rate of salt. The amount depends upon the actual and forecasted pavement temperatures. The Danes use both prewetted and liquid salt. The road weather station system provides an alarm for the roadmaster 2 hours before an event, enabling winter maintenance personnel to apply liquid salt before the beginning of a storm. The application rate is normally 10 g/m^2 (130 lb/lane-mile) with a maximum of 25 g/m^2 (325 lb/lane-mile). It was found that 5 g/m^2 (65 lb/lane-mile) was too small a quantity to work effectively. Generally, one application is required for frost or black ice at the rate of 7.5 to 10 g/m^2 (98 to 130 lb/lane-mile) of equivalent dry salt. During a snowstorm, only snow plowing is performed, and no salt is applied. After the snow ends, 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of salt is applied.

Typical of Danish winter weather, the county of Vajen experiences temperatures that fall below −6°C (21.2°F) only about 10 nights per year. This county experiences snow serious enough for salting operations approximately 60 times per year. Most of the time, however, the temperature during the Danish winter season will fluctuate around 0°C (32°F).

Netherlands

In the Netherlands, slipperiness is caused mainly by the freezing of wet sections of the road surface and by frost or freezing drizzle. Precipitation in the form of glaze ice or snow occurs rarely. If the temperature falls following a period of precipitation, the areas of the road that are still wet may freeze. Preventive salting uses 7 g/m^2 (91 lb/lane-mile) of prewetted salt. This is composed of 5 g/m^2 (65 lb/lane-mile) of dry NaCl and 2 g/m^2 (26 lb/lane-mile) of liquid solution (16% $CaCl_2$ solution or 20% NaCl solution). If the solvent (water) is not counted, this represents about 5.5 g/m^2 (72 lb/lane-mile) of prewetted salt.

Under certain temperature and humidity conditions, ice may form on the road surface as a result of condensation and freezing. Following a cold period in particular, condensation forms rapidly, owing to the "cold buffer" that has built up in the subgrade. This type of slipperiness occurs at unexpected moments and is difficult for drivers to see. Preventive salting using the prewetted method (7 g/m^2 [91 lb/lane-mile]) is used on highways that have sufficient traffic. The application is repeated depending on the quantity of freezing fog or condensation. In addition, if traffic intensity is minimal, such as at night, it is generally necessary to carry out spreading operations more often. In the event of snowfall, action is taken to prevent snow adhering to the road by applying 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of prewetted salt. During the snowfall, the road is kept as clear as possible by plowing and by spreading 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of salt using dry salt. After the snowfall, the remaining snow is generally easy to remove with plows and by spreading 15 to 20 g/m^2 of salt (195 to 260 lb/lane-mile). Conditions such as traffic intensity, the quantity of salt, and the quantity of precipitation, determine the surface conditions of the roadway. In applying the prewetted salt, the maximum application speed is 40 km/hr (24.8 mph) so that air turbulence does not blow the material off the road. It was also noted that maintenance personnel use prewetted salt at temperatures as low as $-15°C$ (5°F), and dry salt at temperatures down to $-7°C$ (19°F).

Summary

In general, most of the aforementioned European countries determined that approximately 5 to 10 g/m^2 (65 to 130 lb/lane-mile) of equivalent dry salt is needed for preventive treatment for frost, black ice, and light snow. Application rates for continuous snowfall vary from 10 to 60 g/m^2 (130 to 780 lb/lane-mile). No consensus exists on how much salt should be applied during snow plowing operations or other conditions. The Swedish MINSALT project, concluded that spreading liquids during a snowfall is of doubtful merit. In contrast, this method was reported to be successful in Norway. In the United Kingdom, plowing is supplemented by spreading salt at 10 g/m^2 (130 lb/lane-mile) to prevent the snow from compacting, while in Denmark, no salt is spread until after the snowfall. Therefore, there appears to be no consensus regarding salt spreading during snowfalls. Table 5 summarizes each country's findings.

Table 5 Summary of European findings

Country	Dry salt (g/m²)	Brine (g/m²)
United Kingdom		
Frost and light snow	10	
Freezing conditions after rain	20 to 40	
Continuous snow forecast	20 to 40	
During prolonged snowfall	10 to 40	
Italy		
Preventive treatment	5 to 10	18 to 37
Thin layer of ice or snow	20 to 25	74 to 92
Finland		
Preventive treatment	2.5	10
Freezing rain	9 to 14	40 to 60
Snowfall for each 10 mm	6	25
Sweden		
Preventive treatment	2.5 to 5	10 to 20
Continuous snow forecast	12.5 to 15	40 to 60
Denmark		
Preventive treatment	7.5 to 10	33 to 44
During prolonged snowfall	None	
	Dry salt (g/m²)	**Prewetted salt (g/m²)**
Netherlands		
Preventive treatment	5.5	7
Snow forecast	11 to 15	15 to 20
During snowfall	15 to 20	

1 g/m^2 = 13 lb/lane-mile.

Comparison of Coralba and Skid Measurements

Pavement friction testing was conducted to determine if a correlation could be established between the Coralba friction tester measurements and ASTM E274 skid trailer results. Both systems were tested in July and August 1991, at the St. Cloud, Minnesota, test track and on I-35 and TH 53 near Duluth, Minnesota. This section describes the results of the tests and the correlation of the Coralba Friction Tester with ASTM E274 skid measurements.

The skid trailer determines a level of friction between a tire on a locked wheel and the pavement. This level of friction is specified in terms of a nondimensional skid number (SN) between 0 and 100. The Coralba friction tester also measures friction between a conventional tire on a pickup or passenger vehicle and the pavement. This value is also nondimensional and ranges from 0.0 to 1.0.

A total of 106 individual measurements were made with the Coralba and 41 with the skid trailer. These were taken at three sites on three pavement types (asphalt concrete [AC], portland cement concrete [PCC], and new PCC). Measurements were made at 20, 30, and 40 mph (32,48, and 64 kph) 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. The study design is summarized in table 6. The individual measurements are shown in Appendix B, and their averages are plotted in figures 4 through 7.

For each of the 24 unique combinations (site, pavement type, speed and device), the mean, standard deviation, and coefficient of variation were calculated for SN and the Coralba measurements in both modes. These statistics are shown in the last three columns of table 7.

Data obtained at 20 mph (32 kph) with the Coralba could not be compared with skid data because the skid trailer was not used at that speed. However, Coralba measurements in the lockup and no lockup modes were compared at this speed.

Pairs of Coralba and skid measurements are summarized in table 8. They are also plotted in figures 4 through 7. These plots show a direct 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 would be misleading and therefore was not performed. Instead, the Spearman nonparametric rank correlation coefficient was calculated for each of the three possible comparisons.

Table 6 Skid and Coralba study design.

Obs.	Site	Pavement type	Speed (mph)	Device	Lockup ?	N[a]
1	I-35	New conc.	30	Coralba	no	6
2	I-35	New conc.	30	Coralba	yes	5
3	I-35	New conc.	30	Skid	yes	5
4	I-35	New conc.	40	Coralba	no	6
5	I-35	New conc.	40	Coralba	yes	6
6	I-35	New conc.	40	Skid	yes	5
7	NBL[b] TH 53	Asphalt	30	Coralba	no	11
8	NBL TH 53	Asphalt	30	Coralba	yes	2
9	NBL TH 53	Asphalt	30	Skid	yes	5
10	NBL TH 53	Asphalt	40	Coralba	no	13
11	NBL TH 53	Asphalt	40	Coralba	yes	4
12	NBL TH 53	Asphalt	39	Skid	yes	5
13	NBL TH 53	Concrete	20	Coralba	no	3
14	NBL TH 53	Concrete	20	Coralba	yes	5
15	NBL TH 53	Concrete	30	Coralba	no	6
16	NBL TH 53	Concrete	30	Coralba	yes	14
17	NBL TH 53	Concrete	30	Skid	yes	5
18	NBL TH 53	Concrete	40	Coralba	no	2
19	NBL TH 53	Concrete	40	Coralba	yes	10
20	NBL TH 53	Concrete	41	Skid	yes	5
21	St. Cloud	Asphalt	30	Coralba	yes	5
22	St. Cloud	Asphalt	30	Skid	yes	5
23	St. Cloud	Asphalt	40	Coralba	yes	5
24	St. Cloud	Asphalt	40	Skid	yes	6
25	NBL TH 53	Asphalt	40	Coralba[c]	no	1
26	NBL TH 53	Concrete	40	Coralba[c]	yes	2
	All sites					147

[a] N = Number of individual measurements.
[b] NBL - Northbound lane.
[c] Measurements made on dry pavement. (All other measurements made on wet pavement.)

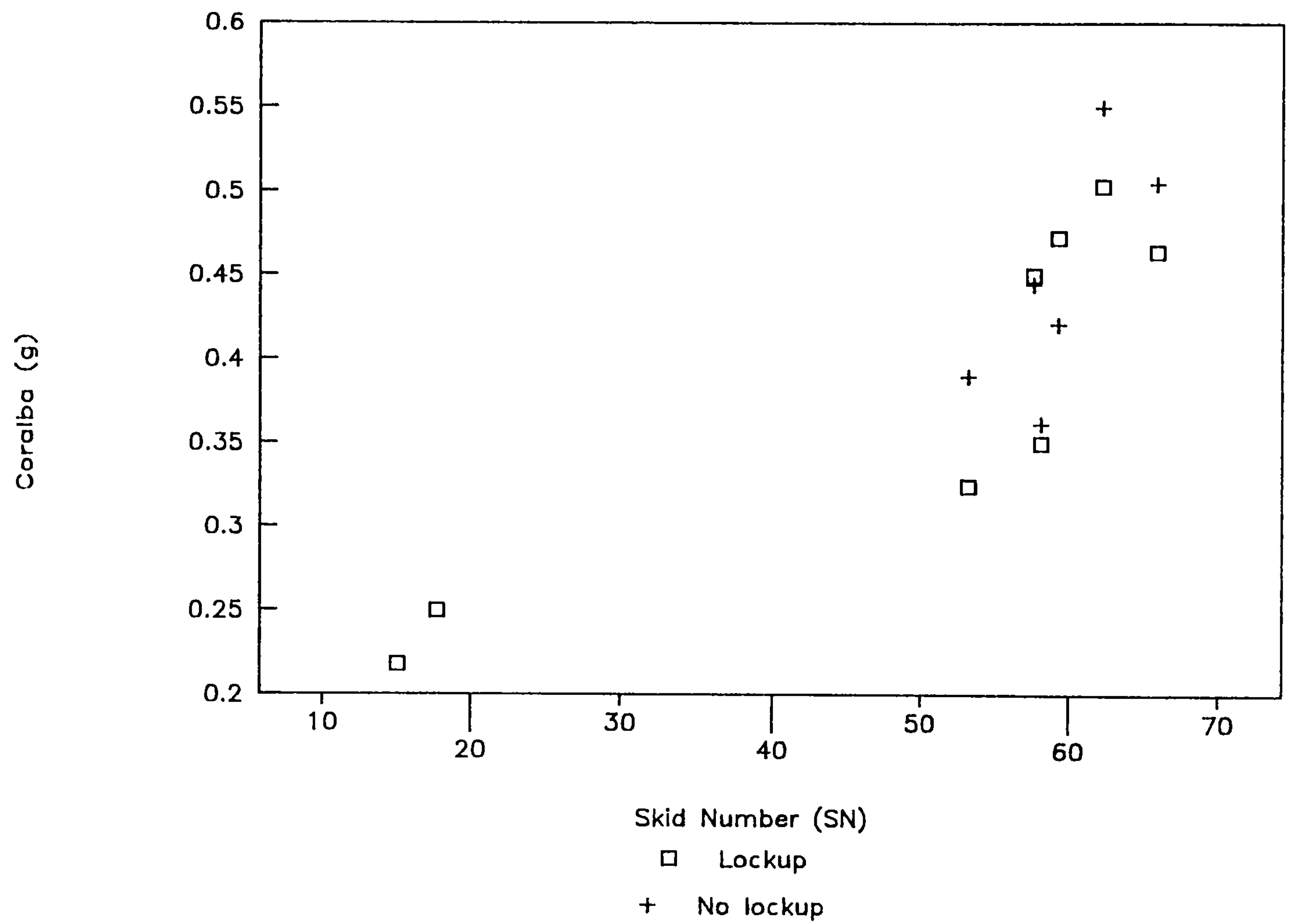


Figure 4 Lockup and no lockup Coralba measurements versus skid trailer (SN) results.

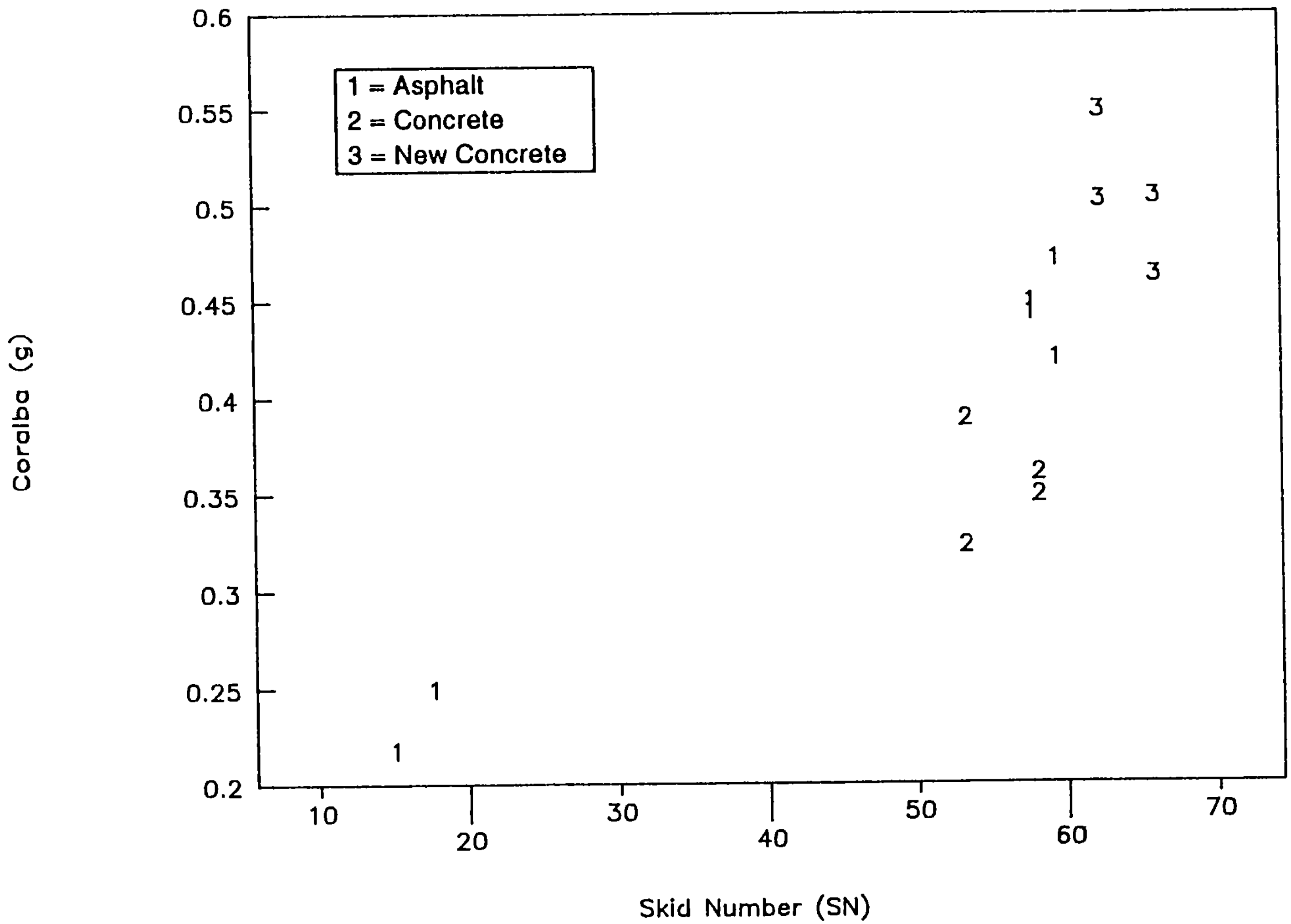


Figure 5 Coralba versus skid trailer measurements for different pavement types.

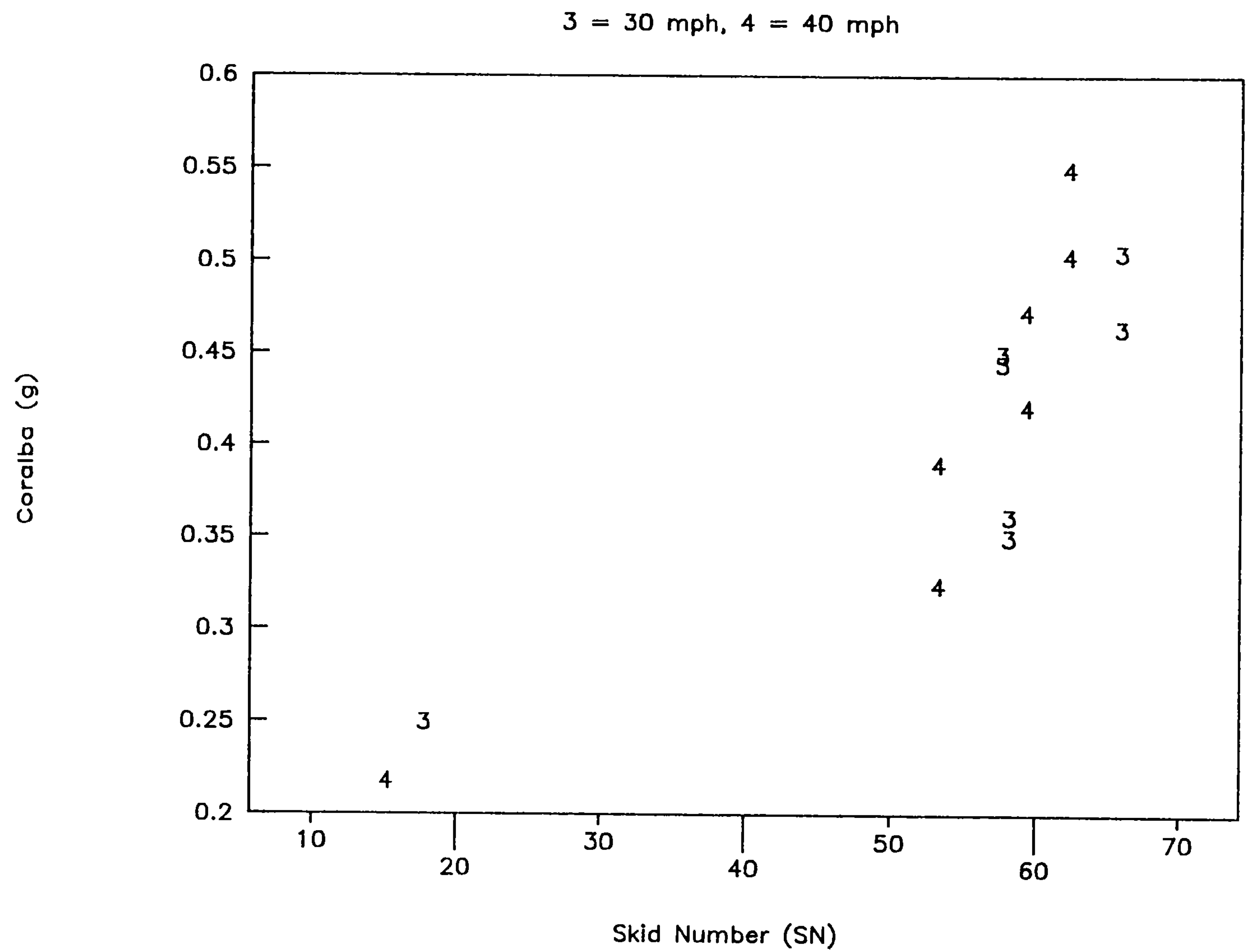


Figure 6 Coralba versus skid trailer measurements for 30 and 40 mph test speeds.

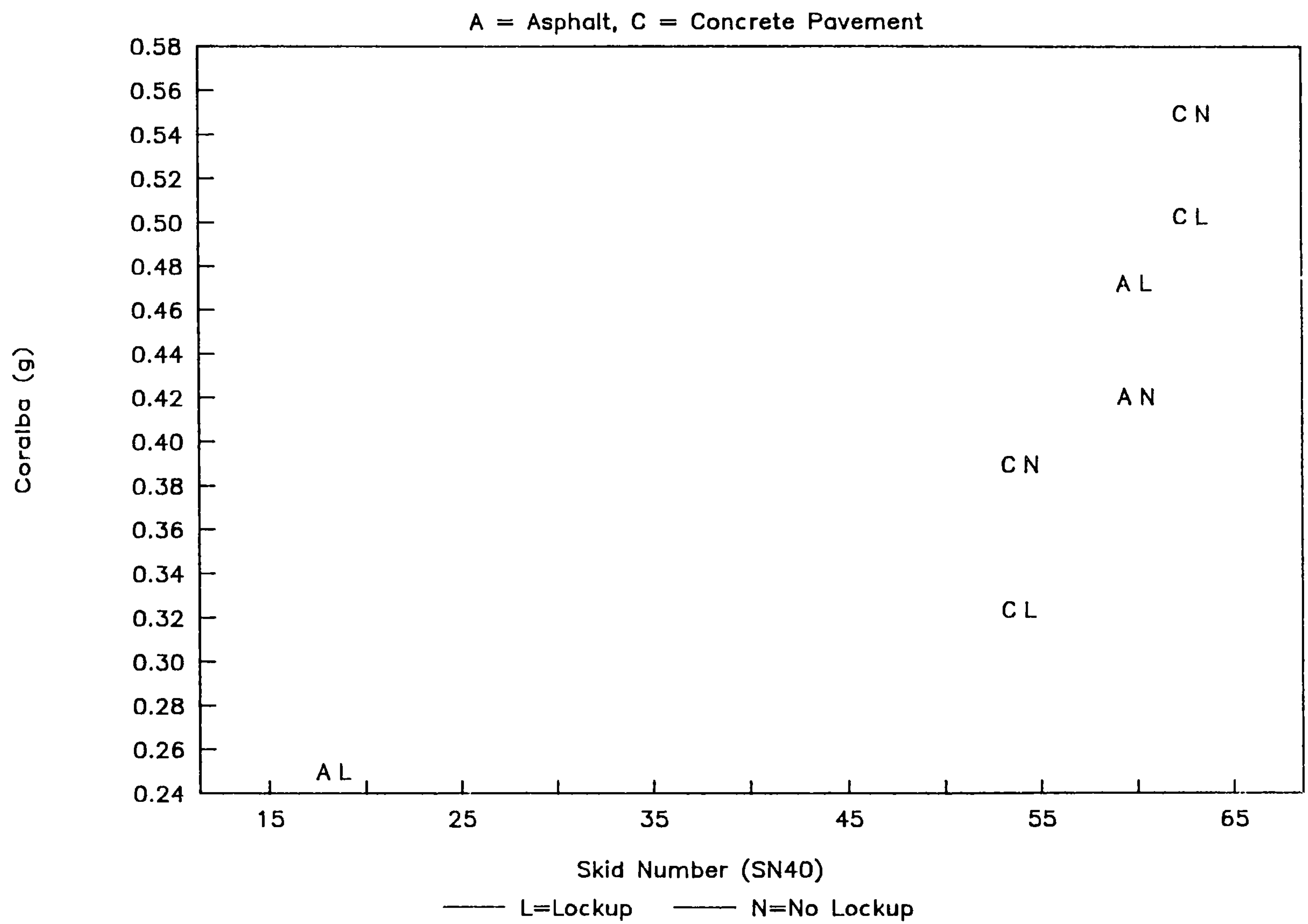


Figure 7 Lockup/no lockup Coralba measurements versus skid trailer results at 40 mph on asphalt and concrete pavement

Table 7 Skid and Coralba measurements—statistics.

Obs.	Site	Pavement type	Speed (mph)	Device	Lockup?	Pvt	Mean	Std Dev	CV[a] (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[b] 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

[a] CV = Coefficient of variation = 100 x standard deviation/mean.
[b] NBL = Northbound lane.

Table 8 Coralba–skid measurement comparison.

Site	Pavement type	Speed (mph)[a]	Skid number	Coralba	
				Lockup	No lockup
I-35	New conc.	30	65.92	0.46	0.51
I-35	New conc.	40	62.26	0.50	0.55
NBL[b] TH 53	Asphalt	30	57.66	0.45	0.44
NBL TH 53	Asphalt	40	59.32	0.47	0.42
NBL TH 53	Concrete	20		0.30	0.33
NBL TH 53	Concrete	30	58.14	0.35	0.36
NBL TH 53	Concrete	40	53.28	0.32	0.39
St. Cloud test track	Asphalt	30	15.10	0.22	
St. Cloud test track	Asphalt	40	17.74	0.25	

[a] 1 mph = 0.62 km/hr.
[b] NBL = Northbound lane.

These Spearman correlation coefficients and their 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 vs 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%, assuming a 95% 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% confidence level; i.e., 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% confidence level.

- The correlation between skid and no lockup Coralba measurements is *not* significantly different from zero.

Based on these results, it was decided that the participating SHAs would use Coralba friction testers during the winter testing. The testers would be operated in a lockup mode at 40 mph (64 kph). However, testing could not be conducted at 30 mph (48 kph) for safety considerations. It was also decided that the testers should not be operated at 20 mph (32 km/hr) because of the high variability in the Coralba measurements obtained at that speed (see the coefficients of variation in table 7).

Laboratory Evaluation of SOBO-20 Salinity Tester

Laboratory studies were conducted to evaluate the utility of the SOBO-20 salinity tester for the semiquantitative measurement of chemical solutions applied to surfaces. The studies consisted of evaluating the type of response and range of detection for five different chemicals:

- sodium chloride (NaCl);
- magnesium chloride ($MgCl_2$);
- Calcium chloride ($CaCl_2$);
- potassium acetate ($KOOCCH_3$; more simply, KAc); and
- calcium magnesium acetate ($Ca/MgOOCCH_3$; more simply, CMA).

Five series of tests were conducted to determine the SOBO-20 meter readings for selected surface chemical concentration levels. The test consisted of the following steps. First, carefully weighed amounts of a 20 % chemical solution by weight were applied to the surface of a stainless steel pan. The amounts of chemical solution applied to the test surface were selected to yield the following equivalent chemical concentration levels of 0.05, 0.10, 0.25, 0.50, 0.75, 1.00, and 1.50 oz/yd^2. The required amounts of 20 % chemical solution (20, 40, 100, 200, 300, 400, and 600 mg) were then applied to attain the chemical surface concentration levels specified. After application of the proper amount of concentrated chemical solution on the stainless test surface, the sampling/testing chamber of the SOBO-20 was placed over the chemical sample. The measuring fluid was forced then into the measuring chamber, and the SOBO-20 displayed a reading on its electronic meter. After the measurement was completed, the solution was collected and the conductivity was measured with an ElectroMark Analyzer

Model 4400 (Markson Science) conductivity meter. Technical grade chemicals typical of those used for snow and ice control were used in these experiments.

Multiple tests were run using a chemical concentration level of 0.50 oz/yd^2 to test the effects of the scale factor.

The results of the SOBO-20 tests and the conductivity measurements for the five chemical solutions are presented in tables 9 through 13. In addition, a composite presentation of the test data is set forth in figure 8. Comparative evaluations of test results revealed interesting information concerning the intensity and linearity of SOBO-20 response and chemical weight relationships according to chemical type and concentration range.

Table 9 SOBO-20 readings and conductivity values of sodium chloride solutions.

SOBO meter			Applied chemical surface concentration			Conductivity[a]
Observed reading[a]	Scale factor	Actual reading[a]	(oz/yd^2)	(g/m^2)	(lb/lane-mile)	(µS)
1.0	x 1/2	0.5	0.05	1.70	22	180
1.0	x 1	1.0	0.10	3.39	44	308
5.0	x 1/2	2.5	0.25	8.48	110	767
4.8	x 1	4.8	0.50	17.0	220	1,517
10.0	x 1/2	5.0	0.50	17.0	220	1,567
15.0	x 1/2	7.5	0.75	25.4	330	2,500
10.0	x 1	10.0	1.00	33.9	440	3,250
15.0	x 1	15.0	1.50	50.9	660	4,767

[a] Average of three determinations.

Table 10 Readings and conductivity values of magnesium chloride solutions.

SOBO meter			Applied chemical surface concentration			Conductivity[a]
Observed reading[a]	Scale factor	Actual reading[a]	(oz/yd^2)	(g/m^2)	(lb/lane mile)	(μS)
1.00	x 1/2	0.50	0.05	1.70	22	135
1.00	x 1	1.00	0.10	3.39	44	250
2.75	x 1/2	1.38	0.25	8.48	110	602
5.25	x 1	5.25	0.50	17.0	220	1,185
10.00	x 1/2	5.00	0.50	17.0	220	1,222
13.38	x 1/2	6.69	0.75	25.4	330	2,712
7.25	x 1	7.25	1.0	33.9	440	3,500
10.00	x 1	10.00	1.50	50.9	660	5,075

[a] Average of three determinations.

Table 11 Readings and conductivity values of calcium chloride solutions.

SOBO meter			Applied chemical surface concentration			Conductivity[a]
Observed reading[a]	Scale factor	Actual reading[a]	(oz/yd^2)	(g/m^2)	(lb/lane mile)	(μS)
1.00	x 1/2	0.50	0.05	1.70	22	132
1.00	x 1	1.00	0.10	3.39	44	255
4.90	x 1/2	2.45	0.25	8.48	110	589
3.90	x 1	3.90	0.50	17.0	220	1,132
8.80	x 1/2	4.40	0.50	17.0	220	1,197
10.00	x 1/2	5.00	0.75	25.4	330	2,025
5.75	x 1	5.75	1.00	33.9	440	2,750
8.00	x 1	8.00	1.50	50.9	660	3,825

[a] Average of three determinations.

Table 12 Readings and conductivity values of potassium acetate solutions.

SOBO meter			Applied chemical surface concentration			Conductivity[a]
Observed reading[a]	Scale factor	Actual reading[a]	(oz/yd^2)	(g/m^2)	(lb/lane mile)	(µS)
0	x 1/2	0	0.05	1.70	22	106
0	x 1	0	0.10	3.39	44	147
2.80	x 1/2	1.40	0.25	8.48	110	374
2.50	x 1	2.50	0.50	17.0	220	776
5.00	x 1/2	2.50	0.50	17.0	220	762
8.25	x 1/2	4.13	0.75	25.4	330	1137
5.00	x 1	5.00	1.00	33.9	440	1675
6.25	x 1	6.25	1.50	50.9	660	2450

[a] Average of three determinations.

Table 13 Readings and conductivity values of calcium magnesium acetate solutions.[a]

SOBO meter			Applied chemical surface concentration			Conductivity[b]
Observed reading[b]	Scale factor	Actual reading[b]	(oz/yd^2)	(g/m^2)	(lb/lane mile)	(µs)
0	x 1/2	0	0.05	1.70	22	59
0	x 1	0	0.10	3.39	44	144
2.0	x 1/2	1.0	0.25	8.48	110	354
2.0	x 1	2.0	0.50	17.0	220	711
4.5	x 1/2	2.3	0.50	17.0	220	710
6.0	x 1/2	3.0	0.75	25.4	330	1031
3.3	x 1	3.3	1.00	33.9	440	1335
4.9	x 1	4.9	1.5	50.9	660	2075

[a] Ice-B-Gon®, 91% CMA (Chevron Chemical Co.)
[b] Average of three determinations.

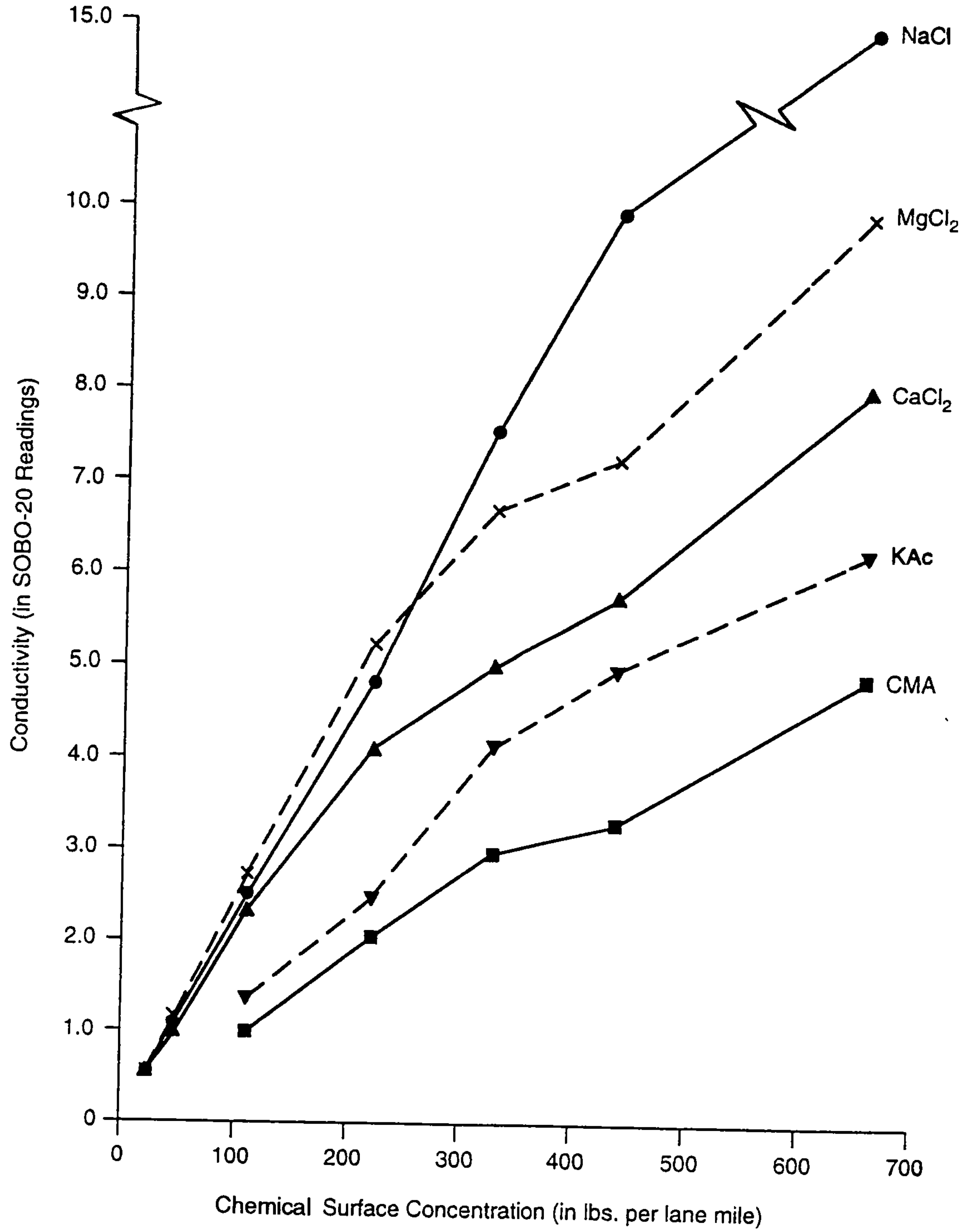


Figure 8 SOBO-20 readings versus chemical surface concentration.

NaCl gave the highest SOBO-20 conductivity readings per surface concentration unit and the most linear response. In addition, the results obtained during this study were in agreement with the values reported by the manufacturer for NaCl.

The four other chemicals ($MgCl_2$, $CaCl_2$, KAc and CMA) gave nonlinear SOBO-20 readings per chemical weight relationships at surface concentration levels of 330 lb/lane-mile or greater.

The intensity of the SOBO-20 response per surface concentration unit varied by chemical type in the following order: NaCl > $MgCl_2$ > $CaCl_2$ > KAc > CMA. Generally, the order of the degree of response was expected. However, this study did not validate the equivalency of NaCl and $CaCl_2$; the conductivity of both these chemicals on the same surface concentration basis should be the same.

The analytical range of the SOBO-20 varies according to the ionic strength of the chemical electrolyte. The strong electrolyte chemicals (NaCl, $MgCl_2$, and $CaCl_2$) gave SOBO-20 readings at the lowest concentration level tested (22 lb/lane-mile); for the weak electrolyte chemicals (KAc and CMA), the lowest detectable concentration level was 110 lb/lane-mile. Accordingly, the analytical ranges of SOBO-20 for the five target chemicals are as follows:

- NaCl, $MgCl_2$, and $CaCl_2$:
  Half scale: 22 to 330 lb/lane-mile
  Full scale: 44 to 660 lb/lane-mile

- KAc and CMA:
  Half scale: 110 to 330 lb/lane-mile
  Full scale: 220 to 660 lb/lane-mile

Since the standard analytical range of the SOBO-20 lacked the sensitivity to detect and analyze KAc and CMA at surface concentration levels below 110 lb/lane-mile, the manufacturer was contacted to determine if a meter could be developed with a more sensitive range. The manufacturer indicated a modified electronic meter with an expanded scale could be produced to an estimated analytical range of from 4.4 to 66.0 lb of NaCl/lane mile.

Based on the results of the laboratory studies of test methods and apparatus, the SOBO-20 salinity meter appeared to be the most promising device for measuring residual anti-icing chemicals on pavements. Several initial conclusions were drawn regarding certain features and limitations of the SOBO-20:

- The main advantage of the SOBO-20 is that the device was designed for fairly rapid sampling and analysis of salt on pavement surfaces at temperatures near or below freezing in a highway environment.

- Although the device was designed for sampling and analyzing NaCl, the unit can be used for testing other conventional salts, such as $CaCl_2$ and $MgCl_2$, at application rates comparable to those of NaCl.

- The device can be used for testing KAc and CMA, but only at application rates greater than 110 lb/lane-mile.

- A more sensitive electronic meter is needed to measure weak electrolytes (namely, KAc and CMA) at surface concentration levels below 110 lb/lane-mile.

Based on the above initial conclusions and considerations, the following decisions were made:

- The present configuration of the SOBO-20 would be used during the winter testing by those SHAs using NaCl, $CaCl_2$ and $MgCl_2$, or mixtures of these strong electrolytes.

- A modified electronic meter with increased sensitivity for lower concentration levels of KAc and CMA would be obtained, evaluated, and supplied to those SHAs using KAc and CMA.

Six SOBO 20 Chloride Measuring Instruments were ordered in November 1991, and were received about one month later. Prior to being shipped to the various transportation agencies, the operation of each unit was verified by a single point calibration check using a saturated NaCl solution and the procedure outlined in the training materials. The results of the calibrations (table 14) indicated that all of the instruments appeared to be in proper working order and that the readings were within reasonable operating limits. A maximum variation of ±1 unit from the true value was observed, which was deemed acceptable, given the limitations of the instrumentation involved.

After calibration, the six instruments (along with their associated maintenance and calibration equipment) were shipped to the various transportation agencies at the end of December 1991.

Table 14 Results of SOBO calibration check.

State agency	Serial number	SOBO reading (full scale)[a]	SOBO reading (half scale)[a]	Solution volume (mL)
CA	1475	5	10	42.0
MD	1476	5	9	41.6
MO	1477	5	9	42.2
OH	1478	6	11	42.4
NY	1479	6	11	42.2
WA	1480	5	10	42.2

[a] Rounded to nearest whole value.

An expanded electronic readout for the SOBO instrument owned by the State of Minnesota was ordered in November 1991 and received by MRI in mid-December 1991. Calibration curves were developed for this meter using stock solutions of reagent grade chemicals. Curves relating the SOBO reading to the equivalent pounds of chemical/lane mile were developed for NaCl, $CaCl_2$, $MgCl_2$, KAc, and CMA. The range of concentrations tested varied from 4.4 to 330 lb/lane-mile with data collected at several of the chemical concentrations used in previous calibrations. The data obtained during calibration of the expanded meter for Minnesota Department of Transportation (MNDOT) are shown in figure 9.

After the above calibration was completed, the meter with expanded readout was shipped to the MNDOT in mid-January 1992.

Finally, about mid-December 1991, the Strategic Highway Research Program requested that another SOBO instrument with an expanded electronic readout be supplied to Michigan Technological University (MTU) for use in their anti-icing experiments. This unit was ordered and, upon receipt, calibrated in an identical manner to that described above for the MNDOT meter. The calibration data for this instrument are shown in figure 10, with a comparison of data obtained for the MTU instrument versus that for the MNDOT instrument shown in figure 11.

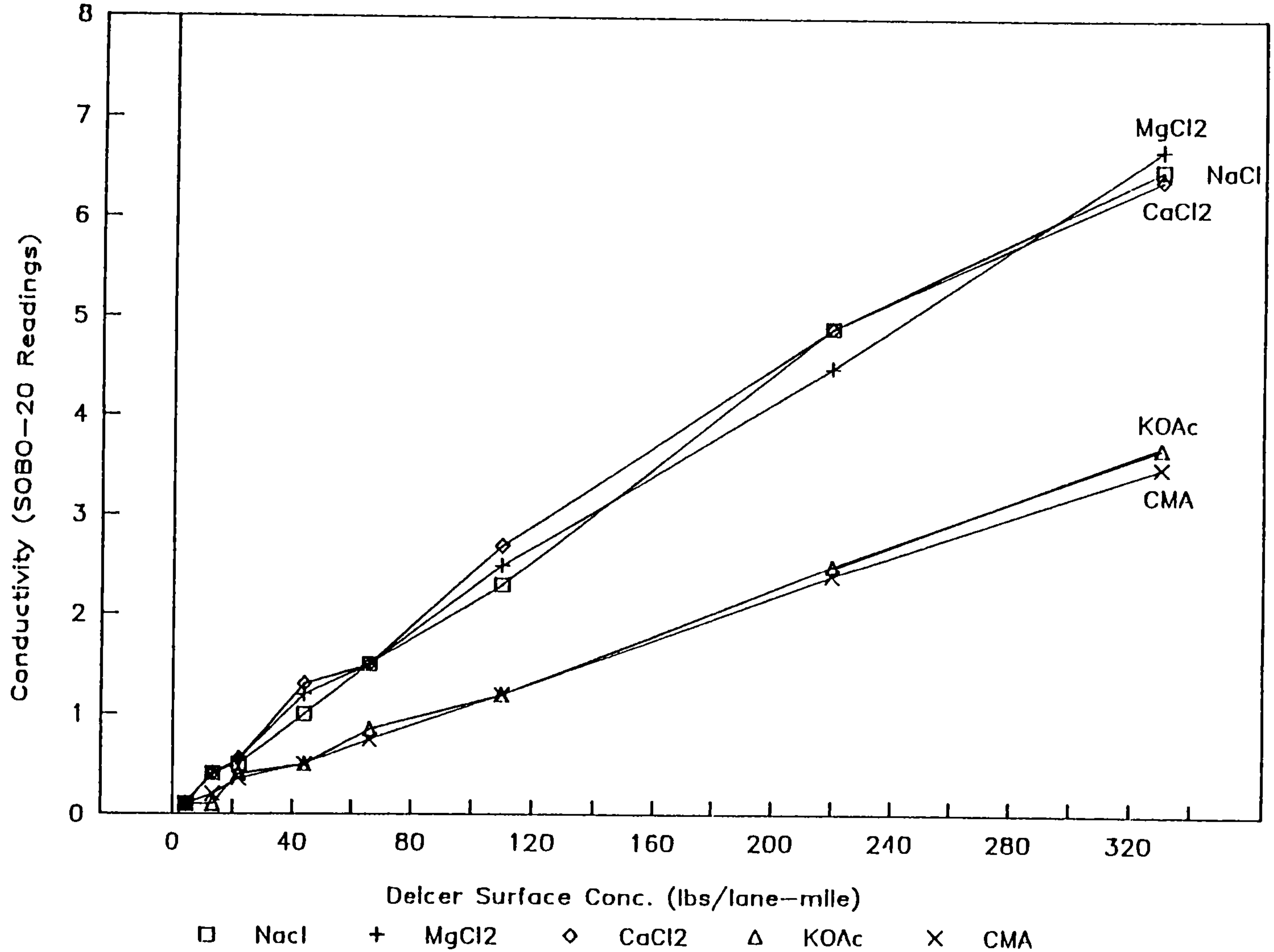


Figure 9 Calibration data for expanded electronic readout provided to MNDOT.

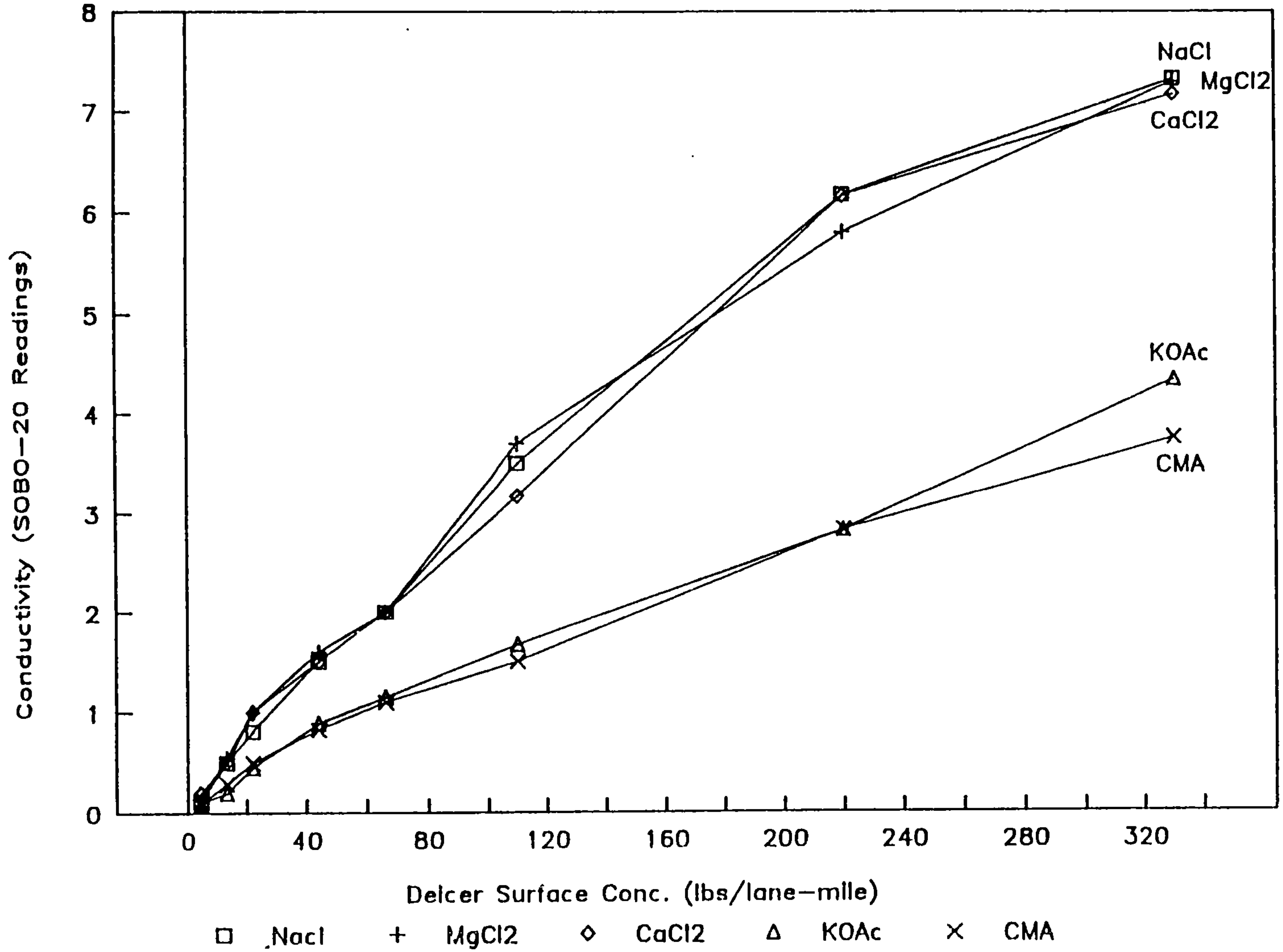


Figure 10 Calibration data for SOBO 20 instrument with expanded meter supplied to MTU.

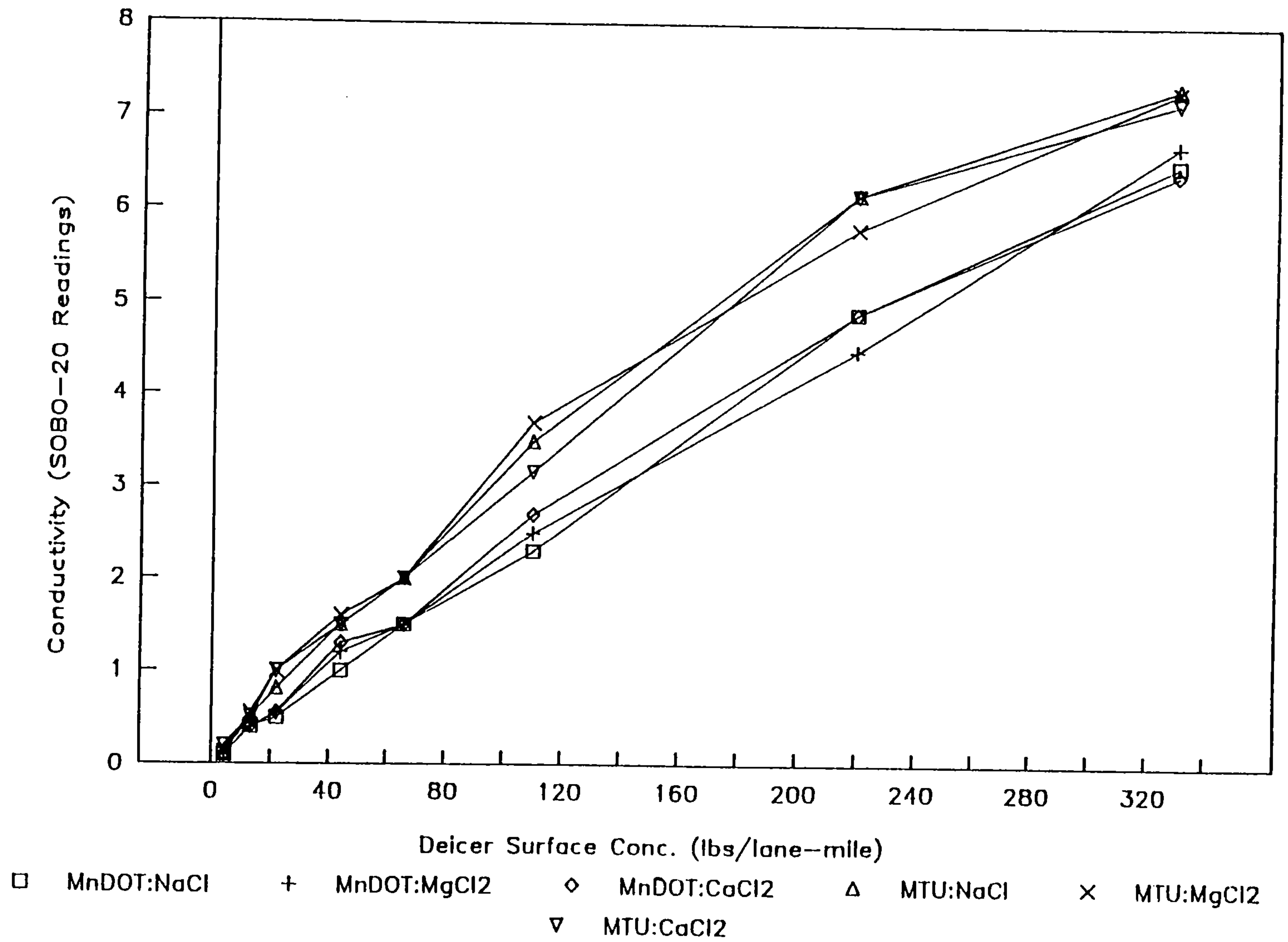


Figure 11 Comparison of expanded calibration data for MNDOT and MTU SOBO 20 instruments.

Evaluating the slopes of the two data sets as shown in figure 11 reveals that the MTU instrument reads about 15% higher than the MNDOT unit. This indicates the presence of a systematic variation between two seemingly identical SOBO instruments. However, it is not known whether the variation in readings results from differences in the meter themselves, the instruments to which they are attached, or both. Ideally, the two meters should be tested on the same SOBO in order to isolate the exact source of variation. This was not possible, however, given the time constraints involved in implementing of the experimental program. The SOBO unit was shipped to MTU in mid-January 1992.

Analysis of Maintenance Field Data

Field observations were made of the anti-icing operations at the selected test sites in the nine participating states of California, Colorado, Maryland, Minnesota, Missouri, Nevada, New York, Ohio, and Washington. Both the experiments and observations were conducted by the state maintenance personnel during the winters of 1991-92 and 1992-93. A series of data recording forms was designed specifically for use by the maintenance personnel. These forms provided the proper format for maintenance personnel to record weather and pavement conditions, spreader equipment operations, and SOBO-20 and Coralba readings during each storm event. Examples of each form are given in Appendix C.

Winter maintenance field data were collected to estimate the effectiveness of anti-icing treatments relative to conventional deicing. The analyses of the field data for each storm event in the two winters were conducted in about the same manner. These provide for each test and control section a chronological history of the meteorological events, pavement conditions, and maintenance activities associated with the storm, including the amount of material applied to each traveled lane. Coralba measurements made in the various traveled lanes and SOBO-20 readings identified by wheeltrack or centerline measurement location are also included in the chronological history of each storm event. The pavement type is identified for each Coralba and SOBO-20 reading.

A number of quality control checks were made on the data as they were entered into a spreadsheet. These checks identified numerous field recording errors and reporting inconsistencies which were subsequently clarified through contacts with the appropriate maintenance personnel.

When possible, graphs were prepared of the weather, pavement conditions, and air temperature as a function of time for the test and control sections. A summary was made of the total material (chemical and abrasives) applied to the test and control sections during each storm event. Also, summaries of each storm event were developed to provide an overview of the event, the test and control section pavement conditions at the first winter maintenance treatment, and a brief history of both the test and control section pavement conditions during the storm.

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 deicing operation. In general, an anti-icing operation is one where a chemical 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 where a chemical is applied on 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 theory, a friction measurement (Coralba reading) could help define that point in the development of a storm. However, the Coralba measurements were generally not made in the field at the appropriate time or were not reliable enough to assist in this determination for all storms. Consequently, it was necessary to develop criteria for classifying of the first maintenance treatment (table 15). The first maintenance operation designation depends on pavement temperature, pavement condition, and type of precipitation. Air temperature is not directly included in the criteria, but is assumed to be below 40°F (4°C). Pavement conditions appropriate for anti-icing operations are dry, wet, and minor accumulation of snow or sleet on the shoulder and roadway. Pavement conditions appropriate during deicing operations include slush, snow or ice pack, and ice. The above 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.

Summary tabulations were made of the maintenance treatment activities on the test and control sections in each state. These tabulations also include the savings achieved in terms of material applied and passes made on the test sections compared to the control sections.

The findings from the winter 1991-92 tests are presented next, followed by those findings from the winter 1992-93 tests.

Table 15 Criteria for determining anti-icing or deicing conditions at time of first treatment application.

Classification of maintenance operation	Pavement temperature	Pavement condition	Type of precipitation
Anti-icing	36° to 33°F and falling below 32°F	Dry	None, but precipitation forecasted
Anti-icing	36° to 33°F and falling below 32°F	Wet	None, rain, freezing rain, sleet, snow, or blowing snow
Anti-icing	≤ 32°F and falling	Dry	None, but precipitation forecasted
Anti-icing	≤ 32°F and falling	Wet	None, rain, freezing, rain, sleet, snow, or blowing snow
Anti-icing	≤ 32°F and falling	Very minor accumulation of snow/sleet on shoulder and road	None, sleet, snow, or blowing snow
Deicing	≤ 32°F	Slush	None, rain, freezing rain, sleet, snow, or blowing snow
Deicing	≤ 32°F	Snow pack	None, sleet, snow, or blowing snow
Deicing	≤ 32°F	Ice	None, rain, or freezing rain

Winter 1991-92 Results

The first anti-icing experiment during the 1991-92 winter was conducted in Nevada in mid-December 1991. Data collection continued to the end of March 1992. At that time, a total of 57 storm events had been recorded by the nine participating states, in spite of the late start of the anti-icing experiments. The number of storm events reported by each state is given in table 16. Over 70% of the events were recorded by Maryland Department of Transportation (MDDOT), Nevada Department of Transportation (NDOT), MNDOT, and New York Department of Transportation (NYDOT) maintenance personnel. No storm events were recorded at 4 of the 14 sites in the nine states because of the extremely mild winter after the anti-icing experiments began.

Table 16 Number of storm events recorded and analyzed for 1991-92 winter.

Geographic area	State	No. of storm events recorded	No. of events analyzed	No. of events with reduced material application[a]
Mountainous states	California	9	0	0
	Maryland	11	11	2
High Plains states	Colorado	1	1	0
	Nevada	8	8	7
Plains states	Missouri	3	1	0
	Ohio	3	3	2
Lake effect states	Minnesota	8	4	0
	New York	14	14	10
Maritime state	Washington	0	0	0
Total	9	57	42	21

[a] These events are defined as ones where lesser amounts of material were used on the test section than on the control section.

Of the 57 storm events recorded, only 42 could be analyzed because there was insufficient data on the other 15 events. The number of storm events analyzed for each state is also given in table 16. The major reasons the 15 events could not be analyzed are incomplete or missing operator activity data, missing weather and pavement condition information, or missing Road Weather Information System (RWIS) data.

Examples of the analyses conducted of the maintenance field data are given in figures 12 through 17. These figures pertain to storm event Number 8 recorded on February 16, 1992, for U.S. 395 in Nevada. Figures 12 and 13 provide a chronological history of the meteorology, 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 12 is for the test section, and figure 13 for the control section. Figures 14 and 15 are graphs of the weather, pavement conditions, and air temperature as a function of time for the test and control sections, respectively. Time in these and associated figures is expressed in terms of a 24-hour clock. Figure 16 is a composite plot of Figures 14 and 15 and shows the road conditions for both the test and control sections as a function of time and treatment applications. When the condition of the test section is better than the condition of the control section the experimental maintenance treatment is considered successful. The experimental maintenance treatment has failed whenever the test section road condition is worse than the control section road condition.

U.S. HIGHWAY 395

DATE: FEBRUARY 16, 1992

TEST							APPLICATION							CORALBA	SOBO			
		TRK	PVMT TEMP	AIR TEMP	ROAD	WTHR	MATERIAL	RATE (lbs/	LANES TREATD		AMOUNT APPLIED (lbs)			FRICTION VALUE	READNG		EQUIVALENT (lbs/ln-ml)	
DATE	TIME	I.D.	(°F)	(°F)	COND	COND	APPLIED	ln-ml)	DL	PL	DL	PL	TRMT	@40 mph	WT	CL	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												

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.

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

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 12 Chronological history of Nevada storm event number 8 for the test section.

U.S. HIGHWAY 395

DATE: FEBRUARY 16, 1992

CONTROL

DATE	TIME	TRK I.D.	PVMT TEMP (°F)	AIR TEMP (°F)	ROAD COND	WTHR COND	APPLICATION: MATERIAL APPLIED	APPLICATION: RATE (lbs/ln-mi)	APPLICATION: LANES TREATD DL	APPLICATION: LANES TREATD PL	APPLICATION: AMOUNT APPLIED (lbs) DL	APPLICATION: 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												

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

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

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).

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

Figure 13 Chronological history of Nevada storm event number 8 for the control section.

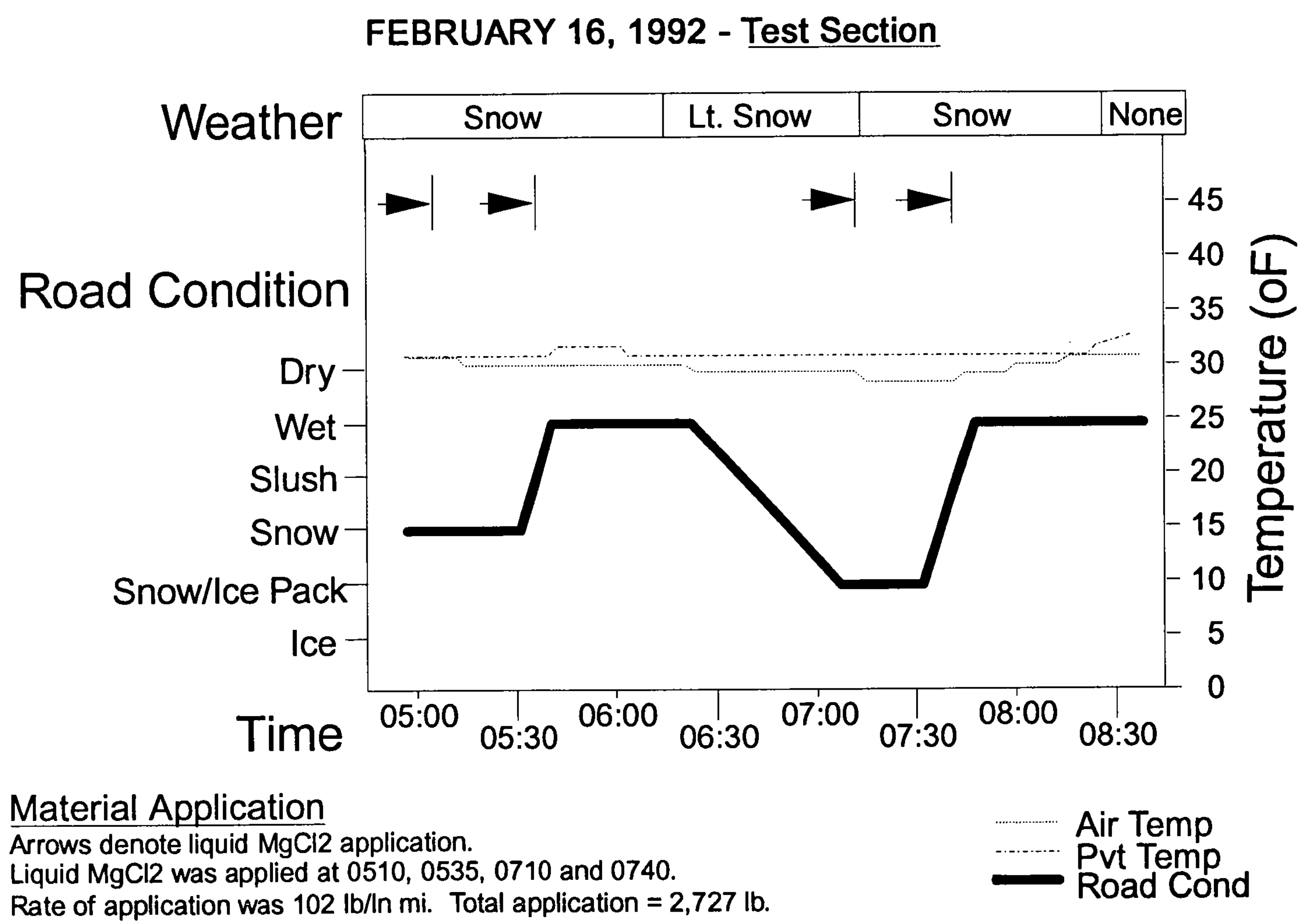


Figure 14 Time history of weather, pavement, and air temperature conditions for the test section on U.S. 395 in Nevada.

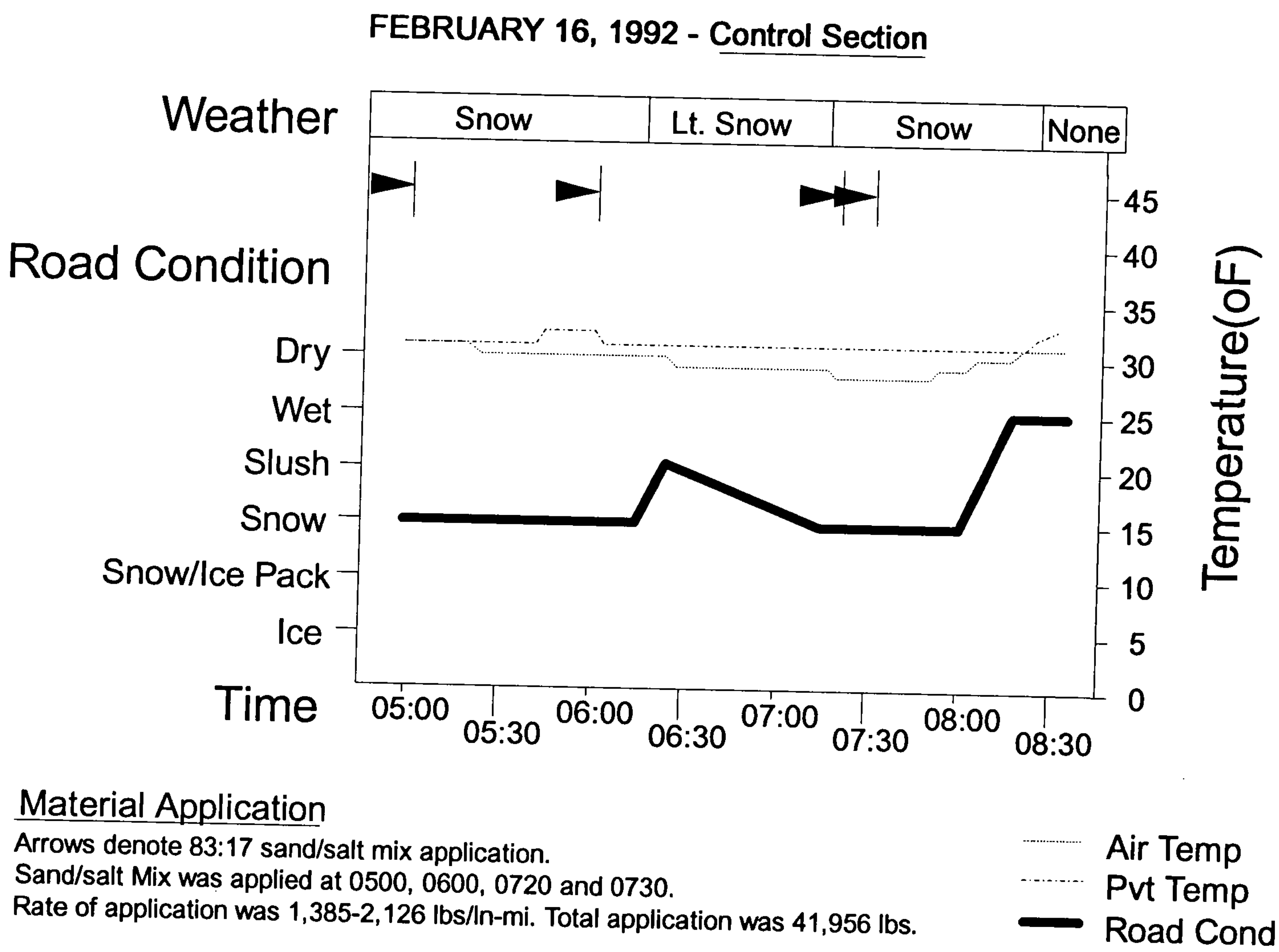


Figure 15 **Time history of weather, pavement, and air temperature conditions for the control section on U.S. 395 in Nevada.**

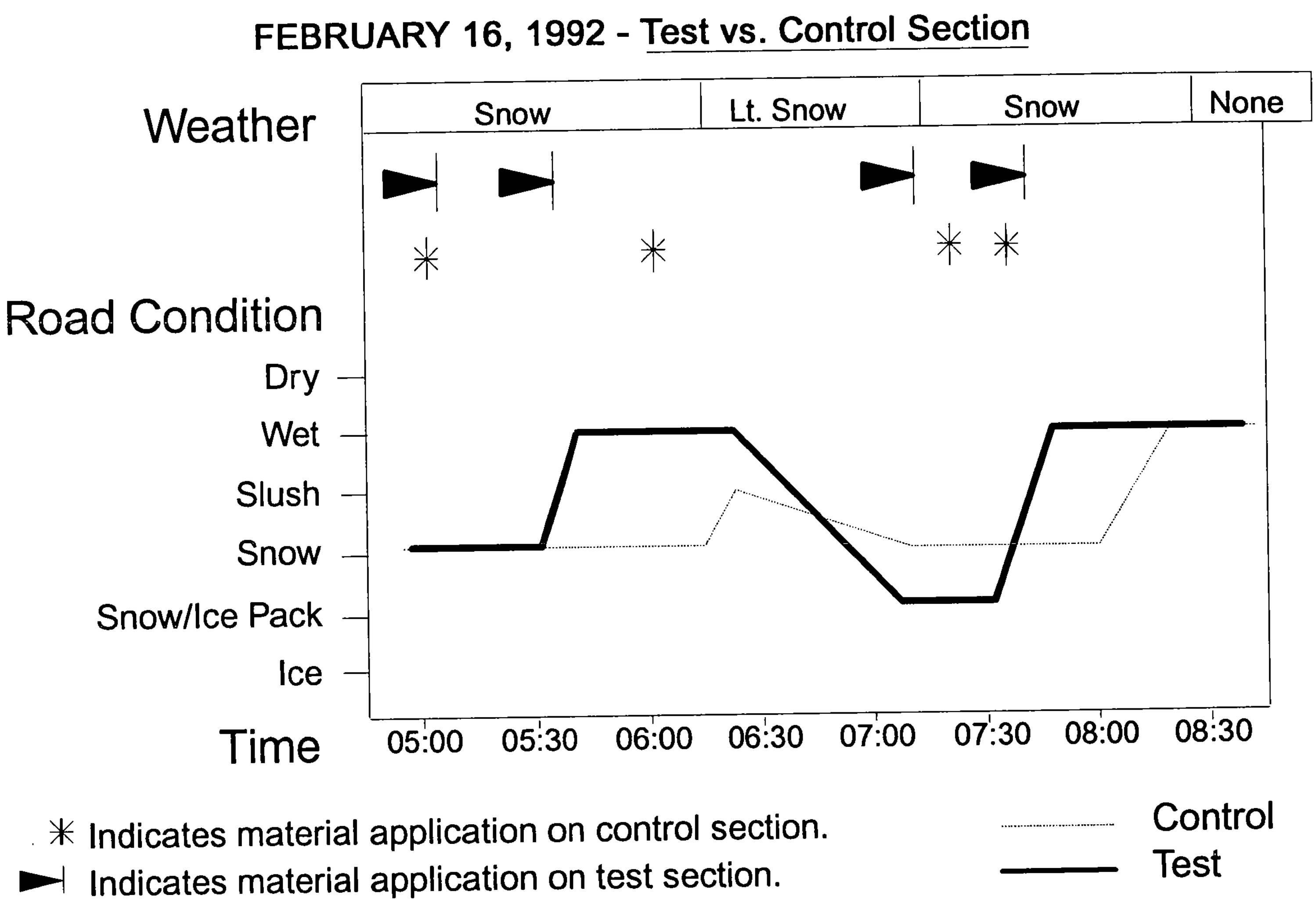


Figure 16 Comparison of time history of road conditions for the test and control sections on U.S. 395 in Nevada.

Figure 17 is a summary of the total material (chemical and abrasives) applied to the test and control sections during the event. For Nevada storm event 8, over 2.6 times as much chemical was applied to the control section as was applied to the test section (3,235 kg [7,133 lb] NaCl versus 1,237 kg [2,727 lb] $MgCl_2$). On a total material basis, including sand, over 15 times as much material was applied to the control section as was applied to the test section (19,027 kg versus 1,237 kg [41,956 lb versus 2,727 lb]).

Similar tabulations and plots for Maryland storm event 6 are given in figures 18 through 22. During this storm, 1.6 times as much chemical was applied to the test section as was applied to the control section when the chemical amounts were normalized with section length (130 kg/km [461 lb/mile] NaCl versus 79 kg/km [280 lb/mile] NaCl). However, on a total material weight basis, about 20 times as much material was applied to the control section as to the test section when the material amounts were normalized with section length (2,675 kg/km [9,492 lb/mile] versus 130 kg/km [461 lb/mile]).

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, five passes of a maintenance truck had to be made on the control section, compared to only three passes on the test section. Also, the pavement condition of the test section only deteriorated to a slush state, while the pavement of the control section deteriorated to a snow-covered condition. The salt application rate of 5.9 g/m^2 (77 lb/lane-mile) applied to the test section was apparently enough to prevent the pavement from reaching a snowy state. However, the 25 kg (55.1 lb) of salt plus 60 kg (132.3 lb) of abrasives applied per lane-mile on the control section did not prevent the pavement from reaching a snowy state.

Tabulations and plots similar to those displayed in figures 12 through 22 were developed for many of the other storm events recorded during the 1991-92 winter.

A summary of the material applied to the test and control sections during the 1991-92 winter is given in Appendix F. The data are for the 42 storm events analyzed from Maryland, Colorado, Nevada, Missouri, Ohio, Minnesota, and New York. Summaries of the maintenance activities on the test and control sections and the savings achieved in material and passes on the test sections in the seven states are also presented in tables 17 through 23. In computing the percentage of material saved, the material amounts applied to the test and control sections in Maryland (MD 495) and Minnesota (I-35) were normalized by section lengths.

During 21 out of 42 (50%) storm events, less chemical and abrasive material was used on the test sections than on the control sections. The distribution of these 21 events by state is also given in table 16. During another three events, about the same amount of material was applied to both the test and control sections. Thus during 24 out of 42 (57%) storm events, smaller or equal amounts of material were used on the test sections than on the control sections.

The rate of chemical reduction achieved on the test sections during the 1991-92 winter was 23% in New York (table 23), 30% in Ohio (table 21), and 49% in Nevada (table 19). The other states reported increased chemical usage. Nevada also reported a 74% reduction in abrasive used over the winter on the test section, as compared to the control section. In only 2 of the 11 storm events recorded in Maryland was less material used on the test section than on the control section. The reason for these discouraging results in Maryland was the use of a truck on the test that had difficulty in maintaining low application rates. The truck used on the control section was able to use, and frequently did, small application rates.

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	4
Material used	Liquid $MgCl_2$
Application rate per pass	102 lbs/ln-mi
Total material applied (all passes combined)	2,727 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	4
Material used	sand/salt mix*
Application rate per pass	1,385 - 2,126 lbs/ln-mi
Total material applied (all passes combined)	41,956 lbs
Total salt applied (all passes combined)	7,133 lbs
Total sand applied (all passes combined)	34,823 lbs

*Sand/salt mix is 83% sand, 17% salt.

Figure 17. Summary of material applied to the test and control sections during Nevada storm event number 8.

MD ROUTE 495

DATE: FEBRUARY 4, 1992

TEST

							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)	SB	NB	SB	NB	TRMT	@40 mph	WT	CL	WT	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	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 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 Pavement and air temperatures 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 18. Chronological history of Maryland storm event number 6 for the test section.

MD ROUTE 495

DATE: FEBRUARY 4, 1992

CONTROL							APPLICATION							CORALBA	SOBO			
								RATE (lbs/ ln-mi)	LANE TRTD		AMOUNT APPLIED (lbs)			FRICTION VALUE	READING		EQUIVALNT lbs/ln-mi	
DATE	TIME	TRK I.D.	PVM TEMP (°F)	AIR TEMP (°F)	ROAD COND	WTHR COND	MAT'L APPLIED		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
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

Notes:
1 Length of section is 10 miles.
2 Pavement type is DGA (Dense Graded Asphalt).
3 Pavement and air temperatures 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 19. Chronological history of Maryland storm event number 6 for the control section.

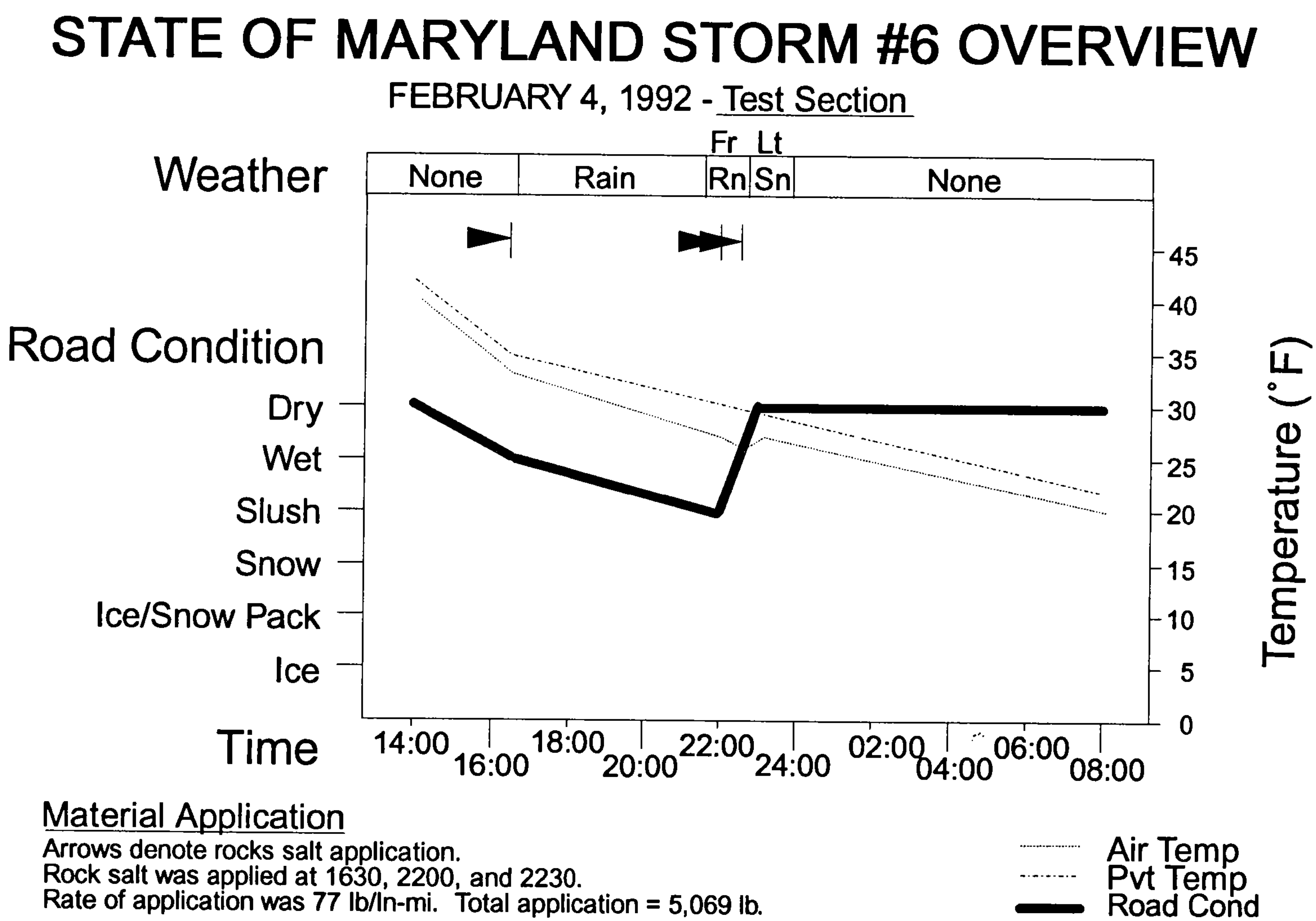


Figure 20. Time history of weather, pavement, and air temperature conditions for the test section on Maryland Route 495.

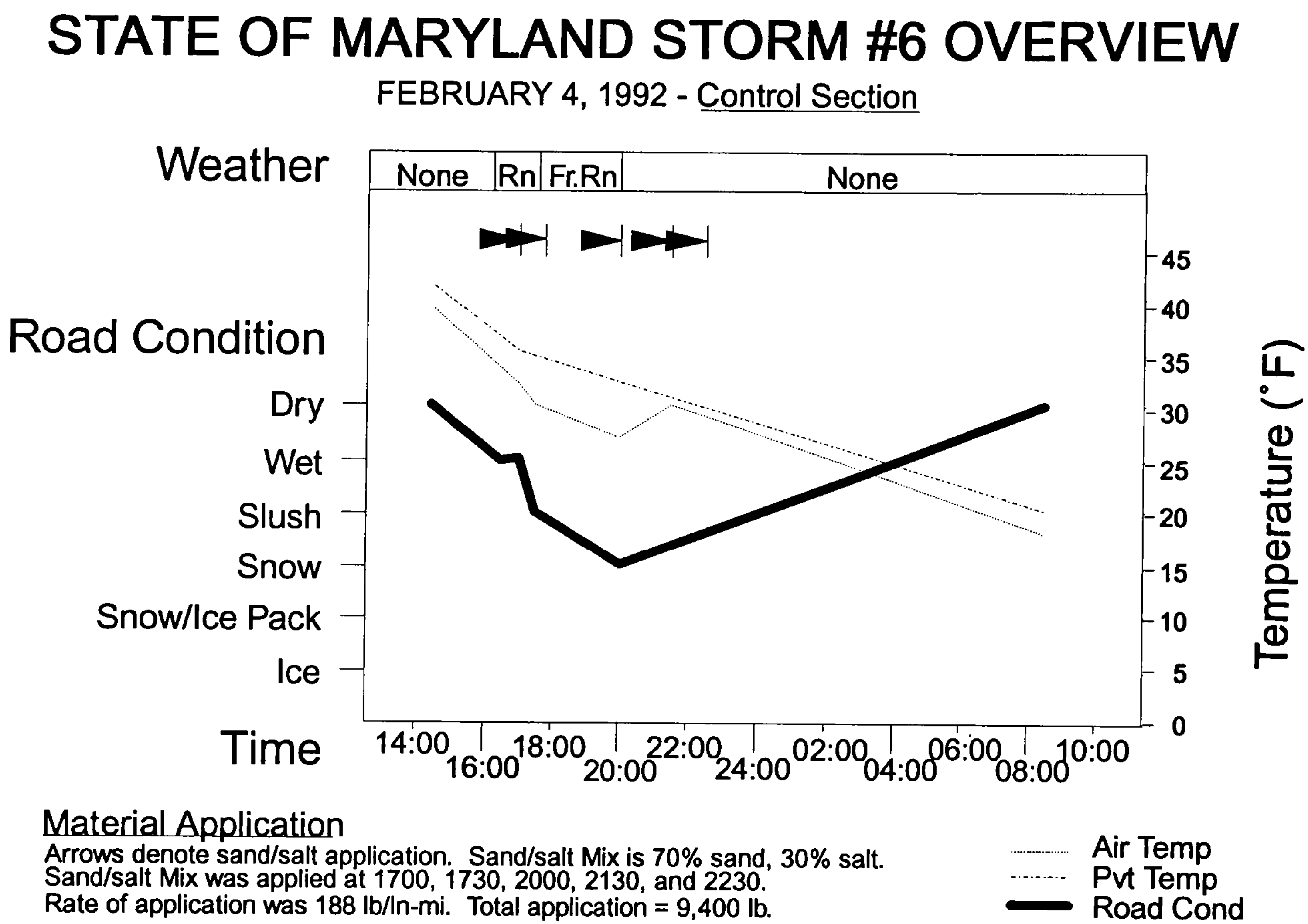


Figure 21. Time history of weather, pavement, and air temperature conditions for the control section on Maryland Route 495.

STATE OF MARYLAND
Storm #6 - February 4, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	3
Material used	100% rock salt
Application rate per pass	77 lbs/ln-mi
Total material applied (all passes combined)	5,069 lbs

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	5
Material used	70:30 sand/salt mix
Application rate per pass	188 lbs/ln-mi
Total material applied (all passes combined)	9,400 lbs
Total salt applied (all passes combined)	2,820 lbs
Total sand applied (all passes combined)	6,580 lbs

Figure 22. Summary of material applied to the test and control sections during Maryland storm event

Table 17 Summary of maintenance activities on test and control sections and savings achieved on test section in Maryland during 1991-92 winter.

Storm No.	Storm date	Test section				Control section				Percent material saved on test section			Passes saved on test section
		Material used (lb)			Total No. passes	Material used (lb)			Total No. passes				
		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material	
	<u>MD 495</u>												
1	1/14/92	28,021	57,499	85,520	14	2,358	13,707	16,066	12	−980.3	−281.4	−383.9	−2
2	1/15/92	24,027	103,582	127,610	17	10,007	32,757	42,763	38	−118.3	−187.5	−171.3	21
3	1/20/92	7,309	40,438	47,747	9	4,595	36,843	41,438	32	−44.6	0.2	−4.8	23
4	1/23/92	6,122	33,257	39,378	7	7,380	25,605	32,986	21	24.6	−18.1	−8.5	14
5	1/31/92	30,991	82,251	113,242	20	5,326	20,421	25,747	22	−429.0	−266.2	−299.8	2
6	2/4/92	5,069	0	5,069	3	2,820	6,580	9,400	5	−63.4	100.0	51.0	2
7	2/13/92	8,189	19,108	27,298	5	1,063	9,564‘	10,627	7	−600.3	−81.6	−133.5	2
8	2/16/92	6,758	0	6,758	4	5,112	9,624	14,736	10	−20.2	100.0	58.3	6
9	2/28/92	23,654	0	23,654	7	3,635	8,482	12,117	10	−491.6	100.0	−77.5	3
10	3/14/92	9,827	22,930	32,757	6	2,269	2,991	5,261	6	−293.7	−596.9	−466.0	0
11	3/15/92 - 3/16/92	13,517	0	13,517	4	2,978	6,948	9,926	4	−312.6	100.0	−23.8	0
Total		163,484	359,065	522,550	96	47,543	173,522	221,067	167	−212.6	−88.1	−114.9	71

Table 18 Summary of maintenance activities on test and control sections and savings achieved on test section on Colorado during 1991-92 winter.

Storm No.	Storm date	Test section: Material used (lb): Chemical	Test section: Material used (lb): Abrasive	Test section: Material used (lb): Total material	Test section: Total No. passes	Control section: Material used (lb): Chemical	Control section: Material used (lb): Abrasive	Control section: Material used (lb): Total material	Control section: Total No. passes	Percent material saved on test section: Chemical	Percent material saved on test section: Abrasive	Percent material saved on test section: Total material	Passes saved on test section
	CO 470												
1	3/9/92	2,640	11,692	14,332	3	2,536	11,551	14,087	3	−4.1	−1.2	−1.7	0
Total		2,640	11,692	14,332	3	2,536	11,551	14,087	3	−4.1	−1.2	−1.7	0

Table 19 Summary of maintenance activities on test and control sections and savings achieved on test section in Nevada during 1991-92 winter.

Storm No.	Storm date	Test section: Material used (lb): Chemical	Test section: Material used (lb): Abrasive	Test section: Material used (lb): Total material	Test section: Total No. passes	Control section: Material used (lb): Chemical	Control section: Material used (lb): Abrasive	Control section: Material used (lb): Total material	Control section: Total No. passes	Percent material saved on test section: Chemical	Percent material saved on test section: Abrasive	Percent material saved on test section: Total material	Passes saved on test section
	US 395												
1	12/18/91	2,676	12,530	15,207	2	0	0	0	0	NA[a]	NA[a]	NA[a]	−2
2	12/28/91	2,727	0	2,727	4	2,703	13,196	15,898	2	−0.9	100.0	82.9	−2
3	1/2/92-1/3/92	1,606	7,518	9,124	1	4,243	20,716	24,959	3	62.2	63.7	63.4	2
4	1/5/92	2,508	5,357	7,864	3	4,777	23,321	28,097	3	47.5	77.0	72.0	0
5	1/6/92-1/7/92	4,142	19,713	23,854	2	5,264	25,701	30,965	3	21.3	23.3	23.0	1
6	2/11/92	0	0	0	0	1,932	9,434	11,366	2	100.0	100.0	100.0	2
7	2/15/92	1,364	0	1,364	2	8,941	43,655	52,597	6	84.7	100.0	97.4	4
8	2/16/92	2,727	0	2,727	4	7,133	34,823	41,956	4	61.8	100.0	93.5	0
Total		17,750	45,118	62,867	18	34,993	170,846	205,838	23	49.3	73.6	69.5	5

[a] NA denotes percent savings not calculated because material was applied only to the test section.

Table 20. Summary of maintenance activities on test and control sections and savings achieved on test section in Missouri during 1991-92 winter.

Storm No.	Storm date	Test section				Control section				Percent material saved on test section			Passes saved on test section
		Material used (lb)			Total No. passes	Material used (lb)			Total No. passes				
		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material	
	I-29												
2	3/18-3/19/92	566	0	566	2	280	0	280	1	−102.1	a	−102.1	−1
Total		566	0	566	2	280	0	280	1	−102.1	a	−102.1	−1

[a] Percent savings is not calculated because no material was applied to either section.

Table 21. Summary of maintenance activities on test and control sections and savings achieved on test section in Ohio 1991-92 winter.

Storm No.	Storm date	Test section				Control section				Percent material saved on test section			Passes saved on test section
		Material used (lb)			Total No. passes	Material used (lb)			Total No. passes				
		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material		Chemical	Abrasive	Total material	
	I-70												
1	2/8/92	2,421	0	2,421	2	2,400	0	2,400	2	−0.9	a	−0.9	0
2	2/13/92	4,842	0	4,842	4	8,400	0	8,400	4	42.4	a	42.4	0
3	2/14/92	2,421	0	2,421	2	3,000	0	3,000	2	19.3	a	19.3	0
Total		9,684	0	9,684	8	13,800	0	13,800	8	29.8	a	29.8	0

[a] Percent savings is not calculated because no material was applied to either section.

Table 22. **Summary of maintenance activities on test and control sections and savings achieved on test section in Minnesota during 1991-92 winter.**

Storm No.	Storm date	Test section: Material used (lb): Chemical	Test section: Material used (lb): Abrasive	Test section: Material used (lb): Total material	Test section: Total No. passes	Control section: Material used (lb): Chemical	Control section: Material used (lb): Abrasive	Control section: Material used (lb): Total material	Control section: Total No. passes	Percent material saved on test section: Chemical	Percent material saved on test section: Abrasive	Percent material saved on test section: Total material	Passes saved on test section
	I-35												
1	2/10/92	7,134	0	7,134	7	7,383	0	7,383	3	−177.0	a	−177.0	−4
3	2/17/92	1,313	0	1,313	1	0	0	0	0	NA[b]	a	NA[b]	−1
4	2/20/92	4,588	0	4,588	3	3,341	0	3,341	3	−293.7	a	−293.7	0
Total		13,035	0	13,035	11	10,724	0	10,724	6	−248.5	a	−248.5	−5
	US 53												
4	2/20/92	9,513	10,200	19,713	2	0	0	0	0	NA[b]	NA[b]	NA[b]	−2
Total		9,513	10,200	19,713	2	0	0	0	0	NA[b]	NA[b]	NA[b]	−2

[a] Percent savings is not calculated because no material was applied to either section.
[b] NA denotes percent savings not calculated because material was applied only to the test section.

Table 23. Summary of maintenance activities on test and control sections and savings achieved on test section in New York during 1991-92 winter.

Storm No.	Storm date	Test section: Material used (lb): Chemical	Test section: Material used (lb): Abrasive	Test section: Material used (lb): Total material	Test section: Total No. passes	Control section: Material used (lb): Chemical	Control section: Material used (lb): Abrasive	Control section: Material used (lb): Total material	Control section: Total No. passes	Percent material saved on test section: Chemical	Percent material saved on test section: Abrasive	Percent material saved on test section: Total material	Passes saved on test section
	SH 104												
1	1/23/93	22,925	0	22,925	13	27,148	0	27,148	8	15.6	a	15.6	−5
2	2/1/92	3,809	0	3,809	2	3,480	0	3,480	1	−9.5	a	−9.5	−1
3	2/4/92	15,105	0	15,105	8	24,363	0	24,363	7	38.0	a	38.0	−1
4	2/8-2/9/92	22,868	0	22,868	13	47,732	0	47,732	14	52.1	a	52.1	1
5	2/11/92	8,742	0	8,742	5	10,143	0	10,143	3	13.8	a	13.8	−2
6	2/12-2/14/92	13,895	0	13,895	6	17,005	0	17,005	5	18.3	a	18.3	−1
7	2/16/92	3,776	0	3,776	2	3,744	0	3,744	2	−0.9	a	−0.9	0
8[b]	2/20/92	0	0	0	0	0	0	0	0	a	a	a	0
9	2/22/92	1,888	0	1,888	1	1,872	0	1,872	1	−0.9	a	−0.9	0
10	2/24/92	7,553	0	7,553	4	6,961	0	6,961	2	−8.5	a	−8.5	−2
11	2/26-2/27/92	7,452	0	7,452	4	10,604	0	10,604	4	29.7	a	29.7	0
12	2/28-2/29/92	21,082	0	21,082	7	24,267	0	24,267	7	13.1	a	13.1	0
13	3/11-3/15/92	75,662	5,959	81,622	33	91,713	3,055	94,768	33	17.5	−95.1	13.9	0
14	3/17/92	5,369	0	5,369	2	6,961	0	6,961	4	22.9	a	22.9	2
15	3/22/92	29,223	0	29,223	11	35,695	0	35,695	11	18.1	a	18.1	0
Total		239,349	5,959	245,309	111	311,688	3,055	314,743	102	23.2	−95.1	22.1	−9

[a] Percent savings is not calculated because no material was applied to either section.
[b] Storm No. 8 was not classified as a storm event because there was no maintenance activity and no precipitation.

The above figures for reductions achieved on the test section in Maryland do not consider the classification of maintenance operations during the first treatment application of each storm on the test and control sections. These maintenance operations were classified as either anti-icing or deicing, as shown in table 24, according to the criteria in table 15. The results of these classifications are given in tables 25 through 30 for the storm events analyzed Colorado, Nevada, Missouri, Ohio, Minnesota, and New York.

Table 24. Classification of maintenance operations during the first treatment application on test and control sections in Maryland during 1991-92 winter.

		Maintenance operations	
Storm No.	Storm date	Test section	Control section
	MD 495		
1	1/14/92	Anti-icing	Anti-icing
2	1/15/92	Deicing	Deicing
3	1/20/92	Deicing	Deicing
4	1/23/92	Deicing	Deicing
5	1/31/92	Anti-icing	Anti-icing
6	2/4/92	Anti-icing	Anti-icing
7	2/13/92	Deicing	Deicing
8	2/16/92	Deicing	Anti-icing
9	2/28/92	Deicing	Deicing
10	3/14/92	Deicing	Deicing
11	3/15/92 - 3/16/92	Anti-icing	Deicing

Table 25. Classification of maintenance operations during the first treatment application on test and control sections in Colorado during 1991-92 winter.

		Maintenance operations	
Storm No.	Storm date	Test section	Control section
	CO 470		
1	3/9/92	Deicing	Deicing

Table 26. Classification of maintenance operations during the first treatment application on test and control sections in Nevada during 1991-92 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	US 395		
1	12/18/92	Deicing	No treatment
2	12/28/92	Anti-icing	Deicing
3	1/2/92 - 1/3/92	Deicing	Deicing
4	1/5/92	Anti-icing	Deicing
5	1/6/92 - 1/7/92	Anti-icing	Anti-icing
6	2/11/92	No treatment	Anti-icing
7	2/15/92	Anti-icing	Anti-icing
8	2/16/92	Deicing	Deicing

Table 27 Classification of maintenance operations during the first treatment application on test and control sections in Missouri during 1991-92 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-29		
2	3/18/92 - 3/19/92	Anti-icing	Anti-icing

Table 28. Classification of maintenance operations during the first treatment application on test and control sections in Ohio during 1991-92 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-70		
1	2/8/92	Deicing	Deicing
2	2/13/92	Deicing	Deicing
3	2/14/92	Anti-icing	Anti-icing

Table 29. Classification of maintenance operations during the first treatment application on test and control sections in Minnesota during 1991-92 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-35		
1	2/10/92	Anti-icing	Anti-icing
3	2/17/92	Anti-icing	No treatment
4	2/20/92	Anti-icing	Deicing
	US 53		
4	2/20/92	Anti-icing	No treatment

Table 30. Classification of maintenance operations during the first treatment application on test and control sections in New York during 1991-92 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	SH 104		
1	1/23/92	Anti-icing	Anti-icing
2	2/1/92	Anti-icing	Anti-icing
3	2/4/92	Anti-icing	Anti-icing
4	2/8/92 - 2/9/92	Deicing	Deicing
5	2/11/92	Anti-icing	Anti-icing
6	2/12/92 - 2/14/92	Deicing	Deicing
7	2/16/92	Anti-icing	Anti-icing
8[a]	2/20/92	–	–
9	2/22/92	Anti-icing	Anti-icing
10	2/24/92	Anti-icing	Anti-icing
11	2/26/92 - 2/27/92	Anti-icing	Anti-icing
12	2/28/92 - 2/29/92	Deicing	Deicing
13	3/11/92 - 3/15/92	Deicing	Deicing
14	3/17/92	Anti-icing	Deicing
15	3/22/92	Anti-icing	Anti-icing

[a] Storm 8 was not classified as a storm event because there was no maintenance activity and no precipitation.

The test plan called for an anti-icing treatment to be applied to the test section while the control section was allowed to undergo conventional deicing. The classification of maintenance operations showed that the parameters of the test plan were more the exception than the rule. Almost all the possible combinations of maintenance operations took place on the test and control sections. Anti-icing operations on the test section and deicing operations on the control section took place during only 5 of the 42 storm events: once during the 11 events in Maryland (storm 11); not at all during the 1 event in Colorado; twice during the 8 events in Nevada (storms 2 and 4); not during the 1 event in Missouri; not during the 3 events in Ohio; once during the 4 events in Minnesota (storm 4 on I-35); and only once during the 14 events in New York (storm 14). The other times when anti-icing occurred on the test sections, either anti-icing or no treatment took place on the control sections. A few times, anti-icing operations were recorded on the control section while deicing or no treatment operations took place on the test section.

Anti-icing operations took place on the test sections during two storms in Minnesota when no treatment was necessary on the corresponding control sections. The remaining treatment combinations mainly involved the conservative approach of using deicing operations on both the test and corresponding control sections.

Table 31 presents the savings achieved during the five storm events in which anti-icing operations were used on the test sections while deicing operations were used on the corresponding control sections.

Table 31 Summary of savings achieved on test sections during anti-icing operations in the 1991-92 winter.

State	Storm No.	Percent material saved on test section			Passes saved on test section
		Chemical	Abrasive	Total material	
MD	11	−312.6	100.0	−23.8	0
NV	2	−0.9	100.0	82.9	−2
NV	4	47.5	77.0	72.0	0
MN	4	−293.7	–	−293.7	0
NY	14	22.9	–	22.9	2

A smaller amount of chemical was used on the test section than to the corresponding control section during two of the five (40%) storm events in which anti-icing operations occurred on the test section and deicing operations were used on the control section. Abrasives were used during three of these five storm events. Smaller amounts of abrasives were used on the test section than on the control section during all three events. No maintenance passes were saved through anti-icing operations.

During 21 out of 42 (50%) storm events, less chemical and abrasive material was used on the test sections than on the control sections. The success of these 21 trials cannot be totally credited to anti-icing operations. Various combinations of anti-icing and deicing operations were used during these 21 storm events. Success can be attributed to better timing of the treatments, more sensible deicing operations, and better awareness on the part of maintenance personnel of the pavement conditions during the storm events.

Coralba Friction Measurements

Five states made Coralba friction measurements during 27 of the 42 storm events analyzed for the 1991-92 winter. States supplying the friction measurements were Maryland (11 storm events), Nevada (1 storm event), Ohio (3 storm events), Minnesota (2 storm events), and New York (10 storm events). Summaries of the Coralba friction measurements made by the five states are given in tables 32 and 33 for the test and control sections, respectively. The data are presented for each state and associated route identification by pavement condition and type of pavement (open-graded asphalt, dense-graded asphalt, and portland cement concrete). The friction measurements made under the various pavement conditions on the three pavement types are presented in terms of the number of measurements (N), the minimum (min) and maximum (max) values, the mean, and the standard deviation (STD).

Some of the states made friction measurements before the first maintenance (anti-icing or deicing) treatment, but most measurements were made after the first or subsequent treatment. Some of the states made selective friction measurements at times preceding deicing applications. It is not known if these selective measurements were made to help decide on the need for additional deicing treatments, or if they were made simply to satisfy the need to collect data during the storm. On numerous occasions, multiple friction measurements were made in succession and no treatment application was made, even when the friction values were low. This latter finding suggests that a majority of the friction measurements were made as part of the storm documentation and not as part of a decision making process concerning the reapplication of deicing or abrasive materials.

Finnish researchers[19, 20] have attempted to correlate Coralba friction measurements with wintertime pavement conditions. The Coralba friction tester ranges determined by Teppo and Katko for different conditions on dense-graded asphalt are given in table 34. The ranges of friction values measured during the 1991-92 winter by four states on dense-graded asphalt test sections are presented in figure 23, along with the Finnish results, for conditions of dry, wet, slush, snow, snow/ice pack, and ice. One New York friction measurement was made on damp pavement. No data are presented for Maryland because those friction measurements were made on open-graded asphalt. Individual measurements made by the states are indicated by small crosses.

Table 32. Summary statistics for Coralba friction measurements (1991-92 test section).

State	Route	Pavement condition	Open graded asphalt N	Min.	Max.	Mean	Std	Dense-graded asphalt N	Min.	Max.	Mean	Std	Portland cement concrete N	Min.	Max.	Mean	Std
MD	495	Dry	7	0.08	0.85	0.49	0.24										
		Wet	23	0.06	0.91	0.36	0.26										
		Damp															
		Slush	8	0.25	0.60	0.40	0.14										
		Snow	7	0.13	0.43	0.28	0.10										
		Snow/Ice Pack															
		Ice	1	0.17	0.17	0.17											
NV	395	Dry															
		Wet						1	0.27	0.27	0.27						
		Damp															
		Slush						2	0.19	0.30	0.25	0.08					
		Snow															
		Snow/Ice Pack															
		Ice															
OH	I-70	Dry						2	0.24	0.30	0.27	0.04					
		Wet						7	0.24	0.36	0.31	0.05					
		Damp															
		Slush															
		Snow															
		Snow/Ice Pack															
		Ice						2	0.18	0.20	0.19	0.01					
MN	US 53	Dry															
		Wet						3	0.21	0.46	0.30	0.14	1	0.42	0.42	0.42	
		Damp															
		Slush															
		Snow						2	0.16	0.20	0.18	0.03	3	0.20	0.22	0.21	0.01
		Snow/Ice Pack															
		Ice															
	I-35	Dry						1	0.28	0.28	0.28		1	0.24	0.24	0.24	
		Wet															
		Damp															
		Slush															
		Snow															
		Snow/Ice Pack															
		Ice															
NY	SR104	Dry						6	0.21	0.41	0.35	0.08	12	0.17	0.45	0.35	0.11
		Damp						1	0.41	0.41	0.41						
		Wet						35	0.13	0.47	0.31	0.10	32	0.06	0.71	0.31	0.13
		Slush						8	0.18	0.42	0.29	0.09	11	0.13	0.43	0.27	0.10
		Snow						12	0.09	0.34	0.20	0.06	9	0.13	0.33	0.20	0.07
		Snow/Ice Pack						10	0.09	0.24	0.15	0.04	9	0.04	0.16	0.14	0.04
		Ice						1	0.12	0.12	0.12		1	0.12	0.12	0.12	
Total No. Meas.		218	46	No. of Measurements				93	No. of Measurements				79	No. of Measurements			

Table 33. Summary statistics for Coralba friction measurements (1991-92 control section).

State	Route	Pavement condition	Open graded asphalt N	Min.	Max.	Mean	Std	Dense-graded asphalt N	Min.	Max.	Mean	Std	Portland cement concrete N	Min.	Max.	Mean	Std
MD	495	Dry	8	0.08	0.97	0.44	0.29										
		Wet	18	0.09	0.85	0.33	0.22										
		Damp															
		Slush	7	0.13	0.60	0.33	0.17										
		Snow	8	0.19	0.51	0.29	0.10										
		Snow/Ice Pack	1	0.18	0.18	0.18											
		Ice	1	0.20	0.20	0.20											
NV	395	Dry															
		Wet															
		Damp															
		Slush						3	0.22	0.30	0.26	0.04					
		Snow															
		Snow/Ice Pack															
		Ice															
OH	I-70	Dry															
		Wet						5	0.27	0.37	0.31	0.05					
		Damp															
		Slush															
		Snow															
		Snow/Ice Pack															
		Ice						4	0.16	0.32	0.23	0.08					
MN	US 53	Dry															
		Wet															
		Damp															
		Slush															
		Snow						2	0.16	0.43	0.30	0.19	5	0.15	0.46	0.22	0.14
		Snow/Ice Pack															
		Ice															
	I-35	Dry															
		Wet											1	0.41	0.41	0.41	
		Damp															
		Slush															
		Snow															
		Snow/Ice Pack															
		Ice															
NY	SR 104	Dry						9	0.13	0.47	0.31	0.12	13	0.14	0.46	0.30	0.11
		Damp						1	0.32	0.32	0.32						
		Wet						37	0.10	0.50	0.32	0.09	29	0.10	0.52	0.31	0.10
		Slush						8	0.15	0.48	0.30	0.12	12	0.16	0.42	0.25	0.11
		Snow						9	0.17	0.43	0.30	0.08	8	0.04	0.31	0.21	0.09
		Snow/Ice Pack						9	0.16	0.41	0.22	0.08	8	0.14	0.35	0.18	0.07
		Ice						2	0.13	0.17	0.15	0.03	3	0.05	0.16	0.11	0.06
Total No. Meas.		211	43	No. of Measurements				89	No. of Measurements				79	No. of Measurements			

Some of the friction measurements made by the states fall within the Finnish range of values, while other measurements fall outside. Also, some of the states' measurements are either too low or too high for the reported pavement condition, suggesting that the state operators were not always consistent in the procedure used for measuring the friction.

Table 34. Coralba friction tester ranges.

Friction number ranges and pavement description				
0.00-0.15	0.15-0.25	0.25-0.30	0.30-0.45	0.45-1.0
Icy conditions Black ice Very slippery	Dry, cold icy condition or compacted snow/ice	Coarse ice or slush or very cold snow patches	Bare and wet or patches of snow between wheel track	Bare and dry

SOBO-20 Salinity Measurements

Four states made SOBO-20 salinity measurements during 24 of the 42 storm events analyzed for the 1991-92 winter. These were Maryland (11 storm events), Ohio (3 events), Minnesota (2 events), and New York (8 events). Nevada was the only one of the nine states not provided a SOBO-20 instrument. During several storms, some states made salinity measurements before the first anti-icing treatment. Most of the time, these pretreatment measurements resulted in zero salinity values. However, in a few storms, the pretreatment measurements indicated a small salinity level, possibly a carry-over from previous storm treatments.

Cases were noted where a low salinity measurement was followed by a chemical application. Other cases were noted where a low measurement was not followed by an application. The same treatment combinations were also noted for high salinity measurements. Thus, it appears that the SOBO-20 measurements were not used consistently to make decisions concerning reapplication treatments.

The SOBO-20 measurements made in Maryland, Minnesota, and New York were made in both the right wheeltrack of the driving (slow lane) and in the centerline between two lanes. Ohio made measurements only in the right wheeltrack of the driving lane. As expected, the wheeltrack salinity values were generally lower than those in the centerline location.

Private Weather Forecasting Information

A private weather forecasting service weather forecasts during the 1991-92 winter for the two test sites in Minnesota. Forecasts were also obtained from the National Weather Service (NWS) for the general area of the two test sites. The private service generally provided very conservative forecasts throughout the winter. No forecast was issued with a probability of precipitation greater than 60% for any given hour. The NWS provided forecasts with 1 to 2 hours advance notice of the beginning of frozen precipitation, with probability of precipitation values up to 100%.

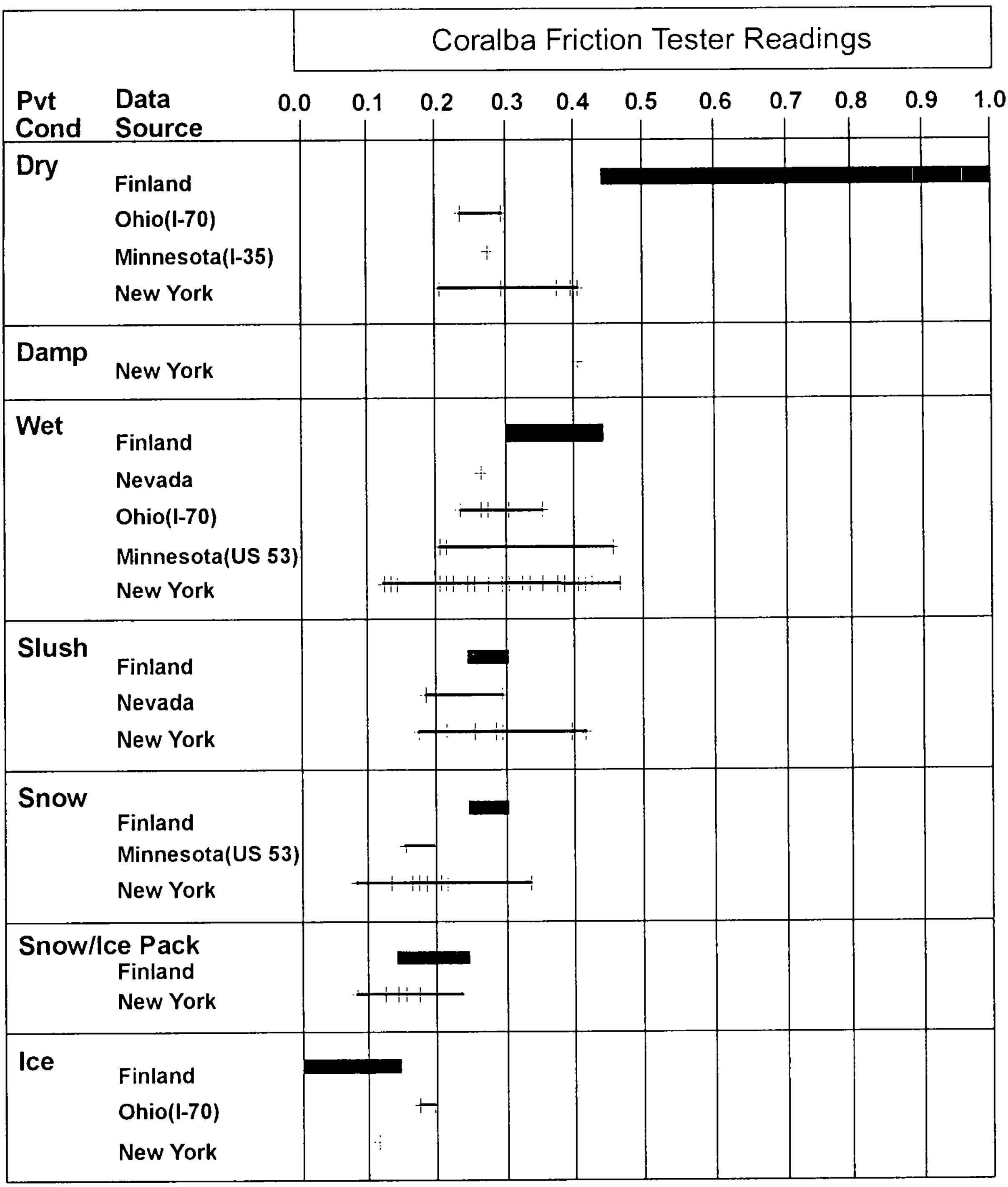


Figure 23. Comparison of Coralba friction measurements for the test sections on dense-graded asphalt made during 1991-92 winter with Finnish results.

No official analysis was made of the success and failure rates of forecasting services. However, Minnesota maintenance personnel thought the NWS forecasts were just as reliable, if not better, than the private service forecasts.

Winter 1992-93 Results

The first anti-icing experiment during the 1992-93 winter was conducted in Minnesota at the beginning of November 1992. Data collection ended at the end of March 1993. At that time, 110 storm events were recorded by the nine participating states. Approximately 66% of the events were recorded by MNDOT, NDOT, and NYDOT maintenance personnel. Events were recorded at all 14 test sites in the nine states.

Of the 110 storm events recorded, 102 (93% of the total) could be analyzed. This percentage is much higher than for the first winter's testing (74%). The number of storm events analyzed for each state is given in table 35. The major reasons the other eight storm events could not be analyzed are the same as were noted for the 1991-92 winter.

Table 35. Number of storm events recorded and analyzed for 1992-93 winter.

Geographic area	State	No. of storm events recorded	No. of events analyzed	No. of events with reduced material application[a]
Mountain state	California	3	0	0
	Maryland	4	4	0
High plains state	Colorado	7	6	3
	Nevada	14	14	11
Plains state	Missouri	11	10	8
	Ohio	10	10	4
Lake effect state	Minnesota	23	20	6
	New York	36	36	30
Maritime state	Washington	2	2	2
Totals	9	110	102	64

[a] These events are defined as ones where smaller amounts of material are used on the test section than on the control section.

Table 36. Summary of maintenance activities on test and control sections and savings achieved on test section in Maryland during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chem-ical	Abrasive	Total material	Total No. passes	Chem-ical	Abrasive	Total material	Total No. passes	Chem-ical	Abrasive	Total material	Number of passes saved on test section
1	1/8-11/93	40,884	40,884	81,769	19	12,191	12,191	24,381	19	-238.6	-238.6	-238.6	0
2	1/24-25/93	15,725	15,725	31,450	8	2,979	3,926	6,905	6	-432.9	-304.4	-359.8	-2
3	1/29/93	15,949	15,949	31,899	7	711	1,658	2,369	2	-2164.7	-871.2	-1259.5	-5
4	2/01/93	9,884	9,884	19,768	4	569	1,327	1,895	2	-1653.8	-652.0	-953.2	-2
Total		82,442	82,442	164,886	38	16,450	19,102	35,550	29	-406.0	-335.7	-368.3	-9

Table 37. Summary of maintenance activities on test and control sections and savings achieved on test section in Colorado during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chem- ical	Abrasive	Total materia l	Total No. passes	Chem- ical	Abrasive	Total materia l	Total No. passes	Chem- ical	Abrasive	Total materia l	Number of passes saved on test section
	CO I-25												
1	11/20-21/92	1,722	16,261	17,983	7	808	9,292	10,100	4	-113.1	-75.0	-78.0	-3
3	11/23/92	492	4,646	5,138	2	202	2,323	2,525	1	-143.6	-100.0	-103.5	-1
4	12/3-5/92	711	6,969	7,680	3	808	9,292	10,100	4	12.0	25.0	24.0	1
5[a]	12/12-13/92	0	0	0	0	0	0	0	0	b	b	b	0
6	2/03/93	0	0	0	0	1,010	11,615	12,625	5	100.0	100.0	100.0	5
7	2/10/93	984	9,292	10,276	4	1,212	13,938	15,150	6	18.8	33.3	32.2	2
	C-470												
2	11/21/92-12/04/92	12,575	52,234	64,809	14	1,796	7,462	9,258	2	-600.2	-600.0	-600.0	-12
Total		16,484	89,402	105,886	30	5,836	53,922	59,758	22	-182.5	-65.8	-77.2	-8

[a] Maintenance activity on Storm #5 was spot sanding only for both test and control sections.
[b] Percent savings is not calculated because no material was applied to either section.

Table 38. Summary of maintenance activities on test and control sections and savings achieved on test section in Nevada during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chem-ical	Abrasive	Total materia l	Total No. passes	Chem-ical	Abrasive	Total materia l	Total No. passes	Chem-ical	Abrasive	Total materia l	Number of passes saved on test section
1	11/19/92	0	0	0	0	1,488	7,265	8,753	1	100.0	100.0	100.0	1
2	12/6-7/92	8,571	0	8,571	11	3,205	15,649	18,854	2	-167.4	100.0	54.5	-9
3	12/11/92	3,117	0	3,117	4	2,802	13,358	16,160	3	-11.2	100.0	80.7	-1
4	12/16-18/92	15,219	29,607	44,826	14	8,454	41,275	49,729	8	-80.0	28.3	9.9	-6
5	12/28-30/92	7,553	0	7,553	6	0	0	0	0	NA[a]	b	NA[a]	-6
6	1/1/93	779	0	779	1	0	0	0	0	NA[a]	b	NA[a]	-1
7	1/5-9/93	21,434	28,566	50,000	26	9,691	47,316	57,007	10	-121.2	39.6	12.3	-16
8	1/9-10/93	4,675	0	4,675	6	11,742	57,328	69,070	10	60.2	100.0	93.2	4
9	1/12-14/93	9,350	0	9,350	12	16,295	79,560	95,855	13	42.6	100.0	90.2	1
10	1/15-18/93	15,542	37,374	52,916	17	17,906	87,425	105,331	25	13.2	57.3	49.8	8
11	1/26-27/93	4,398	0	4,398	10	5,771	28,178	33,949	7	23.8	100.0	87.0	-3
12	2/11/93	3,117	0	3,117	4	0	0	0	0	NA[a]	b	NA[a]	-4
13	2/15-20/93	27,038	40,984	68,022	29	20,641	100,776	121,417	19	-31.0	59.3	44.0	-10
14	2/22-27/93	24,028	0	24,028	23	7,785	38,010	45,795	7	-208.6	100.0	47.5	-16
Total		144,821	136,531	281,352	163	105,780	516,140	621,920	105	-36.9	73.5	54.8	-58

[a] NA denotes percent savings not calculated because material was used only on the test section.
[b] Percent savings is not calculated because no material was applied to either section.

Table 39. Summary of maintenance activities on test and control sections and savings achieved on test section in Missouri during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chem-ical	Abrasive	Total materia l	Total No. passes	Chem-ical	Abrasive	Total materia l	Total No. passes	Chem-ical	Abrasive	Total materia l	Number of passes saved on test section
	I-29												
1	11/6-7/92	280	0	280	1	2,240	0	2,240	2	87.5	a	87.5	1
3	11/25/92	1,120	0	1,120	1	1,120	0	1,120	1	0	a	0	0
4	12/5-6/92	1,126	0	1,126	4	4,502	0	4,502	1	75.0	a	75.0	-3
5	12/30/92	283	0	283	1	1,120	0	1,120	1	74.7	a	74.7	0
	US-71												
2	11/22/92	1,009	1,260	2,269	2	1,853	2,349	4,202	2	45.5	46.4	46.0	0
4	12/5-6/92	3,530	4,410	7,941	7	5,560	7,047	12,607	6	36.5	37.4	37.0	-1
7	1/7-8/93	1,009	1,260	2,269	2	1,853	2,349	4,202	2	45.5	46.4	46.0	0
8	1/18/93	1,513	1,890	3,403	3	2,780	3,524	6,304	3	45.6	46.4	46.0	0
9	1/20/93	2,020	2,518	4,538	6	4,633	5,873	10,506	5	56.4	57.1	56.8	-1
10	2/15/93	1,853	2,349	4,202	2	1,853	2,349	4,202	2	0	0	0	0
Total		13,74 3	13,687	27,431	29	27,51 4	23,491	51,005	25	50.1	41.7	46.2	-4

[a] Percent savings is not calculated because no material was applied to either section.

Table 40. Summary of maintenance activities on test and control sections and savings achieved on test section in Ohio during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chemical	Abrasive	Total material	Total No. passes	Chemical	Abrasive	Total material	Total No. passes	Chemical	Abrasive	Total material	Number of passes saved on test section
	I-70												
1	11/28/92	2,421	0	2,421	2	3,000	0	3,000	2	19.3	a	19.3	0
2	12/02/92	1,210	0	1,210	1	1,200	0	1,200	1	-0.8	a	-0.8	0
3	12/10/92	4,842	0	4,842	4	7,200	0	7,200	4	32.8	a	32.8	0
4	1/08/93	2,442	0	2,442	2	2,400	0	2,400	2	-1.8	a	-1.8	0
5	1/10/93	7,325	0	7,325	6	10,800	0	10,800	5	32.2	a	32.2	-1
8	2/21/93	6,104	0	6,104	5	9,000	0	9,000	5	32.2	a	32.2	0
	I-71												
6	2/13-14/93	4,278	4,134	8,412	6	4,134	4,134	8,268	6	-3.5	0	-1.7	0
7	2/16/93	4,278	4,134	8,412	6	4,134	4,134	8,268	6	-3.5	0	-1.7	0
9	2/21/93	9,360	0	9,360	6	9,360	0	9,360	6	0	a	0	0
10	2/25-26/93	10,272	9,926	20,198	12	9,926	9,926	19,852	12	-3.5	0	-1.7	0
Total		52,532	18,194	70,726	50	61,154	18,194	79,348	49	14.1	0	10.9	-1

[a] Percent savings is not calculated because no material was applied to either section.

Table 41. Summary of maintenance activities on test and control sections and savings achieved on test section in Minnesota during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chem-ical	Abrasive	Total material	Total No. passes	Chem-ical	Abrasive	Total material	Total No. passes	Chem-ical	Abrasive	Total material	Number of passes saved on test section
	I-35												
2	11/8-9/93	10,552	0	10,552	3	1,983	0	1,983	1	-416.4	a	-416.4	-2
3	11/15-17/93	18,838	0	18,838	4	4,360	0	4,360	3	-319.3	a	-319.3	-1
4	11/19-20/93	2,122	0	2,122	1	2,964	0	2,964	1	30.5	a	30.5	0
5	12/1-2/93	2,920	0	2,920	1	8,707	0	8,707	3	67.5	a	67.5	2
6	12/03/93	2,920	0	2,920	1	1,983	0	1,983	1	-42.9	a	-42.9	0
10	12/22/93	0	0	0	0	2,082	0	2,082	1	100.0	a	100.0	1
11	12/25/93	8,971	0	8,971	2	0	0	0	0	NA[b]	a	NA[b]	-2
13	1/2-3/93	8,699	0	8,699	3	6,385	0	6,385	2	-32.2	a	-32.2	-1
14	1/12-15/93	44,274	0	44,274	9	43,077	0	43,077	6	0.3	a	0.3	-3
15	1/20-23/93	16,807	0	16,807	5	32,470	0	32,470	7	49.8	a	49.8	2
16	1/26/93	10,416	0	10,416	3	2,902	0	2,902	1	-248.3	a	-248.3	-2
	US-53												
1	11/2-4/93	29,764	0	29,764	7	29,599	0	29,599	7	-0.6	a	-0.6	0
2	11/8-9/93	6,456	0	6,456	1	6,456	0	6,456	2	0	a	0	1
3	11/16-17/93	45,852	0	45,852	7	37,122	0	37,122	6	-23.5	a	-23.5	-1
4	11/19-20/93	13,532	0	13,532	3	9,684	0	9,684	2	-39.7	a	-39.7	-1
5	12/01/93	4,842	0	4,842	1	4,842	0	4,842	1	0	a	0	0
8	12/13/93	7,323	0	7,323	2	9,684	0	9,684	2	24.4	a	24.4	0
14	1/12/93	24,752	0	24,752	3	24,210	24,210	48,420	3	-2.2	100.0	48.9	0
15	1/23/93	12,880	0	12,880	1	12,105	0	12,105	1	-6.4	a	-6.4	0
16	12/26/93	8,246	0	8,246	1	8,070	0	8,070	1	-2.2	a	-2.2	0
Total		280,166	0	280,166	58	248,685	24,210	272,895	51	-12.7	100.0	-2.7	-7

[a] Percent savings is not calculated because no material was applied to either section.
[b] NA denotes percent savings not calculated because material was used only on the test section.

Table 42. Summary of maintenance activities on test and control sections and savings achieved on test section in New York during 1992-93 winter.

Storm No.	Storm date	Test section: Material used (lb): Chemical	Test section: Material used (lb): Abrasive	Test section: Material used (lb): Total material	Test section: Total No. passes	Control section: Material used (lb): Chemical	Control section: Material used (lb): Abrasive	Control section: Material used (lb): Total material	Control section: Total No. passes	Percent material saved on test section: Chemical	Percent material saved on test section: Abrasive	Percent material saved on test section: Total material	Number of passes saved on test section
1	12/02/92	3,461	0	3,461	1	3,461	0	3,461	1	0	a	0	0
2	12/4-5/92	10,485	0	10,485	7	24,012	0	24,012	7	56.3	a	56.3	0
3	12/7-9/92	26,523	0	26,523	16	33,689	0	33,689	12	21.3	a	21.3	-4
4	12/10-12/92	52,710	0	52,710	25	68,464	0	68,464	25	23.0	a	23.0	0
5	12/23-24/92	9,883	0	9,883	8	24,196	0	24,196	9	59.2	a	59.2	1
6	12/25/92	1,320	0	1,320	1	0	0	0	0	NA[b]	a	NA[b]	-1
7	12/26-27/92	14,836	0	14,836	8	33,449	0	33,449	11	55.6	a	55.6	3
8	1/1-2/93	27,581	0	27,581	9	23,213	0	23,213	7	-18.8	a	-18.8	-2
9	1/03/93	6,994	0	6,994	2	8,743	0	8,743	3	20.0	a	20.0	1
10	1/08/93	10,023	0	10,023	4	16,842	0	16,842	5	40.5	a	40.5	1
11	1/10-11/93	43,654	0	43,654	14	51,740	0	51,740	14	15.6	a	15.6	0
12	1/12-14/93	30,412	0	30,412	14	70,452	0	70,452	22	56.8	a	56.8	8
13	1/15/93	831	0	831	1	3,368	0	3,368	1	75.3	a	75.3	0
14	1/17-18/93	14,750	0	14,750	9	25,846	0	25,846	10	42.9	a	42.9	1
15	1/19/93	5,122	0	5,122	5	13,859	0	13,859	5	63.0	a	63.0	0
16[c]	1/22-23/93	0	0	0	2	0	0	0	2	a	a	a	0
17	1/24-26/93	22,747	0	22,747	13	37,499	0	37,499	13	39.3	a	39.3	0
18	1/27-31/93	45,768	0	45,768	32	66,630	0	66,630	31	31.3	a	31.3	-1
19	2/1-2/93	40,966	0	40,966	19	64,566	0	64,566	23	36.6	a	36.6	4
20	2/04/93	5,109	0	5,109	2	3,542	0	3,542	1	-44.2	a	-44.2	-1
21	2/5-6/93	38,233	0	38,233	22	77,735	0	77,735	20	50.8	a	50.8	-2

Table 42 (Continued)

Storm No.	Storm date	Test section: Material used (lb): Chemical	Abrasive	Total material	Total No. passes	Control section: Material used (lb): Chemical	Abrasive	Total material	Total No. passes	Percent material saved on test section: Chemical	Abrasive	Total material	Number of passes saved on test section
23	2/10/93	1,554	0	1,554	1	0	0	0	0	NA[b]	a	NA[b]	-1
24	2/11-14/93	75,483	0	75,483	36	134,546	0	134,546	38	43.9	a	43.9	2
25	2/16-18/93	38,853	0	38,853	25	82,832	0	82,832	24	53.1	a	53.1	-1
26	2/19-20/93	3,125	0	3,125	2	4,162	0	4,162	1	24.9	a	24.9	-1
27	2/21-24/93	77,805	0	77,805	35	139,596	0	139,596	40	44.3	a	44.3	5
28	3/03/93	3,143	0	3,143	2	6,737	0	6,737	2	53.3	a	53.3	0
29	3/4-6/93	33,937	0	33,937	17	68,622	0	68,622	19	50.5	a	50.5	2
30	3/08/93	1,554	0	1,554	1	3,542	0	3,542	1	56.1	a	56.1	0
31	3/10-11/93	29,275	0	29,275	15	53,575	0	53,575	17	45.4	a	45.4	2
32	3/13-15/93	15,379	0	15,379	6	15,708	0	15,708	5	2.1	a	2.1	-1
33	3/17-18/93	4,679	0	4,679	3	17,536	0	17,536	5	73.3	a	73.3	2
34	3/20/93	3,107	0	3,107	2	7,084	0	7,084	2	56.1	a	56.1	0
35	3/21-22/93	3,125	0	3,125	2	7,704	0	7,704	2	59.4	a	59.4	0
36	3/26/93	1,571	0	1,571	1	3,368	0	3,368	1	53.4	a	53.4	0
Total		707,105	0	707,105	364	1,203,402	0	1,203,402	381	41.2	a	41.2	17

[a] Percent savings is not calculated because no material was applied to either section.
[b] NA denotes percent savings not calculated because material was used only on the test section.
[c] Maintenance activity on Storm #16 was spot salting only for both test and control sections.

Table 43. Summary of maintenance activities on test and control sections and savings achieved on test section in Washington during 1992-93 winter.

		Test section				Control section				Percent material saved on test section			
		Material used (lb)				Material used (lb)							
Storm No.	Storm date	Chemical	Abrasive	Total material	Total No. passes	Chemical	Abrasive	Total material	Total No. passes	Chemical	Abrasive	Total material	Number of passes saved on test section
1	12/10/92	3,319	0	3,319	2	3,000	27,000	30,000	4	-10.6	100.0	88.9	2
2	12/17/93	4,700	0	4,700	3	2,663	23,965	26,628	7	-76.5	100.0	82.3	4
Total		8,019	0	8,019	5	5,663	50,965	56,628	11	-41.6	100.0	85.8	6

A summary is given in Appendix G of the material applied to the test and control sections in all nine states during the second winter testing. Summaries of the maintenance activities on the test and control sections and the reductions in material use and number of passes in the nine states are in tables 36 through 43. When computing the percent of material saved, the material amounts applied to the test and control sections in Maryland and Minnesota (I-35) were normalized with respect to section lengths.

During 64 of 102 (63%) storm events, less chemical and abrasive material was used on the test sections than on the control sections. During another nine events, about the same amount of material was supplied to both the test and control sections. Thus, during 73 out of 102 (72%) storm events, less or equal amounts of material were used on the test sections as on the control sections.

The percent of chemical reductions achieved on the test sections during the 1992-93 winter were 50% in Missouri (table 39), 14% in Ohio (table 40), and about 41% in New York (table 42). The other states reported increased chemical usage. Table 44 is a comparison of the chemical reductions during the two winters in each state.

Table 44. Percent chemical saved on the test sections during the 1991-92 and 1992-93 winters.

Geographic area	State	1991-92 winter	1992-93 winter
Mountain states	California	–	–
	Maryland	−212.6	−406.0
High plains states	Colorado	−4.1	−182.5
	Nevada	49.3	−36.9
Plains states	Missouri	−102.1	50.1
	Ohio	29.8	14.1
Lake effect states	Minnesota	−248.5	−12.7
	New York	23.2	41.2
Maritime state	Washington	–	−41.6

The 50% reduction in chemical usage recorded by Missouri during the second winter contrasts the increase (102%) recorded during the first winter. A possible explanation for this radical reversal is that more events were recorded in Missouri during the second winter (11) than were recorded during the first winter (3). This increased number of events provided maintenance personnel with the opportunity to experiment with the testing procedures.

Reduction of chemical use in Ohio during the second winter (14%) was about half that achieved during the first winter (30%). No clear explanation could be found for this increased use.

The 41% reduction in chemical usage recorded by New York during the second winter was almost double that during the first winter (23%). This significant reduction was due, in large part, to the increased awareness on the part of the maintenance personnel of the operating conditions of the test section before and during the 36 storm events recorded.

The increased chemical usage recorded by Nevada during the second winter (37%) was considerably different from the 49% reduction achieved during the first winter. This was principally the result of four storm events (storms 2, 4, 7, and 14) during which much greater amounts of chemical were used on the test section than on the control section. During three of these storms, snow/ice pack and icing conditions developed on the test pavement as a result of relatively low pavement temperatures of -4.4°C (24°F) and below. The other storm (storm 2) involved freezing rain and sleet along with snow showers. The pavement temperature during storm 2 was around -1.7° to -1.1°C (28.9° to 30.0°F). These four storm events suggest that the liquid chemical used was not adequate for the low pavement temperature -4.4°C (24.1°F) and for freezing rain conditions. The same temperature limitation for liquid chemicals has also been recognized by the Finnish Road National Administration.

In none of the four storm events recorded in Maryland and in only three of six events analyzed for Colorado was less chemical used on the test section than on the control sections. In fact, chemical use increased in both states during the 1992-93 winter compared to the first winter. The reason for the Maryland results was the continued use of a truck on the test section that had difficulty in reducing the application rate to the prescribed level. On the other hand, the application rates used on the control section in Maryland were much lower than used for conventional deicing. The negative results experienced in Colorado were mainly due to maintenance activities during three storms. During two of these, about twice as much chemical was applied to the test section as was applied to the control section. During the third storm, seven times as much chemical was applied to the test section as to the control section.

Minnesota experienced increased chemical usage during both winters. The results for the second winter show a dramatic improvement over the first winter (−12.7% for the 1992-93 winter versus −248.5% for the 1991-92 winter).

Washington did not reduce chemical usage during the second winter. These results are not unexpected because only two events were available for analysis. No data were available from Washington for the first winter.

Table 45 presents a comparison of the abrasive saved during the two winters in each state. Reduction in abrasives used during the second winter was about 74% in Nevada (table 38), about 42% in Missouri (table 39), 100% in Minnesota (table 41), and 100% in Washington (table 43). Maryland and Colorado reported increased abrasive usage. No abrasives were used on either the test or control sections in New York. The 100% reduction in abrasives used in Minnesota occurred during only one storm. The 100% reduction in abrasives used in Washington occurred because abrasives were used on the control section, but not on the test section.

Table 45. Percent abrasive saved on the test sections during the 1991-92 and 1992-93 winters.

Geographic area	State	1991-92 winter	1992-93 winter
Mountain states	California	–[a]	–[a]
	Maryland	−88.1	−335.7
High plains states	Colorado	−1.2	−65.8
	Nevada	73.6	−73.5
Plains states	Missouri	–[b]	41.7
	Ohio	–[b]	0.0
Lake effect states	Minnesota	–[b]	100.0
	New York	−95.1	–[b]
Maritime state	Washington	–[c]	100.0

[a] Not analyzed.
[b] Abrasives not used during the experiments.
[c] No data.

The maintenance operations during the first treatment application on the test and control sections were classified for each storm. These operations were classified as either anti-icing or deicing, according to the criteria in table 15. Results are given in tables 46 through 53. The classification again showed that the test plan was not generally followed. Almost all possible combinations of maintenance operations on the test and control sections occurred. There were numerous instances of anti-icing operations on both the test and control sections. However, there was only one storm where anti-icing operations occurred on the control section and deicing operations took place on the test section.

Combinations of anti-icing operations on the test section and deicing operations on the control section took place during 13 of the 102 storm events analyzed. Table 54 presents the savings achieved during these 13 events. Less chemical was used on the test section than on the control section during 8 (62%) of the 13 events. Abrasives were used during 8 of these 13 storm events. Smaller amounts of abrasives were used on the test section than on the corresponding control section during seven of the eight events. The second winter shows an improvement over the first. One maintenance pass was saved through anti-icing operations during these 13 storm events (table 54).

During 64 (63%) out of 102 storm events analyzed for the second winter, less chemical and abrasive material was used on the test sections than on the control sections. Various combinations of anti-icing and deicing operations were used during these 64 storm events. The success achieved can be attributed to better timing of the treatment applications, more sensible deicing operations, and a better awareness on the part of maintenance personnel of the pavement conditions before and during the storms.

Coralba Friction Measurements

Six states made Coralba friction measurements during 62 of the 102 storm events analyzed for the 1992-93 winter: Maryland (3 storm events), Nevada (10 events), Missouri (3 events), Ohio (7 events), Minnesota (12 events), and New York (27 events).

Summaries of the Coralba friction measurements made by the six states are given in tables 55 and 56 for the test and control sections, respectively. Much like the 1991-92 winter, some of the six states made friction measurements before the first maintenance (anti-icing or deicing) treatment, but most measurements were made after the first or subsequent treatment. Some of the states made selective friction measurements at times preceding deicing applications. It is not known if these selective measurements were made to help decide the need for additional deicing treatments, or if they were made simply to satisfy the need to collect data during the storm. On numerous occasions, multiple friction measurements were made in succession and no treatment was made, even when the friction values were low. This latter finding again suggests that a majority of the friction measurements were made as part of the storm documentation and not as part of a decision-making process concerning the reapplication of deicing or abrasive materials.

Table 46. Classification of maintenance operations during the first treatment application on test and control sections in Maryland during 1992-93 winter.

		Maintenance operations	
Storm No.	Storm date	Test section	Control section
	MD 495		
1	1/8-11/93	Anti-icing	Anti-icing
2	1/24-25/93	Deicing	Deicing
3	1/29/93	De-icing	Deicing
4	2/01/93	Anti-icing	Deicing

Maryland and Ohio (I-70 site) experienced limited success in using the Coralba in conjunction with treatment application. In Maryland, the first Coralba measurements were taken as precipitation began to fall. The subsequent readings were all made in conjunction with applications (within 1 hr). For two storms in Ohio (I-70 site), most measurements were made 1/2 hr before a treatment, indicating that maintenance personnel were using the Coralba to assess pavement conditions.

Table 47. Classification of maintenance operations during the first treatment application on test and control sections in Colorado during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-25		
1	11/20-21/92	Anti-icing	Anti-icing
3	11/23/92	Deicing	Deicing
4	12/3-5/92	Deicing	Deicing
5	12/12-13/92	Spot sanding	Spot sanding
6	2/03/93	Spot sanding	Deicing
7	2/9-10/93	Anti-icing	Deicing
	CO 470		
2	11/21/92-12/04/92	Deicing	Deicing

Table 48. Classification of maintenance operations during the first treatment application on test and control sections in Nevada during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	US-395		
1	11/19/92	No treatment	Anti-icing
2	12/6-7/92	Deicing	Deicing
3	12/11/92	Deicing	Deicing
4	12/16-18/92	Anti-icing	Deicing
5	12/28-30/92	Anti-icing	No treatment
6	1/01/93	Deicing	No treatment
7	1/5-9/93	Deicing	Deicing
8	1/9-10/93	Anti-icing	Anti-icing
9	1/12-14/93	Anti-icing	Deicing
10	1/15-18/93	Anti-icing	Deicing
11	1/26-27/93	Deicing	Deicing
12	2/11/93	Anti-icing	No treatment
13	2/15-20/93	Anti-icing	Anti-icing
14	2/22-27/93	Anti-icing	Deicing

Table 49. Classification of maintenance operations during the first treatment application on test and control sections in Missouri during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test Section	Control Section
	I-29		
1	11/6-7/92	Anti-icing	Anti-icing
3	11/25/92	Anti-icing	Deicing
4	12/5-6/92	Deicing	Deicing
5	12/30/92	Anti-icing	Anti-icing
	US-71		
2	11/22/92	Anti-icing	Anti-icing
4	12/5-6/92	Anti-icing	Deicing
6	1/1-2/93	Anti-icing	Anti-icing
7	1/7-8/92	Deicing	Deicing
8	1/18/93	Deicing	Deicing
9	1/20/93	Anti-icing	Anti-icing
10	1/15-16/93	Anti-icing	Anti-icing

Table 50. Classification of maintenance operations during the first treatment application on test and control sections in Ohio during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-70		
1	11/28/92	Anti-icing	Anti-icing
2	12/1-2/92	Anti-icing	Anti-icing
3	12/10/92	Deicing	Deicing
4	1/08/93	Anti-icing	Anti-icing
5	1/9-10/93	Anti-icing	Deicing
8	2/21/93	Deicing	Deicing
	I-71		
6	2/13-14/93	Anti-icing	Anti-icing
7	2/16/93	Deicing	Deicing
9	2/21/93	Deicing	Deicing
10	2/25-26/93	Anti-icing	Anti-icing

Table 51. Classification of maintenance operations during the first treatment application on test and control sections in Minnesota during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	I-35		
2	11/8-9/92	Deicing	Deicing
3	11/15-16/92	Deicing	Deicing
4	11/19-20/92	Deicing	Deicing
5	12/1-2/92	Anti-icing	Anti-icing
6	12/03/92	Deicing	Deicing
10	12/22/92	No treatment	Deicing
11	12/25/92	Deicing	No treatment
13	1/2-3/93	Anti-icing	Anti-icing
14	1/12-15/93	Deicing	Deicing
15	1/20-23/93	Anti-icing	Anti-icing
16	1/26/93	Anti-icing	Anti-icing
	US-53		
1	11/2-4/92	Deicing	Deicing
2	11/8-9/92	Deicing	Deicing
3	11/16-17/92	Deicing	Deicing
4	11/19-20/92	Deicing	Deicing
5	12/01/92	Deicing	Deicing
8	12/13/92	Deicing	Anti-icing
14	1/12/93	Deicing	Deicing
15	1/23/93	Deicing	Deicing
16	1/26/93	Deicing	Deicing

Table 52. Classification of maintenance operations during the first treatment application on test and control sections in New York during 1992-93 winter.

Storm No.	Storm date	Maintenance operations	
		Test section	Control section
	SH 104		
1	12/2-3/92	Anti-icing	Anti-icing
2	12/4-5/92	Anti-icing	Anti-icing
3	12/7-9/92	Anti-icing	Anti-icing
4	12/10-12/92	Deicing	Deicing
5	12/23-24/92	Anti-icing	Anti-icing
6	12/25/92	Anti-icing	No treatment
7	12/26-27/92	Deicing	Deicing
8	1/1-2/93	Anti-icing	Anti-icing
9	1/03/93	Deicing	Deicing
10	1/08/93	Anti-icing	Anti-icing
11	1/10-11/93	Anti-icing	Anti-icing
12	1/12-14/93	Anti-icing	Deicing
13	1/15/93	Anti-icing	Anti-icing
14	1/17-18/93	Anti-icing	Anti-icing
15	1/19/93	Deicing	Deicing
16	1/22-23/93	Anti-icing	Deicing
17	1/24-26/93	Anti-icing	Anti-icing
18	1/27-31/93	Anti-icing	Anti-icing
19	2/1-2/93	Anti-icing	Deicing
20	2/04/93	Anti-icing	Anti-icing
21	2/5-6/93	Deicing	Deicing
22	2/08/93	Anti-icing	Anti-icing
23	2/10/93	Anti-icing	No treatment
24	2/11-14/93	Anti-icing	Deicing
25	2/16/93	Anti-icing	Anti-icing
26	2/19-20/93	Anti-icing	Anti-icing
27	2/21-23/93	Anti-icing	Anti-icing

Table 52 (Continued)

Storm No.	Storm date	Maintenance operations: Test section	Maintenance operations: Control section
	SH 104		
28	3/03/93	Anti-icing	Anti-icing
29	3/4-6/93	Anti-icing	Anti-icing
30	3/08/93	Anti-icing	Anti-icing
31	3/10-11/93	Anti-icing	Anti-icing
32	3/13-15/93	Anti-icing	Anti-icing
33	3/17-18/93	Anti-icing	Anti-icing
34	3/20/93	Anti-icing	Anti-icing
35	3/21-22/93	Anti-icing	Anti-icing
36	3/26/93	Anti-icing	Anti-icing

Table 53 Classification of maintenance operations during the first treatment application on test and control sections in Washington during 1992-93 winter.

Storm No.	Storm date	Maintenance operations: Test section	Maintenance operations: Control section
	I-90		
1	12/10/92	Anti-icing	Deicing
2	12/17/92	Deicing	Deicing

Table 54. Summary of savings achieved on test sections during anti-icing operations in the 1992-93 winter.

State	Storm No.	Percent material saved on test section: Chemical	Abrasive	Total material	Passes saved on test section
MD	4	−1,653.8	−652.0	−953.2	-2
CO I-25	7	18.8	33.3	32.2	2
NV	4	−80.0	28.3	9.9	−6
NV	9	42.6	100.0	90.2	1
NV	10	13.2	57.3	49.8	8
NV	14	−208.6	100.0	47.5	−16
MO I-29	3	0.0	—[a]	0.0	0
MO US-71	4	36.5	37.4	37.0	−1
OH I-70	5	32.2	—[a]	32.2	−1
NY	12	56.8	—[a]	56.8	8
NY	19	36.6	—[a]	36.6	4
NY	24	43.9	—[a]	43.9	2
WA	1	-10.6	100.0	88.9	2

[a] Percent savings is not calculated since no material was applied to either section.

Table 55. Summary statistics for Coralba friction measurements (1992-93 test section).

State	Route	Pavement condition	Open-graded asphalt					Dense-graded asphalt					Portland cement concrete				
			N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std
MD	495	Dry															
		Wet	8	0.27	0.50	0.41	0.09										
		Damp															
		Slush	2	0.30	0.39	0.35	0.06										
		Snow															
		Snow/Ice Pack	1	0.21	0.21	0.21											
		Ice															
NV	395	Dry						6	0.36	0.42	0.39	0.02					
		Wet						63	0.23	0.48	0.36	0.05					
		Damp															
		Slush						6	0.25	0.38	0.32	0.05					
		Snow						118	0.16	0.43	0.27	0.05					
		Snow/ice Pack						10	0.22	0.40	0.32	0.05					
		Ice															
MO	US 71	Dry						1	0.38	0.38	0.38						
		Wet						2	0.35	0.38	0.37	0.02					
		Damp															
		Slush						1	0.45	0.45	0.45						
		Snow						3	0.15	0.24	0.21	0.05					
		Snow/Ice Pack															
		Ice															
OH	I-71	Dry															
		Wet						4	0.56	0.96	0.81	0.17					
		Damp															
		Slush						6	0.31	0.96	0.58	0.23					
		Snow						24	0.29	0.58	0.41	0.09					
		Snow/Ice Pack						19	0.10	0.54	0.45	0.09					
		Ice						6	0.28	0.60	0.40	0.12					
	I-70	Dry															
		Wet						5	0.31	0.44	0.39	0.05					
		Damp															
		Slush						3	0.21	0.41	0.29	0.11					
		Snow															
		Snow/Ice Pack						2	0.21	0.23	0.22	0.01					
		Ice															

Table 55 (Continued)

State	Route	Pavement condition	Open-graded asphalt N	Min.	Max.	Mean	Std	Dense-graded asphalt N	Min.	Max.	Mean	Std	Portland cement concrete N	Min.	Max.	Mean	Std
MN	US 53	Dry															
		Wet						8	0.22	0.43	0.29	0.07	17	0.20	0.38	0.26	0.05
		Damp															
		Slush						14	0.11	0.25	0.18	0.04	24	0.05	0.29	0.16	0.05
		Snow						25	0.09	0.21	0.15	0.03	45	0.08	0.23	0.16	0.04
		Snow/Ice Pack						1	0.17	0.17	0.17		4	0.12	0.20	0.15	0.04
		Ice											1	0.12	0.12	0.12	
	I-35	Dry						1	0.25	0.25	0.25		1	0.27	0.27	0.27	
		Wet						15	0.28	0.53	0.39	0.09	10	0.32	0.50	0.39	0.07
		Damp															
		Slush						10	0.17	0.38	0.26	0.07	13	0.23	0.50	0.32	0.07
		Snow						1	0.21	0.21	0.21						
		Snow/ice Pack															
		Ice															
NY	SR 104	Dry						58	0.25	0.84	0.41	0.08	41	0.02	0.52	0.41	0.09
		Damp						10	0.39	0.47	0.42	0.03	4	0.32	0.48	0.39	0.07
		Wet						221	0.02	0.59	0.32	0.09	118	0.08	0.47	0.32	0.07
		Slush						81	0.10	0.48	0.23	0.07	53	0.05	0.38	0.22	0.07
		Snow						69	0.02	0.35	0.21	0.07	35	0.01	0.32	0.19	0.06
		Snow/Ice Pack						19	0.08	0.30	0.18	0.05	8	0.11	0.22	0.17	0.04
		Ice						9	0.06	0.35	0.19	0.10	8	0.02	0.36	0.18	0.13
Total No. Meas.		1,214	11	No. of Measurements				821	No. of Measurements				382	No. of Measurements			

Table 56 Summary statistics for Coralba friction measurements (1992-93 control section).

State	Route	Pavement condition	Open 1-1 graded asphalt					Dense-graded asphalt					Portland cement concrete				
			N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std
MD	495	Dry															
		Wet	7	0.39	0.60	0.47	0.08										
		Damp															
		Slush	3	0.34	0.44	0.39	0.05										
		Snow	1	0.27	0.27	0.27											
		Snow/Ice Pack															
		Ice															
NV	395	Dry						2	0.23	0.41	0.32	0.13					
		Wet						56	0.19	0.43	0.33	0.06					
		Damp															
		Slush						15	0.18	0.37	0.26	0.07					
		Snow						116	0.12	0.37	0.21	0.04					
		Snow/ice Pack						7	0.15	0.24	0.18	0.03					
		Ice															
MO	US 71	Dry															
		Wet															
		Damp															
		Slush						2	0.22	0.25	0.24	0.02					
		Snow						3	0.18	0.27	0.22	0.05					
		Snow/Ice Pack						2	0.14	0.20	0.17	0.04					
		Ice															
OH	I-71	Dry															
		Wet						4	0.77	0.87	0.84	0.05					
		Damp															
		Slush						2	0.10	0.77	0.44	0.47					
		Snow						31	0.00	0.54	0.39	0.11					
		Snow/Ice Pack						8	0.44	0.52	0.47	0.04					
		Ice						5	0.26	0.55	0.39	0.14					
	I-70	Dry															
		Wet						9	0.33	0.46	0.40	0.04					
		Damp															
		Slush						2	0.26	0.44	0.35	0.13					
		Snow						2	0.28	0.30	0.29	0.01					
		Snow/Ice Pack															
		Ice															

Table 56 (Continued)

State	Route	Pavement condition	Open 1-1 graded asphalt					Dense-graded asphalt					Portland cement concrete				
			N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std	N	Min.	Max.	Mean	Std
MN	US 53	Dry															
		Wet						8	0.21	0.32	0.28	0.04	17	0.15	0.43	0.27	0.07
		Damp															
		Slush						14	0.14	0.30	0.19	0.05	20	0.04	0.22	0.15	0.04
		Snow						25	0.11	0.36	0.17	0.05	48	0.06	0.22	0.14	0.04
		Snow/Ice Pack						1	0.19	0.19	0.19		2	0.18	0.18	0.18	0.00
		Ice						1	0.14	0.14	0.14						
	I-35	Dry															
		Wet						10	0.27	0.45	0.37	0.06	13	0.20	0.48	0.32	0.08
		Damp															
		Slush											4	0.25	0.32	0.28	0.03
		Snow						1	0.15	0.15	0.15		1	0.17	0.17	0.17	
		Snow/ice Pack															
		Ice											2	0.19	0.22	0.21	0.02
NY	SR 104	Dry						24	0.24	0.53	0.40	0.07	30	0.25	0.48	0.38	0.06
		Damp						13	0.33	0.50	0.40	0.05	7	0.24	0.42	0.32	0.06
		Wet						144	0.12	0.52	0.33	0.08	110	0.02	0.43	0.27	0.08
		Slush						45	0.12	0.46	0.29	0.08	46	0.01	0.39	0.22	0.08
		Snow						48	0.04	0.40	0.23	0.08	40	0.09	0.33	0.19	0.05
		Snow/Ice Pack						19	0.01	0.33	0.18	0.08	13	0.07	0.29	0.17	0.07
		Ice						5	0.22	0.38	0.30	0.07	6	0.03	0.24	0.14	0.08
Total No. Meas.		994	11	No. of Measurements				624	No. of Measurements				359	No. of Measurements			

The ranges of friction values that five states recorded on dense-graded asphalt test sections during the 1992-93 winter are presented in figure 24 along with the Finnish results. New York provided friction measurements under damp pavement conditions. Again, no data are presented for Maryland because their friction measurements were made on open-graded asphalt. Individual measurements made by the states are indicated by small crosses. Two Coralba units were supplied to Ohio Department of Transportation (ODOT), one each for I-70 and I-71. Results achieved for these two sites are also shown in figure 24. Many of the friction measurements fall outside the Finnish range. Also, some of the states' measurements are either too low or too high for the reported pavement condition, suggesting that the state operators were not always consistent in the procedure used for measuring the friction.

In summary, more states recorded friction measurements during the 1992-93 winter than during 1991-92. Also, two states experienced limited success using the Coralba as a tool to assess appropriate application times. However, the problems of inconsistent measurements and lack of understanding of the Coralba's use and intent remained the same as during the previous winter.

SOBO-20 Salinity Measurements

Five states made SOBO-20 salinity measurements during 17 of the 102 storm events analyzed for the 1992-93 winter. These were Maryland (four storm events), Ohio I-70 site (four events), Missouri US-71 (one event), New York (six events), and Washington (two events). Neither Nevada nor the Ohio I-71 site had a SOBO-20 instrument. As was the case during the 1991-92 winter, some of the states made salinity measurements before the first (anti-icing) application treatment. Most of the time, these pretreatment measurements showed zero salinity. However, in a few storms, the pretreatment measurements indicated there was some small salinity, possibly a carry-over from previous storm treatments.

Much like the 1991-92 data, cases were noted where a low salinity value was followed by a chemical application. Other cases were noted where a low salinity measurement value was not followed by an application treatment. The same application combinations were noted also for high salinity values. Thus, it appeared that the SOBO-20 measurement value levels were not used consistently to make decisions concerning reapplication treatments.

New York experienced operational difficulty with its SOBO-20 instrument during the second winter. The instrument was inoperable or under major repair for 29 of 36 storms. Numerous attempts were made to repair the defective unit, including shipping it to the U.S. vendor and

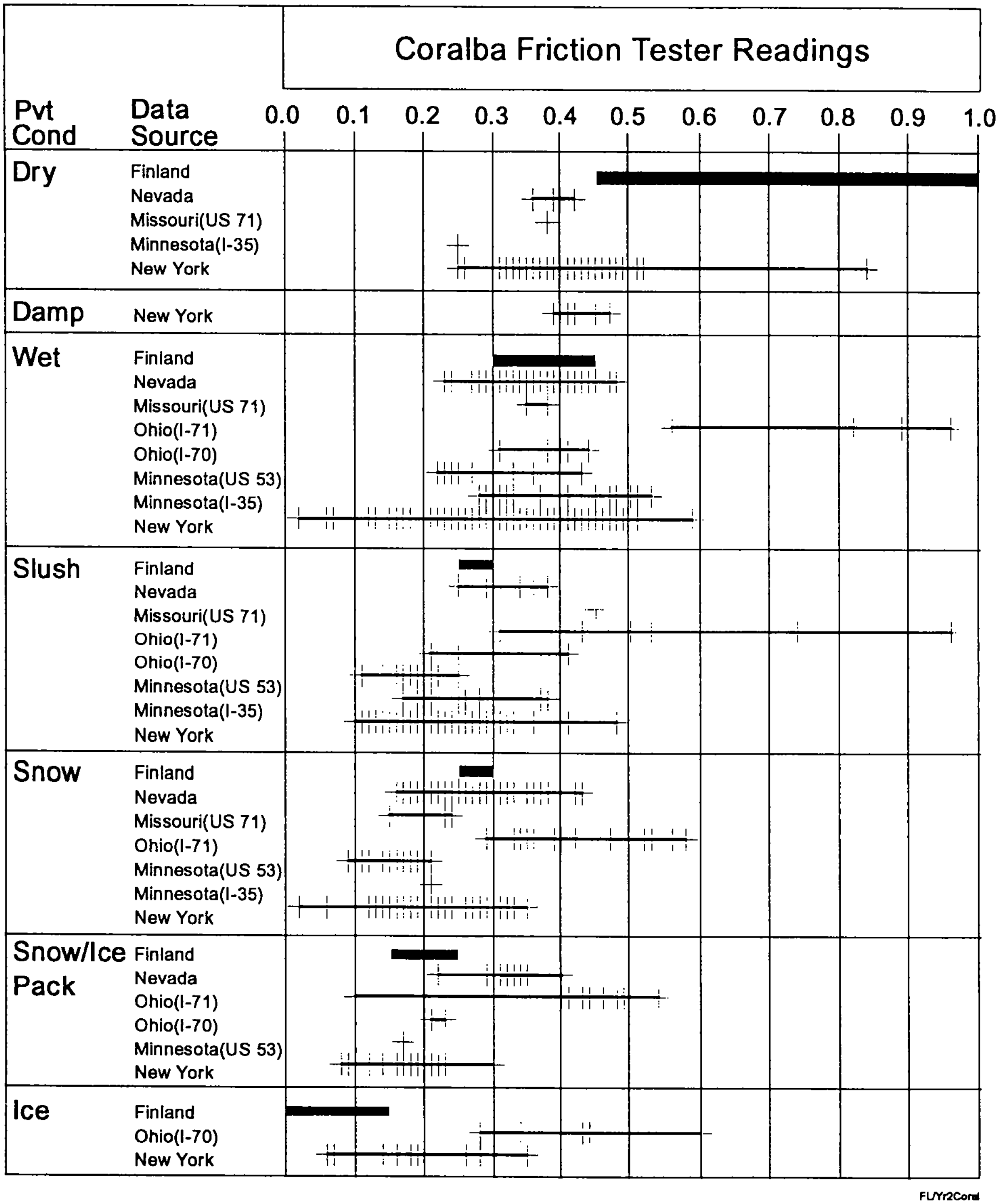


Figure 24. Comparison of Coralba friction measurements for the test sections on dense-graded asphalt made during 1992-93 winter with Finnish results.

the manufacturer in Switzerland, with little success. Some of the SOBO-20 readings from New York were inconsistent, and the defects of the SOBO-20 account for those readings. New York did take special interest this winter in the SOBO-20 measurements, and developed unique forms for recording the data.

Missouri also experienced some operational difficulty with its SOBO-20 instrument. Missouri (US-71 site) and Washington submitted SOBO-20 data for the first time in the 1992-93 winter and so did not profit from the experience of the 1991-92 winter. This fact may account for the inconsistencies in the readings from these two states.

In summary, more states recorded SOBO-20 data during the 1992-93 winter than during the 1991-92 winter, but the total number of storm events with SOBO-20 data was fewer. The SOBO-20 measurements made in Maryland, Missouri, and New York were taken in both the right wheeltrack of the driving (slow lane) and in the centerline between two lanes. Ohio (I-70 site) made measurements only in the right wheeltrack of the driving lane. Washington made measurements at several lateral locations on the road, including the wheeltrack of the driving lane, the wheeltrack of the passing lane, the wheeltrack of the center lane, and in the centerline between the slow and center lanes. As expected, the wheeltrack salinity values were generally lower than those obtained at the other positions.

Cost-Benefit Analysis of Anti-Icing Operations

The preceding discussion has established that anti-icing operations can improve road surface conditions during winter storms. In order to decide whether to use an anti-icing approach to winter maintenance, highway agencies must be aware of the costs of implementing anti-icing and must be able to determine whether a particular anti-icing strategy would be cost-effective in their climate conditions.

A cost-benefit model for evaluating anti-icing strategies was developed as part of the research. This model has been tested using benefit estimates determined from the maintenance field data collected by the participating state highway agencies (SHAs). The costs of anti-icing operations have been estimated based on the experience of the MNDOT, and the costs of capital equipment have been based on the equipment purchased for use by the participating SHAs for this project. These example calculations serve to illustrate the cost-benefit methodology.

The objective of this analysis is to compare the costs and benefits of anti-icing operations with conventional deicing. This analysis focuses on two aspects of the cost-benefit comparison:

- Comparing of the direct costs and benefits to the highway agency between anti-icing operations and conventional deicing.

- Comparing the additional benefits to motorists from improved road conditions that result from anti-icing operations and conventional deicing.

Each of these aspects of the cost-benefit analysis is discussed below.

The analysis is performed by the net-annual-cost method, in which all costs and benefits are expressed on an annualized basis. Benefits to the public and reduced expenditures for the highway agency are expressed as positive values; increased costs to the highway agency are expressed as negative values. The net annual cost is their algebraic sum. A net annual cost greater than zero indicates that anti-icing is a cost-effective alternative to conventional deicing; a net annual cost less than zero indicates that anti-icing is not a cost-effective alternative. The net-annual-cost method is entirely analogous to the net-present-value method, which is recommended for highway applications in the Association of American State and Highway Transportation Officials (AASHTO) *Manual on User Benefit Analysis for Highway and Bus-Transit Improvements*[21], except that the costs and benefits are considered on an annual basis, rather than as present values. This method was chosen because annual costs are generally more familiar and more meaningful to highway maintenance engineers than their equivalent present values.

The following discussion presents the cost-benefit methodology with of examples of typical cost and benefit values. The cost-benefit model has been developed as a Lotus 1-2-3 worksheet, so that any highway agency can supply data to perform an analysis applicable to its own conditions.

Direct Costs and Benefits to Highway Agencies of Anti-Icing Operations

The following discussion addresses the direct cost impact of anti-icing operations on highway agencies. Benefits to the general public of anti-icing, in the form of improved travel conditions, are considered in a later section.

Input Data to the Cost-Benefit Methodology

The cost-benefit methodology compares the costs incurred by highway agencies for anti-icing operations with those for conventional deicing. This comparison is made for a single truck route; i.e., the portion of the highway system assigned for treatment to a specific truck during storm operations. Users can easily expand the results from one truck route to multiple routes with similar conditions. By changing appropriate input parameters the methodology can also assess truck routes with different maintenance priority levels or different treatment strategies.

The following climate, treatment strategy, and treatment cost data are needed to apply the cost-benefit methodology:

- number of storms per winter;
- number of storm hours per winter;
- number of lane-miles covered by truck route;
- average truck speed during treatment operations (including allowance for deadheading, reloading material, and breaks);
- level of maintenance priority (treatment coverage time expressed in hours per day);
- conventional deicing strategy (amounts and types of material per lane-mile);
- anti-icing strategy (amounts and types of material per lane-mile);
- maintenance worker (i.e., truck driver) labor cost per hour;
- truck operating cost per hour (depreciation, fuel, tires, repairs, etc.); and
- cost of additional capital equipment required for anti-icing operations.

Each of these cost items is discussed below in more detail.

Climate Data

Climate data are represented in the model by the number of storms per winter and the total number of hours during those storms. The number of storm hours per winter represents the total duration of the time during which winter maintenance operations would be underway. Obviously, many winter maintenance costs are directly proportional to the number of storm hours; the latter consist of a number of discrete storm periods. The number of storms affects the costs of anti-icing operations because each storm, no matter how short or long, requires one pretreatment pass to apply a small amount of chemical (typically, a solid chemical prewetted with a liquid chloride solution).

Example cost-benefit calculations have been performed for a range of climate conditions ranging from 100 to 900 storm hours per winter. This represents the typical range of climate conditions for the states that participated in this project. A total duration of storm operations of 100 hours per winter might represent a plains state, such as Missouri, in a relatively mild winter; 900 hours per winter would represent a mountain or lake-effect state in a normal to severe winter. The duration of storms per winter for each climate was determined on the presumption that as the number of storms increases, the average duration per storm is also likely to increase. Thus, we assumed an average duration per storm of 20 hours for a climate with 100 storm hours per winter, increasing to 30 hours per storm for a climate with 900 storm hours per winter. Five typical combinations, representing a range of climate conditions that were considered in the example applications, are shown:

Number of storm hours per winter	Number of storms per winter
100	5
300	12
500	18
700	25
900	30

Highway agencies can use the example computations for this range of climate conditions to consider the cost-effectiveness of anti-icing for their particular climate. The cost-effectiveness of anti-icing may change from year to year as the severity of the winter climate varies. To interpret the results of the example applications of the cost-benefit methodology, highway agencies can select the combination of conditions from the above list that most closely matches their own climate. And, of course, agencies that assemble their own data can apply the cost-benefit methodology directly.

Typical Truck Routes and Maintenance Priority Classifications

The truck routes used by highway agencies are assigned various maintenance priority classifications. High priority routes require a shorter treatment cycle, and thus fewer lane-miles can be assigned to one truck. Table 57 shows the maintenance priority levels used by the MNDOT, together with the number of lane-miles, cycle time, average truck speed, and treatment coverage time for each.

Table 57. Length and treatment coverage of MNDOT truck routes based on maintenance priority classification.

Maintenance priority classification	Typical ADT range (veh/day)	Lane-miles per truck	Assumed average truck speed (mph)[a]	Cycle time (hr)	Treatment coverage time (hr/day)
Urban commuter	Over 10,000	31.5	15	2.1	24
Rural commuter	2,000 – 10,000	48.0	15	3.2	20
Primary	800 – 2,000	67.5	15	4.5	18
Secondary	Under 800	90.0	15	6.0	12

[a] 1 mph = 1.609 km/hr.

Source: MNDOT Maintenance Manual.

The table shows the distance typically assigned to each truck under each maintenance priority classification, ranging from 50.7 to 144.8 lane-km (31.5 to 90.0 lane-miles). An important parameter representing the productivity of winter maintenance operations is the average truck speed in treatment operations. Typically, maintenance trucks travel at approximately 48.3 km/hr (30 mph) when plowing and spreading; they may go faster when just plowing. However, an allowance has to be made for deadheading to and from the garage, turning around, reloading material, and breaks. MNDOT assumes a net average speed of 24.1 km/hr (15 mph), including the items listed above. The cycle time, which represents the time required for the truck to make one pass over each lane-mile for which it is responsible, is calculated as the ratio of the number of lane-miles to the average travel speed. Highway agencies typically treat high-priority routes on a 24-hr/day basis and lower-priority routes for fewer hours per day. The treatment coverage time in hours per day has been included as an input variable in the model.

For illustrative purposes, the example calculations used below are based on a truck route of 64.4 lane-km (40.0 lane-miles), which is approximately halfway between MNDOTs practice for urban commuter and rural commuter routes. The same average speed of 24 km/hr (15 mph) as used by MNDOT has been used in our sample calculations. For our example, 64.4 lane-km (40.0 lane-miles) at an average speed of 24 km/hr (15 mph) implies a cycle time of 2.67 hr. Thus the truck could cover its full assigned route nine times in a 24-hr day. Expressed another way, the truck has a productivity rate of 0.042 hr/lane-km (0.067 hr/lane-mile).

Treatment Strategies and Costs

The cost-benefit methodology requires users to specify the treatment strategies used both for conventional deicing and for anti-icing. The strategies are specified in terms of the application rates for chemicals and abrasives in pounds per lane-mile, and the prewetting rate used is for anti-icing expressed in gallons per ton. Currently, the methodology allows the user to specify each strategy in terms of the application rates and costs for three materials: solid NaCl, abrasive (sand), and liquid $CaCl_2$ for prewetting.

The example computation is based on a conventional deicing strategy involving the application of 19.2 g/m^2 (250 lb/lane-mile) of solid NaCl per pass. No abrasives or prewetting are used in the conventional deicing strategy. The anti-icing strategy is based on the application of 7.7 g/m^2 (100 lb/lane-mile) of solid NaCl per pass, prewetted at the spinner with liquid $CaCl_2$ at the rate of 21 L/metric ton (5 gal/ton). This is the same anti-icing strategy some of the states used during the experiments. A higher rate of wetting could be used in alternative strategies. No abrasives are used in the anti-icing strategy.

Based on data provided by the MNDOT, the treatment costs are estimated as $32.52/metric ton ($29.50/ton) for solid NaCl and $0.14/L ($0.53/gal) for liquid $CaCl_2$. The cost of abrasives, if used, is estimated as $9.1/metric ton ($8.26/ton).

Based on these cost data and on the application rates presented above, the material cost per lane-mile for one pass is $3.69 for the conventional deicing strategy and $1.61 for the anti-icing strategy. This reduced material cost per pass is one of the benefits to highway agencies of employing an anti-icing strategy. Anti-icing strategies should also result in cost savings due to a decrease in the number of passes during storm periods, since road sections are not retreated until a need is identified based on pavement sensor data, friction tests, residual salinity tests, or visual observations. However, anti-icing operations do involve the cost for a pretreatment pass that would not be required for conventional deicing.

The cost-benefit methodology is based on the assumption that a truck plows and applies chemicals to one lane at a time. However, the costs are essentially no different if two trucks plow and apply chemicals in tandem over a truck route twice as long, or if a truck plows one lane without applying chemicals to that lane and then, in the next pass, plows the adjacent lane while applying chemicals to both lanes.

Maintenance Worker and Truck Operating Costs

The cost-benefit methodology requires data on the cost per hour for a maintenance worker (i.e., truck driver) and for the operating cost of the truck. Based on MNDOT data, the labor cost for a maintenance worker is estimated at $25.50 per hour, including salary, fringe benefits, overhead, and overtime differential. This is based on the assumption that 2/3 of the hours worked are paid as straight time and 1/3 as overtime. Based on the assumed net speed of

24.1 km/hr (15 mph), this corresponds to a labor cost of $1.06 per lane-km ($1.70 per lane-mile) treated.

The cost of truck operation is estimated at $24.00 per vehicle-hour, based on current equipment charges in Minnesota. This includes depreciation of the vehicle, plow, spreader, and operating costs such as fuel, lubricants, tires, and repairs. Based on an assumed net speed of 15 mph, this corresponds to a vehicle cost of $0.99 per lane-km ($1.60 per lane-mile) treated.

Capital Equipment Costs for Anti-Icing Operations

Anti-icing operations require expenditures for capital equipment that are not required for conventional deicing. These include

- improved spreaders for applying smaller and more carefully controlled amounts of chemicals;
- ground-oriented spreader controls that maintain a constant application rate as the speed of the truck varies;
- prewetting equipment (tanks, hoses, nozzles, etc.) to coat the solid chemical with liquid chemical at the spinner;
- a RWIS consisting of pavement sensors, weather station, communications, and computer hardware and software, to process and display the data;
- a Coralba friction meter for determining whether an additional treatment should be made; and
- a SOBO device for measuring the residual chemical on the pavement to assist in determining whether an additional treatment should be made.

The improved spreader tailgate, ground-oriented controls, and prewetting equipment are required for each truck used in anti-icing operations. The RWIS is a fixed-site installation; it is estimated that one RWIS system, with multiple sensors, can provide data to a supervisor responsible for approximately 10 truck routes. Similarly, the Coralba and SOBO equipment can provide data for approximately 10 truck routes.

Table 58 provides estimated costs for these capital items, based on the costs of similar items purchased in this project. No additional expenditure would be required for ground-oriented controls by highway agencies that already use them for conventional deicing. The table includes the estimated service life of each item, the number of trucks served by the item, and the annual cost per truck. Annual costs have been computed based on a discount rate or minimum attractive rate of return of 4%. The total capital cost of equipment required for anti-icing operations is estimated at $1,977 per truck per year.

Table 58. Estimated cost of capital equipment required for anti-icing operations.

Equipment	Initial cost ($)	Estimated service life (years)	Number of trucks served by one unit	Annual cost per truck ($)
Improved spreader	4,000	10	1	493
Ground-oriented spreader controls	1,800	7	1	300
Prewetting equipment	2,800	3	1	178
Road weather information system	40,000	5	10	899
Coralba friction tester	1,800	5	10	40
SOBO salinity tester	3,000	5	10	67
Total	53,400			1,977

Effectiveness of Anti-Icing Operations

As explained above, anti-icing operations involve costs for a pretreatment pass prior to each storm, and for capital expenditures of nearly $2,000 per truck per year to obtain the specialized equipment needed. Benefits to highway agencies result from decreased material application rates and from a decrease in the number of passes over each roadway section during any given storm.

One benefit of effective anti-icing is a reduction in the number of passes required during each storm. This reduction can be realized by delaying retreating a roadway section until pavement sensors, friction tests, residual salinity measurements, visual observations, or some combination of these indicates a need.

One way for highway agencies to achieve cost savings from reducing in the required number of passes is to use the personnel and vehicles that are no longer required on a given truck route on other routes. In other words, highway agencies can achieve benefits from highway operations by increasing the average length of truck routes.

The data for the 1991-92 winter indicate that anti-icing operations reduced the number of passes over each road section during storms by an average of 22.3%. Extensive experience with anti-icing operations in New York during the 1992-93 winter found a comparable reduction in the number of passes of only 6.5%. Thus, experience during these two winters indicates that the effectiveness of anti-icing operations in reducing the number of passes can vary substantially as a result of climate conditions and highway agency practices. Our example cost-benefit calculation has been based on an average reduction of 15% in the number of passes during storms due to anti-icing operations. We have also performed a sensitivity analysis of the cost savings due to anti-icing operations over the range of reductions from 5% to 30%. This analysis covers the most likely range of effectiveness in reducing the frequency of during-storm passes that might be expected from anti-icing operations in actual practice. The results of both the example calculations and the sensitivity analysis are presented in the next section.

Summary of Highway Agency Costs and Benefits

Table 59 summarizes the results of the example application of the cost-benefit methodology for climates ranging from 100 to 900 storm hours per winter for one truck route consisting of 64.4 lane-km (40.0 lane-miles) of road treated continuously on a 24-hr/day schedule. The assumptions concerning climate, truck operations, treatment strategies and costs, and capital equipment requirements on which this table is based are presented in the preceding sections. The table shows the labor, vehicle operation, and material costs for one pretreatment pass prior to each storm; the reduced costs for during-storm treatment due both to the decreased number of passes and the lower material application rates; and the increase in annual capital costs for the additional equipment required for anti-icing.

This calculation indicates that anti-icing operations can result in net cost savings to highway agencies over the full range of climate conditions considered. However, it is important to note that the primary source of cost savings from anti-icing is the reduced material costs associated with both the lower chemical application rates for each pass and the fewer number of passes. Since the effectiveness of prestorm treatment may only extend for the first few hours of each storm, these findings suggest that cost savings similar to those from anti-icing may also be realized through sensible deicing (i.e., reducing application rates and using new technology to hold off retreatment until necessary, but not using a pretreatment pass).

Table 60 presents a sensitivity analysis of the net cost savings from anti-icing operations based on the percent reduction in the number of passes required for each road section for during-storm treatment. The assumptions are the same as those used in table 59 (including the assumed reduction in chemical application rates for anti-icing operations) except that the percent reduction in the number of during-storm passes is varied. The range considered for the reduction in number of passes is 5% to 30%, which includes the estimate of 15% effectiveness used in table 59. The table shows that anti-icing operations are cost-effective under the climate conditions and effectiveness estimates considered. Although the net cost savings from anti-icing become very small for mild winter climates (such as 100 storm hours per winter) and low effectiveness estimates (such as a reduction of only 5% in the required number of passes during storms), the net cost savings are still greater than zero. It is likely that similar cost savings can also be obtained from sensible deicing.

Table 59. Annual benefits and costs to highway agencies per truck route for anti-icing operations.

Winter Climate Conditions					
Storm hours per winter:	100	300	500	700	900
Storms per winter:	5	12	18	25	30
Annual Benefits and Costs per Truck Route					
Additional cost for pretreatment passes ($)					
Labor	−340	−816	−1,224	−1,700	−2,040
Vehicle operations	−320	−768	−1,152	−1,600	−1,920
Materials	−322	−772	−1,157	−1,608	−1,929
Reduced cost due to decreased number of passes and decreased application rate per pass ($)					
Labor	383	1,148	1,913	2,678	3,443
Vehicle operations	360	1,080	1,800	2,520	3,240
Materials	3,482	10,445	17,408	24,372	31,335
Additional cost for capital equipment ($) (see Table 58)	−1,977	−1,977	−1,977	−1,977	−1,977
Total Cost Savings per Truck Route ($)	1,266	8,340	15,611	22,685	30,152
Summary of Benefits and Costs ($)					
Labor	43	332	689	978	1,403
Vehicle operations	40	312	648	920	1,320
Materials	3,160	9,673	16,251	22,764	29,406
Equipment	−1,977	−1,977	−1,977	−1,977	−1,977
Total Cost Savings per Truck Route ($)	1,266	8,340	15,611	22,685	30,152

Note: Positive amounts represent cost savings or benefits to highway agencies from anti-icing operations. Negative amounts represent increased costs to highway agencies from anti-icing operations. The table is based on analysis of one maintenance route covering 64.4 lane-km (40.0 lane-miles) of freeway, assuming 15% reduction in number of passes during storms. This maintenance route receives continuous 24-hr/day treatment at an assumed net speed of 24 km/hr (15 mph). Other assumptions on which the table is based are discussed in the preceding section.

Table 60. Sensitivity of annual benefits and costs to highway agencies for anti-icing operations as a function of percent reduction in number of passes during storms.

Winter Climate Conditions					
Storm hours per winter:	100	300	500	700	900
Storms per winter:	5	12	18	25	30
Anti-icing Effectiveness (percent reduction in number of passes during storms)	**Total Annual Cost Savings per Truck Route ($)**				
5%	529	6,131	11,930	17,352	23,526
10%	898	7,236	13,770	20,108	26,839
15%	1,266	8,340	15,611	22,685	30,152
20%	2,633	9,444	17,451	25,411	33,464
25%	2,002	10,548	19,291	27,838	36,777
30%	2,370	11,652	21,131	30,414	40,089

Benefits to Motorists from Anti-Icing Operations

Winter travel conditions improved by anti-icing operations can benefit the general public by decreasing the potential for accidents, reducing delays, and reducing the likelihood that motorists will have to forgo trips because of poor road surface conditions. These benefits are discussed in this section, with emphasis on the effect of anti-icing operations on accidents.

Effect of Anti-icing Operations on Accidents

Anti-Icing has the potential of reducing the amount of time during which motorists are exposed to ice and snow-covered pavements. Since lower accident rates would be expected on wet or dry pavements than on ice and snow-covered pavements, reducing the number of hours when pavements are covered with ice and snow should reduce in the frequency of traffic accidents.

Maintenance data for storms in the 1991–92 winter provided by participating SHAs were reviewed to determine what improvement in pavement condition can be expected from anti-icing operations. Five storms from that winter had enough data to compare the maintenance history of the test section (treated with an anti-icing strategy) and the control section (treated with a conventional deicing strategy). Two of these storms occurred in Nevada, two in New York, and one in Ohio. These data indicate the control sections had ice and snow-covered pavements for approximately 50% of the time during storm periods and that the duration of ice and snow conditions on the test sections was reduced by 5% to 35%. The average reduction in ice and snow exposure on the test sections was 20%; this is equivalent to a reduction in exposure to ice and snow-covered pavements of 10 hr per winter in a climate that experiences 100 storm hours per winter, or a reduction of 90 hr per winter for a climate with 900 storm hours per winter. The maintenance records indicate that the pavements were generally wet during the periods when they were not ice and snow-covered.

Variation of Accident Rates as a Function of Pavement Surface Condition

The variation of accident rates as a function of pavement surface condition was evaluated from accident data obtained from the NYDOT for five controlled-access freeway routes in and near Rochester in Monroe County, New York. These routes include a total length of 132.7 centerline-km (82.45 centerline-miles) of freeway, which constitute essentially all freeways within Monroe County. One of these freeways includes the test site on SR 104 used in our anti-icing field tests and includes a RWIS.

Accident data for the sites described above were obtained and analyzed for two winter periods:

- October 1, 1989, to April 30, 1990; and
- October 1, 1990, to April 30, 1991.

The accident data provided by the NYDOT include the pavement surface condition (dry, wet, ice and snow) when each accident occurred, as observed by the investigating police officer. For approximately 8% of the accidents, the pavement surface condition was listed as unknown. Pavement surface conditions for these accidents were determined using the pavement sensor data from the SR 104 site or, when necessary, from weather data for Rochester/Monroe County Airport.

The NYDOT also provided average daily traffic (ADT) volume data for these sites for both 1989 and 1991. These data were used to estimate the vehicle-miles of travel during each of the two winters.

Exposure times of different pavement conditions (dry, wet, ice and snow) were estimated using weather data from Rochester/Monroe County Airport with the WETTIME computer model[22, 23, 24], which was developed by Midwest Research Institute for Federal Highway Administration (FHWA).

Table 61 shows an analysis of the accident and exposure data. During the two years evaluated, the Rochester area experienced an average of 8.9% ice and snow exposure during the winter season (October through April). This is equivalent to 453 hr per winter of ice and snow exposure or about 50% of the average of 900 storm hours per winter that would be expected in this lake-effect snowfall area.

These data also indicate that the accident rate during ice and snow conditions is typically about eight times higher than during dry-pavement conditions, and about two times higher than during wet-pavement conditions. Based on these data, the accident rate on a freeway would be expected to decrease from 4.6 to 2.3 accidents per million vehicle-miles for every hour during which ice and snow-covered pavements were converted to wet pavements.

Table 61. Accident and exposure data for freeway sites in Monroe County, New York.

	Period		
	Winter 1989–1990[a]	Winter 1990–1991[a]	Combined
Length (miles)	82.5	82.5	82.5
Travel (million veh-mi)[b]	744.0	838.6	1,582.6
Total accident rate	1.3	1.0	1.1
No. of reportable accidents[c]			
Dry	344	378	722
Wet	234	194	428
Ice and snow	417	235	652
Total	995	807	1,802
% of accidents			
Dry	34.6	46.8	40.1
Wet	23.5	24.0	23.8
Ice and snow	41.9	29.1	36.2
% of exposure[d]			
Dry	78.3	79.9	79.1
Wet	10.9	13.0	12.0
Ice and snow	10.8	7.1	8.9
Accident rate (per MVM)			
Dry	0.6	0.6	0.6
Wet	2.9	1.8	2.3
Ice and snow	5.2	4.0	4.6
Combined	1.3	1.0	1.1

[a] October 1 through April 30.
[b] Exposure (million vehicle-miles of travel MVM) based on NYDOT ADT data for 1989 and 1991.
[c] Number of accidents by pavement surface condition, based on NYDOT records.
[d] Percent of exposure by pavement surface condition, based on weather data for Monroe County Airport.

Accident Reduction Benefits from Anti-Icing Operations

Table 62 summarizes the accident reduction benefits that can be expected from anti-icing operations. These estimates are based on the following assumptions:

- The truck route being analyzed is located on a four-lane, divided freeway with an ADT volume of 20,000 veh/day.

- Pavements are normally ice and snow covered during 50% of storm hours when treated by conventional deicing.

- Anti-icing reduces exposure to ice and snow covered pavements by 20%. During the hours when the pavement would have been otherwise covered with ice and snow, the pavement is wet instead.

- Ice and snow-covered pavements on freeways experience 4.6 accidents per million vehicle-miles, while wet pavements experience 2.3 accidents per million vehicle-miles.

- Based on California Department of Transportation data, the severity distribution of freeway accidents is 3.2% fatal accidents, 44.6% injury accidents, and 52.2% property-damage-only (PDO) accidents.[25]

- Based on recent FHWA data, the average costs of accidents are $1,700,000 for fatal accidents, $14,000 for injury accidents, and $3,000 for PDO accidents.[26]

Table 62 shows that the accident cost reduction from anti-icing operations on a 64.4 lane-km (40.0 lane-mile) truck route ranges from approximately $12,000 per year for climates with 100 storm hours per winter to nearly $110,000 per year for a climate with 900 storm hours per winter. This result is based on analysis of a freeway with an ADT of 20,000 veh/day. The accident cost reductions would be expected to increase or decrease roughly in proportion to the ADT.

Effect of Anti-Icing Operations on Traffic Speeds and Volumes

Pavement surface conditions, and thus winter maintenance activities, have a definite effect on traffic speeds and volumes, but adequate data are not available to quantify them. Traffic speed and volume data were collected during portions of the 1992–93 winter for the test site on SR 104 near Rochester, New York. Average 15-minute speeds as low as 46.7 km/hr (29 mph) were observed during storm periods compared with normal average speeds that exceed 88.5 km/hr (55 mph). However, such reduced speeds are apparently experienced only during the worst parts of storms when pavement conditions are very adverse. Limited visibility may also be a factor. However, during many storms when pavement conditions were not at their worst, traffic speeds were reduced only marginally, if at all. Unfortunately, sufficient data are not available for this site to compare a broad cross section of storm and nonstorm

Table 62. Estimated accident rate and accident cost reduction per truck route for anti-icing operations.

Winter Climate Conditions					
Storm hours per winter:	100	300	500	700	900
Storms per winter:	5	12	18	25	30
Percent of storm hours with ice and snow-covered pavement under conventional deicing	50	50	50	50	50
Number of hours per winter with ice and snow-covered pavement under conventional deicing	50	150	250	350	450
Effectiveness of Anti-icing Operations					
Expected percent reduction in ice and snow exposure due to anti-icing operations	20	20	20	20	20
Expected number of hours of reduced ice and snow exposure	10	30	50	70	90
Highway and Traffic Volume Data					
Number of lane-miles per truck route	40	40	40	40	40
Number of lanes on highway	4	4	4	4	4
Number of centerline miles	10	10	10	10	10
Highway ADT	20,000	20,000	20,000	20,000	20,000
Estimated million vehicle-miles of travel during hours of reduced ice and snow exposure	0.083	0.250	0.417	0.583	0.750
Accident Rate and Severity Distribution					
Accident rate per million vehicle-miles on ice and snow-covered pavements	4.6	4.6	4.6	4.6	4.6
Accident rate per million vehicle-miles on wet pavements	2.3	2.3	2.3	2.3	2.3
Percentage of fatal accidents	3.2	3.2	3.2	3.2	3.2
Percentage of injury accidents	44.6	44.6	44.6	44.6	44.6
Percentage of PDO accidents	52.2	52.2	52.2	52.2	52.2
Expected Accident Reduction					
Expected annual number of fatal accidents reduced	0.006	0.018	0.031	0.043	0.055
Expected annual number of injury accidents reduced	0.085	0.256	0.427	0.598	0.769
Expected number of PDO accidents reduced	0.100	0.300	0.500	0.700	0.900
Expected number of total accidents reduced	0.192	0.575	0.958	1.342	1.725
Total Annual Accident Cost Savings ($)	11,924	35,771	59,618	83,465	107,312

conditions during comparable time periods. Thus, the distribution of storm effects on traffic speeds, and the average or typical effect, cannot be determined.

Similar conclusions were drawn from the analysis of traffic volume data. It is clear from the available data that traffic volumes can be reduced substantially during storm periods, but sufficient data for comparable nonstorm periods are not available for comparison.

Since anti-icing has been shown to reduce the number of hours during which pavements are ice and snow-covered, anti-icing can be expected to reduce traffic delays (i.e., increase traffic speeds) and to reduce the number of trips that are foregone because of adverse road conditions. However, since these effects are highly variable and depend on the character of specific storms, the traffic speed and volume effects cannot be adequately quantified to be incorporated in a cost-benefit analysis.

Discussion of Cost-Benefit Analysis Results

Table 63 summarizes the combined annual cost savings from anti-icing operations that are expected to accrue to both highway agencies and motorists. These results are based on the example application of the cost-benefit methodology presented above. The highway agency cost savings from anti-icing result from both the decreased number of passes for during-storm treatment and the decreased chemical application rates. The motorist cost savings result from accident reductions due to reduced hours of exposure to ice and snow-covered pavements.

The cost-benefit analysis results indicate that, under virtually all conditions considered, despite the required capital investment in new technology of approximately $2,000 per truck per year, anti-icing can result in cost savings for highway agencies. In areas with very mild winter climates, these cost savings can be quite small, but they are greater than zero. We emphasize these cost savings are for one 64.4 lane-km (40.0 lane-mile) truck route; even the modest savings for one truck route will result in substantial total savings when multiplied by the number of truck routes in a city, county, highway district, or state.

Since the effectiveness of prestorm treatment may last only for the first few hours of each storm, these findings suggest that cost savings similar to those from anti-icing may also be realized through sensible deicing (i.e., reducing application rates and using new technology to delay retreatment until necessary, but not using a pretreatment pass). Thus, the strategies that can be used to achieve cost savings from new winter maintenance technology go beyond just anti-icing; new technology (better spreaders and spreader controls, pavement sensors, friction testers, and salinity testers) may benefit highway agencies, even when prestorm treatment is not part of the chosen treatment strategy.

Table 63. Annual benefits and costs for highway agencies and motorists per truck route for anti-icing operations.

Winter Climate Conditions					
Storm hours per winter:	100	300	500	700	900
Storms per winter:	5	12	18	25	30
Benefits and Costs					
Annual cost savings to highway agencies ($)					
Labor	43	332	689	978	1,403
Vehicle operations	40	312	648	920	1,320
Materials	3,160	9,673	16,251	22,764	29,406
Equipment	−1,977	−1,977	−1,977	−1,977	−1,977
Total	1,266	8,340	15,611	22,685	30,152
Annual accident cost savings to motorists ($)	11,924	35,771	59,618	83,465	107,312
Total Annual Cost Savings per Truck Route ($)	13,190	44,111	75,229	106,150	137,464

Note: Positive amounts represent cost savings or benefits for highway agencies or motorists from anti-icing operations. Negative amounts represent increased costs to highway agencies or motorists from anti-icing operations. Figures are based on analysis of one maintenance truck route covering 40.0 lane-miles of freeway, assuming 15% reduction in number of passes during storms, and 20% reduction in exposure to ice and snow-covered pavements.

Finally, it should be noted that the potential accident savings for motorists appear to be three to seven times the potential savings for highway agencies. These potential safety benefits should not be overlooked in the decision to adopt anti-icing or sensible deicing strategies. At the same time, it should be recognized that a large proportion of the accident-cost savings result from a reduction of relatively small numbers of fatal accidents. The high cost of a fatal accident (estimated here as $1,700,000) is a key factor in the safety benefits. Nevertheless, even if the accident-cost savings estimated here are overstated, the safety benefits from anti-icing and sensible deicing are real and need to be considered.

Survey of Worldwide Spreader Equipment Market

Researchers sought information from both U.S. and foreign vendors, agencies, and associations about sources of equipment that can apply controlled quantities of solid, prewetted solid, and liquid deicing chemicals at the application rates required for effective anti-icing treatments.

A list of 68 manufacturers of spreader controls, aggregate (including solid deicer) spreaders, and fertilizer spreaders was obtained from the 1991 *Public Works Manual*. Each manufacturer was asked for information on the operation and performance characteristics of the equipment used in snow and ice-control operations. Thirty manufacturers responded with sales literature for frame-mounted, dump body, and slide-in, hopper-type salt and sand spreaders, controls, pumps, and snow removal equipment. Some spreader manufacturers claim their products can achieve precise application rates in combination with electronic controls. However, no technical information was provided to substantiate these claims. Appendix H contains a list of the vendors who replied, along with a summary of the information provided.

Researchers also contacted 111 equipment manufacturers, national road agencies, research organizations, trade associations, and chambers of commerce in Australia, Austria, Belgium, Canada, Denmark, England, Finland, France, Germany, Japan, the Netherlands, Republic of Korea, and Sweden. Useful information was obtained from the major equipment manufacturers.

Since much of the research and development on spreader equipment has been conducted in Europe, the project team visited a number of manufacturing facilities there.

In Scandinavian and other European countries, anti-icing is conducted with spreaders that dispense salt brine and/or prewetted salt. There are two types of liquid spreaders: spray bar and spinners. The preferred type of spreader appears to depend both on maintenance philosophy and on the operator. The Finnish National Road Administration has approximately the same number of each type of liquid spreaders. According to the Finnish agency, the advantage of the spray bar is that the pressurized flow from the nozzles will lift a slight layer of compacted snow off the road. The disadvantages include the plugging of nozzles by impurities so that filters on the supply line need to be cleaned intermittently; limit of the application speeds because of the size of the pumps and nozzles; and the loss of some of the liquid in air currents.

The advantages of the spinners are that there are no nozzles to plug and greater application speeds can be obtained.

Scandinavian and other European spreader manufacturers also market spreaders that dispense prewetted material. These spreaders meet one or more countries' specifications for application rates and spread pattern. More details on equipment are given in Appendix E.

Results from Limited Testing of Spreader Capabilities

Various American spreader manufacturers were contacted by letter to determine what test procedures have been developed in the highway or fertilizer industry regarding the evaluation of spreaders for application and spreading pattern. In addition, individuals in nine companies were interviewed by telephone on the use of test procedures to evaluate spreader capabilities.

The researchers learned that U.S. spreader manufacturers have no extensive testing of their equipment. Among the reasons given is that each state has difficult requirements concerning spreader equipment and there is generally no "off-the-shelf" spreader equipment. Researchers also learned that no two trucks will deliver an identical amount of material with the same control setting because of variations in hydraulic system performance.

A U.S. manufacturer of urethane spinners reported that the research and development for his product was done in Europe in 1980. To his knowledge, no spreader research and development is being conducted in the United States at this time. A hydraulics control vendor revealed that all the research and development for his spreader controls was done in Denmark.

The project survey indicated that the following elements affect the spread pattern:

- spinner speed;
- spinner fin design;
- truck speed;
- amount of material being discharged to the spinner;
- amount of moisture on the material; and
- gradation of the material, which affects density.

Spreader equipment can be classified into three basic types: slide-in or fixed hopper spreaders, tailgate spreaders, and liquid spreaders. The various design elements of each type are given in table 64. Spreader test variables for solid material and liquids are given in table 65.

In developing a testing protocol for evaluating spreader capabilities, the researchers assigned fixed values to some of the test variables, while other variables were measured and evaluated. A number of concepts were tested to evaluate the variables influencing material application rate and material distribution patterns.

First, the project team measured the application rates of some typical highway spreaders in a dynamic mode. Truck speeds of 15, 25, and 35 mph (24.1, 40.2, and 56.3 km/hr) were selected as typical speeds used during salt application. Since the trucks usually travel in third or fourth gear at these speeds, it was first necessary to determine the respective engine rpm during actual operation. Next, each vehicle was hoisted off the ground with the wheels raised to clear the floor surface. The amount of material dispensed from the feed mechanism over a measured time and for a specific control setting was collected and weighed at each engine rpm to establish the material application rate (i.e., mass/unit time).

It was found that the material application rate varied substantially, both from spreader to spreader and from that specified by the spreader control manufacturer. Also, a number of the spreader vehicles had faulty hydraulic systems, which prevented the controls from providing accurate or repeatable results from setting to setting.

A series of spreader tests was performed to develop the most efficient method for measuring the material distribution pattern. A Schmidt spreader mounted on a Unimog truck was used for tests conducted during cold weather at an inactive truck weigh station along I-35 near Duluth, Minnesota. Three different methods of collecting salt spread during the tests were evaluated: hand sweeping, collection pans, and vacuuming of pavement strips. Dry rock salt meeting ASTM D632 Grade 1 was used.

Three test series were conducted. The arrangement shown in figure 25 was used first. (Note that the vehicle wheeltracks are located between sampling locations 4 and 5 and locations 6 and 7.) The amount of material collected by two different types of collection pans (i.e., one plastic and one aluminum) was compared to the hand sweeping of the equivalent area of the pavement at sampling location 5 along line AB. Tests were conducted at actual vehicle speeds of 23, 32, and 40 km/hr (14, 20, and 25 mph) with three passes made at each speed. A hand-held radar unit was used to measure the truck speeds.

The material distribution patterns are shown in figure 26 for truck speeds of 23, 32, and 40 km/hr (14, 20, and 25 mph) as determined by hand sweeping. Figure 27 shows a comparison of hand sweeping and pan collection at sampling location 5 (i.e., the area directly beneath the spinner), the center of which is 5.3 m (17.3 ft) from the left edge of sampling location 1. As indicated by the hand sweeping data (figure 26), the amount of material applied by the spreader varies with both vehicle speed and sample location.

The second test series was performed with the same vehicle, but using hand sweeping, two different types of collection pans, and vacuuming of 15-m-by-0.4-m (50-ft-by-1.35-ft) strips of pavement, using an industrial vacuum cleaner (figure 28). Again, three passes were made during each test at vehicle speeds of 23 and 32 km/hr (14 and 25 mph). The data obtained by vacuuming were compared to those obtained by hand sweeping and pan collection at selected locations.

The material distribution pattern is shown in figure 29 for truck speeds of 23 and 40 km/hr (14 and 25 mph) as determined by vacuum sweeping. Although material loading does vary somewhat with transverse distance and vehicle speed, the vacuuming data show a relatively consistent distribution pattern from one speed to another. This indicates that the distributor control system may be operating in the "ground-oriented" manner intended by the manufacturer. Comparing the various collection techniques in the aforementioned tests (figures 30 to 32), suggests that hand sweeping and vacuuming are relatively comparable at the boundary of the distribution pattern where loadings are low, but are not comparable at higher loadings close to the spinner (i.e., center of pattern).

In the last set of experiments, material distribution data were obtained from an array of plastic collection pans and compared to equivalent vacuum sweeping data using the arrangement shown in figure 33. The same vehicle was driven at speeds of 23, 32, and 40 km/hr (14, 25, and 35 mph). Three passes were made at each speed.

Table 64. Design elements of spreaders used for snow and ice control.

- **I. Slide-in or fixed hopper**
  - A. Feed mechanism
    - 1. Chain drive
    - 2. Belt drive
  - B. Material disaggregation
    - 1. Special control mechanism
    - 2. No control
  - C. Application rate control
    - 1. Manual on-off control settings
    - 2. Nonground-oriented control
    - 3. Ground-oriented control
      - a. Open loop
      - b. Closed loop
  - D. Spinner distribution system
    - 1. Number of spinners
    - 2. Spinner position
      - a. Symmetrical
      - b. Asymmetrical
    - 3. Spinner design
      - a. Spinner height above pavement
      - b. Number of fins
      - c. Fin height
      - d. Fin configuration
        - (1) Straight
        - (2) Curved
    - 4. Spinner discharge speed control
  - E. Prewetting capability
    - 1. On load
    - 2. At or above spinner
  - F. Prewetting liquid flow rate
    - 1. Fixed
    - 2. Variable
- **II. Tail gate spreader**
  - A. Feed mechanism
    - 1. Auger
    - 2. Drum roller
  - B. Material disaggregation
    - 1. Special control mechanism
    - 2. No control
  - C. Application rate control
    - 1. Manual on-off control settings
    - 2. Nonground-oriented control
    - 3. Ground-oriented control
      - a. Open loop
      - b. Closed loop
  - D. Spinner distribution system
    - 1. Number of spinners
    - 2. Spinner position
      - a. Symmetrical
      - b. Asymmetrical
    - 3. Spinner design
      - a. Spinner height above pavement
      - b. Number of fins
      - c. Fin height
      - d. Fin configuration
        - (1) Straight
        - (2) Curved
    - 4. Spinner discharge speed control
  - E. Prewetting capability
    - 1. On load
    - 2. At or above spinner
  - F. Prewetting liquid flow rate
    - 1. Fixed
    - 2. Variable
- **III. Liquid spreader**
  - A. Feed mechanism
    - 1. Single pump
    - 2. Multiple pumps
  - B. Application rate control
    - 1. Manual on-off control settings
    - 2. Nonground-oriented control
    - 3. Ground-oriented control
      - a. Open loop
      - b. Closed loop
  - C. Spray distribution system
    - 1. Single nozzle system
    - 2. Header (spray bar) system
      - a. Number of nozzles
      - b. Nozzle spacing
      - c. Type of nozzle (spray)
        - (1) Fan
        - (2) Cone
        - (3) Drill
      - d. Spray distribution pattern
      - e. Droplet size distribution
  - D. Spinner distribution system
    - 1. Number of spinners
    - 2. Spinner design
      - a. Spinner height above pavement
      - b. Number of fins
      - c. Fin height
      - d. Fin configuration
        - (1) Straight
        - (2) Curved
    - 3. Spinner discharge speed control

Table 65 Spreader test variables.

Solid material spreaders	Liquid spreaders
Truck speed	Truck speed
Gradation of spreading material	Liquid viscosity
Density of spreading material	Liquid density
Application rate	Concentration of solution
Amount of moistening	Pump pressure
Spinner speed	Pump output
Road roughness	Spray distribution
Pavement type	Application rate
Pavement surface condition	Road roughness
Wind velocity and direction	Pavement type
Influence of traffic	Pavement surface condition
Safety considerations	Wind velocity and direction
	Influence of traffic
	Safety considerations

The material loading obtained from the collection pans during the last set of tests (figure 34) are substantially higher than those obtained by vacuuming for truck speeds of 23, 40, and 56 km/hr (14, 25, and 35 mph). In addition, no consistent relationship could be found between the collection-pan results and those results obtained by vacuuming. These findings indicate that additional work is needed to establish the most appropriate collection method to evaluate spreader patterns.

Following these tests, the project team learned that there are European protocols for testing spreader capabilities. Some European governments require spreader manufacturers to demonstrate compliance with the protocols before the equipment can be used in the country. An extensive visit was made to several Scandinavian and other European manufacturing and research facilities to obtain first-hand knowledge of these foreign protocols and to review various anti-icing studies. The British, Danish, and German protocols for testing spreader capabilities are presented in the next section.

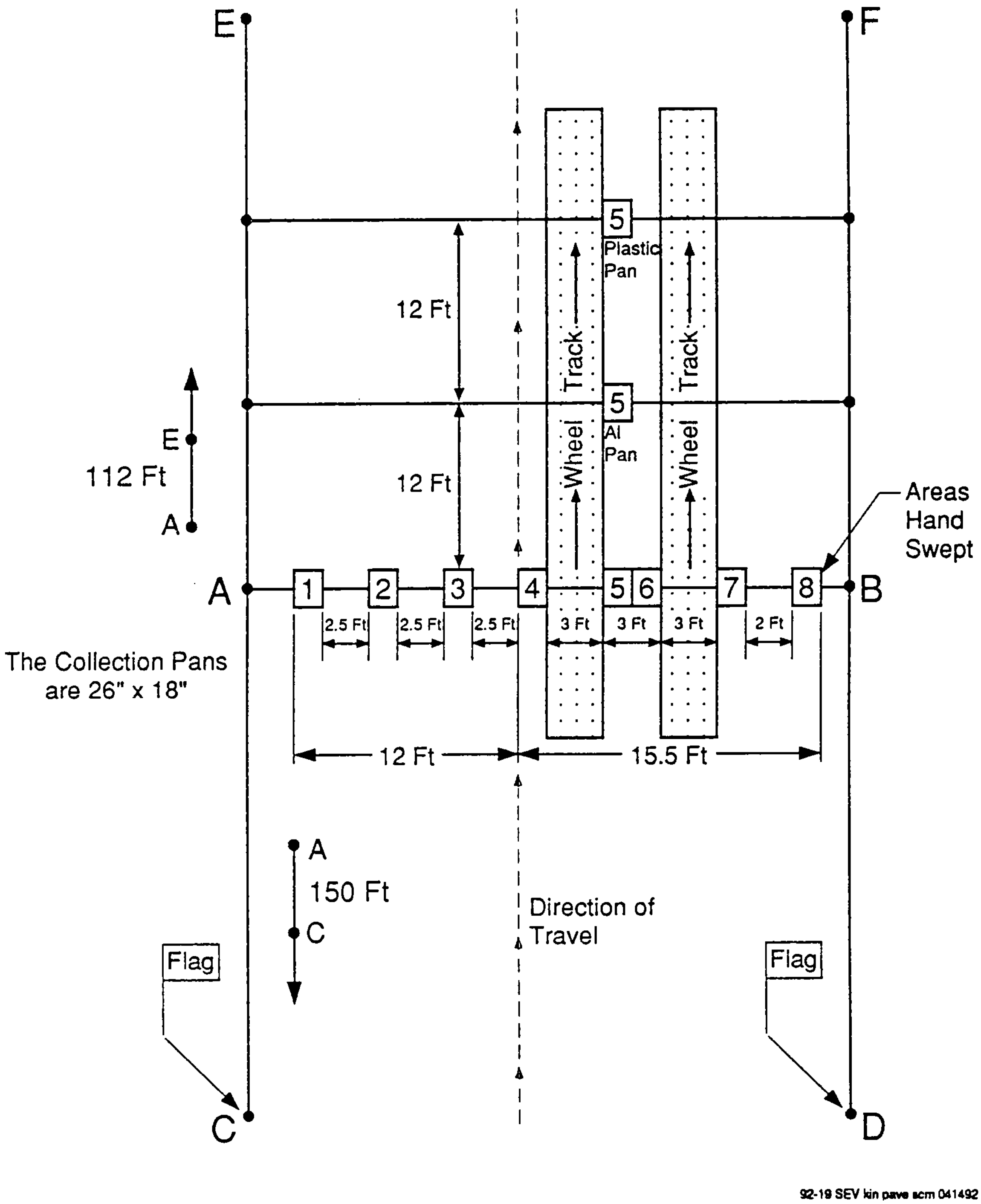


Figure 25. Arrangement for the first series of spreader tests.

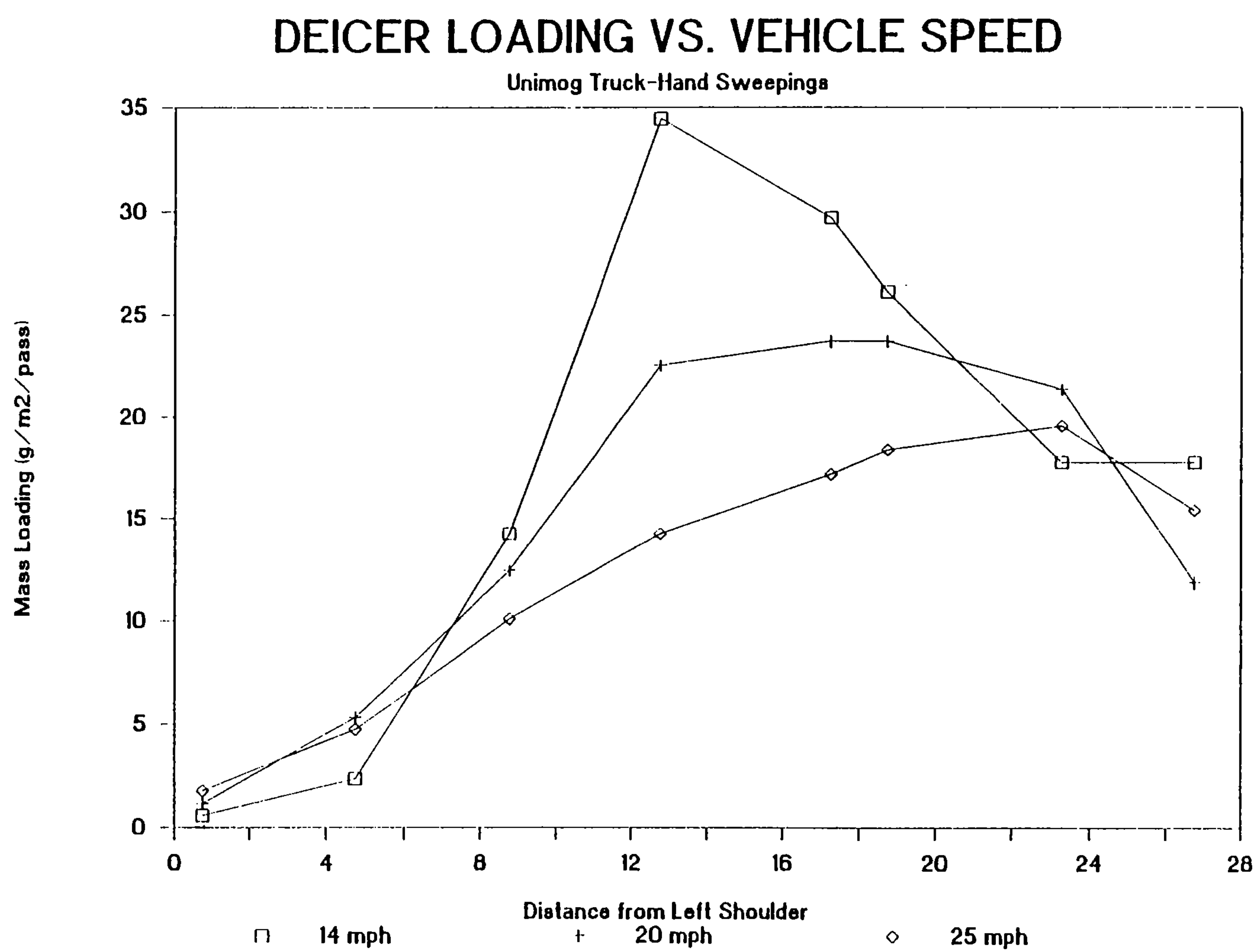


Figure 26. Salt distribution patterns determined by hand sweeping on 3/17/92.

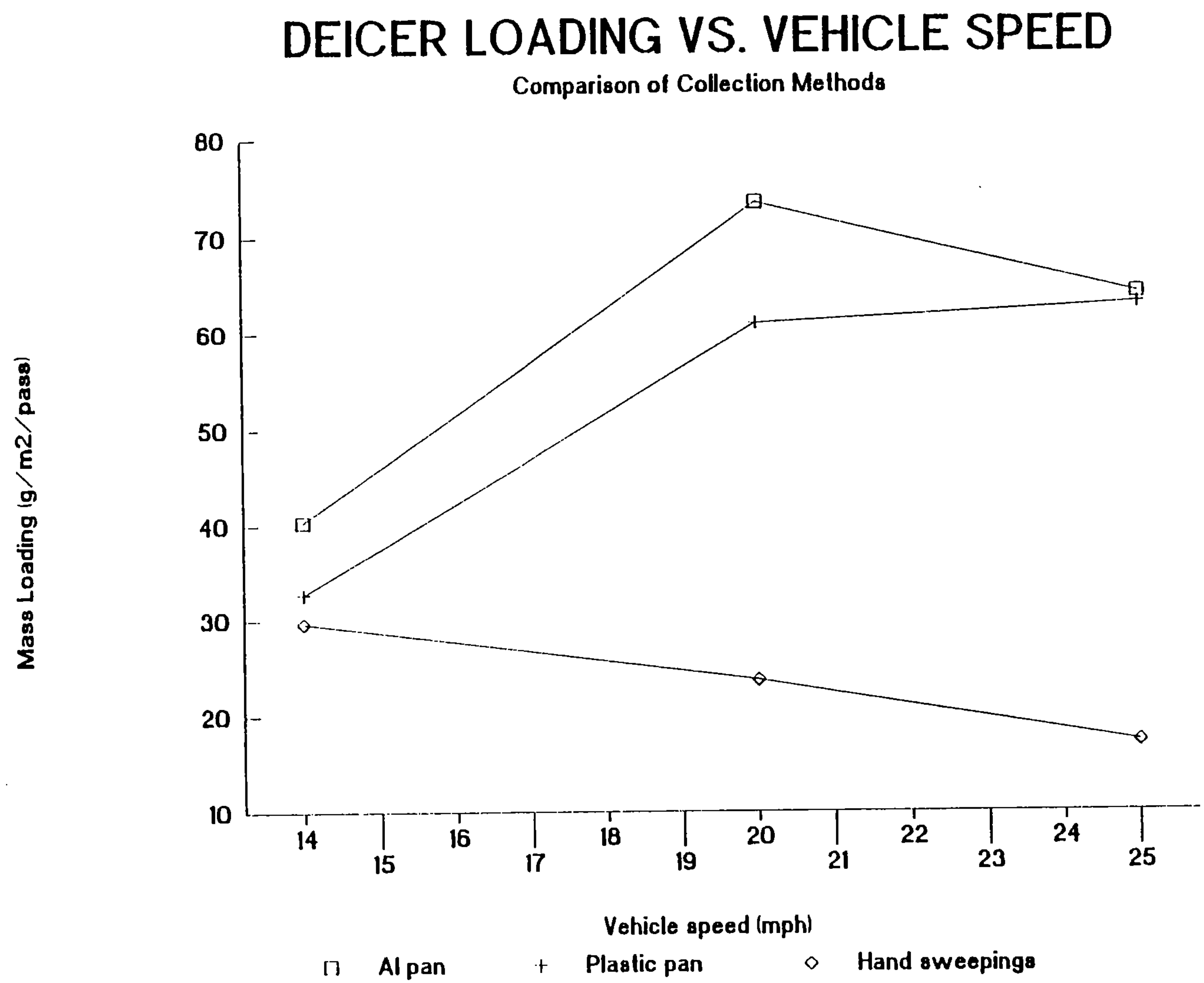


Figure 27. Deicer loadings determined by hand sweeping compared to those determined by collection pans (3/17/92).

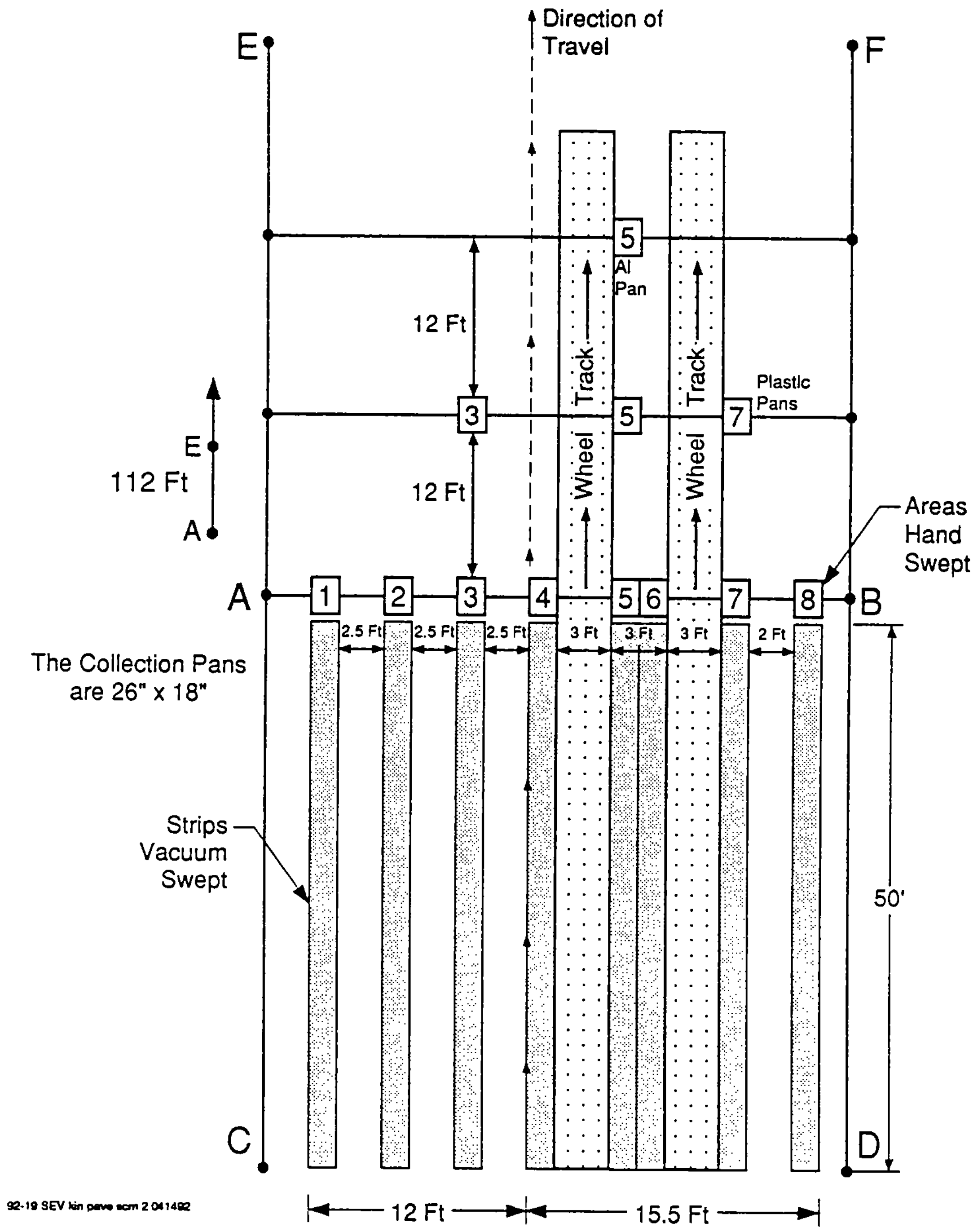


Figure 28. Arrangement for second series of spreader tests.

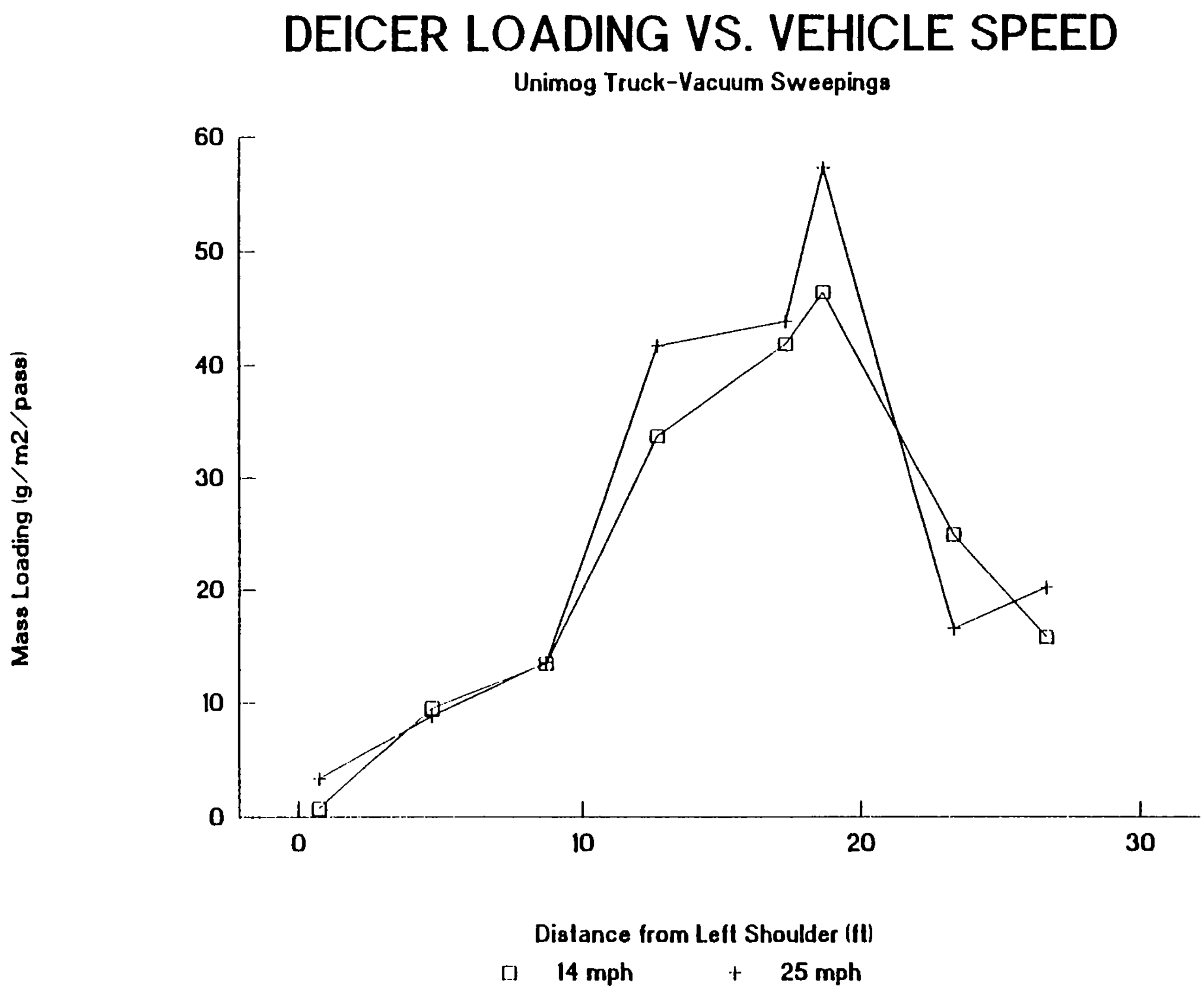


Figure 29. Deicer distribution pattern determined by vacuum sweeping on 3/18/92.

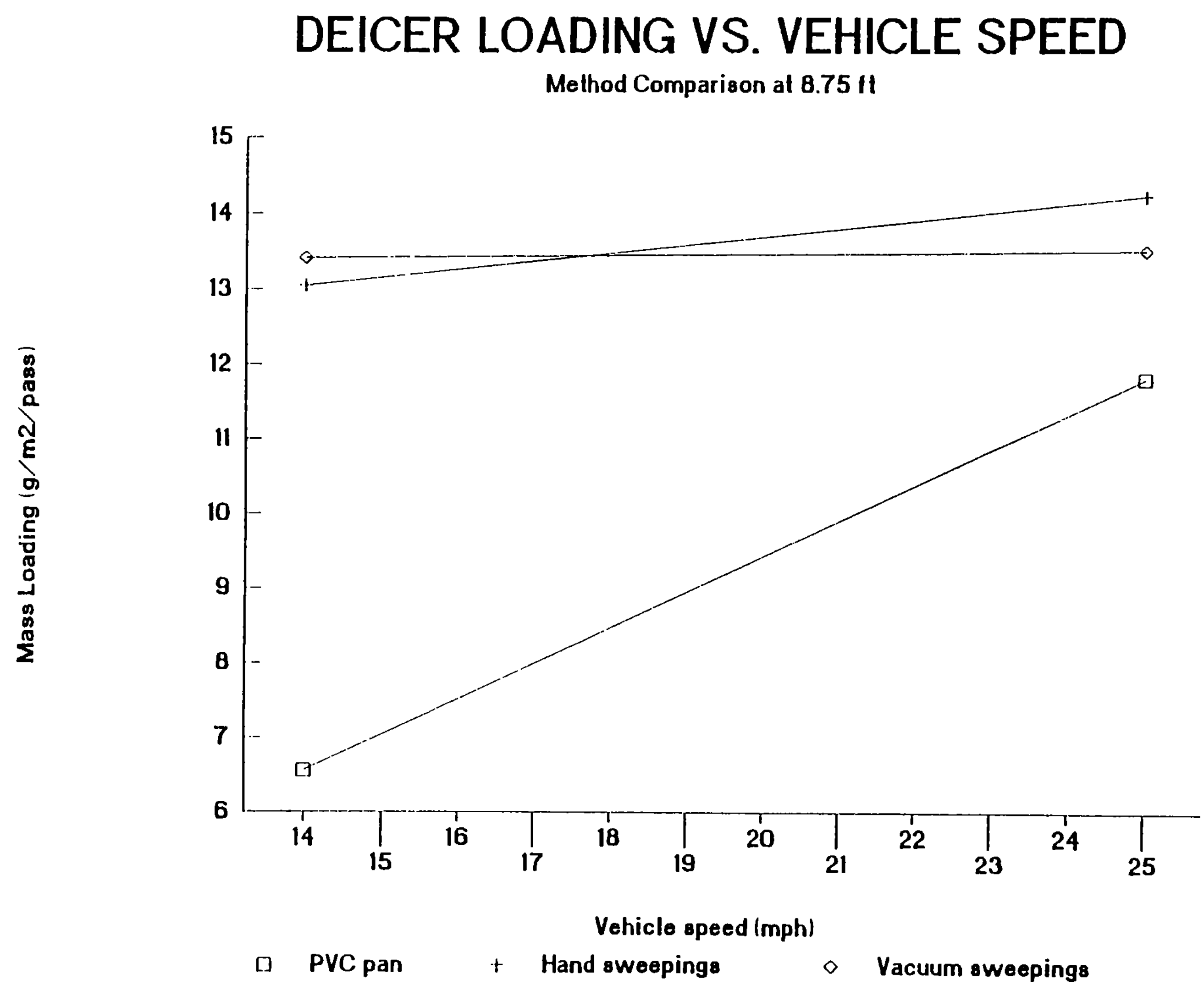


Figure 30. Comparison of deicer loadings for three different collection methods at sampling location 3 (3/18/92).

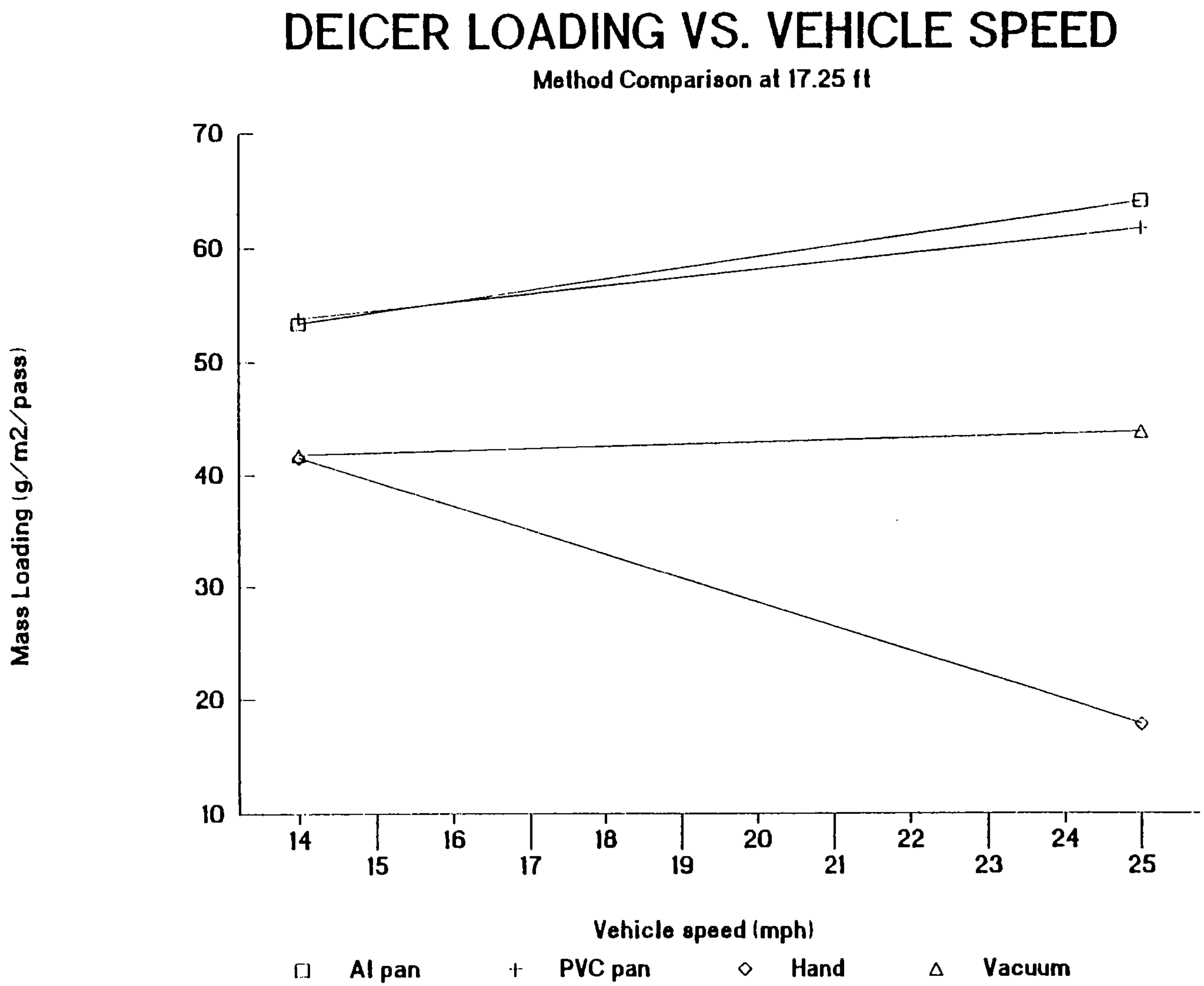


Figure 31. Comparison of deicer loadings for four different collection methods at sampling location 5 (3/18/92).

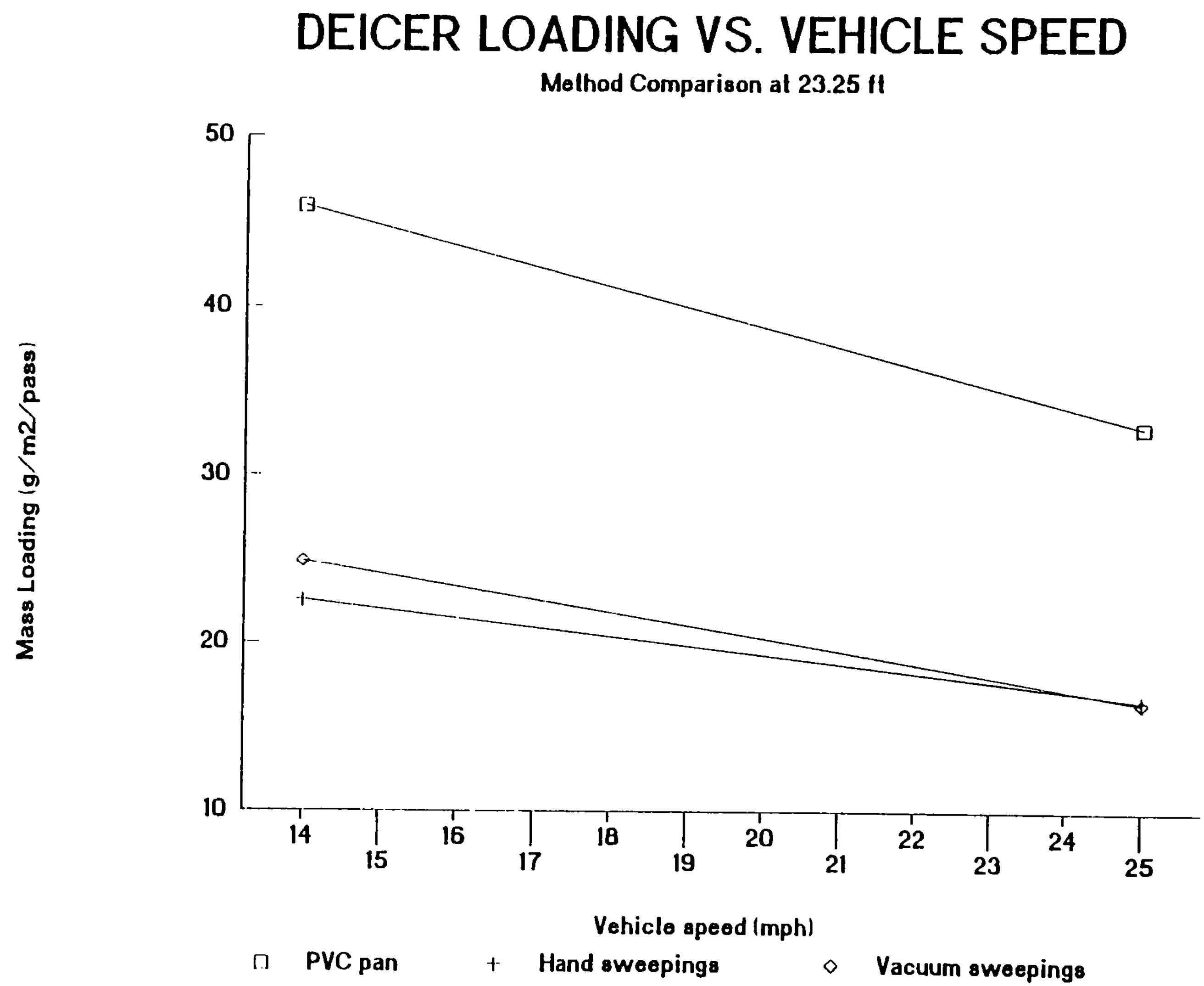


Figure 32. Comparison of deicer loadings for three different collection methods at sampling location 7 (3/18/92).

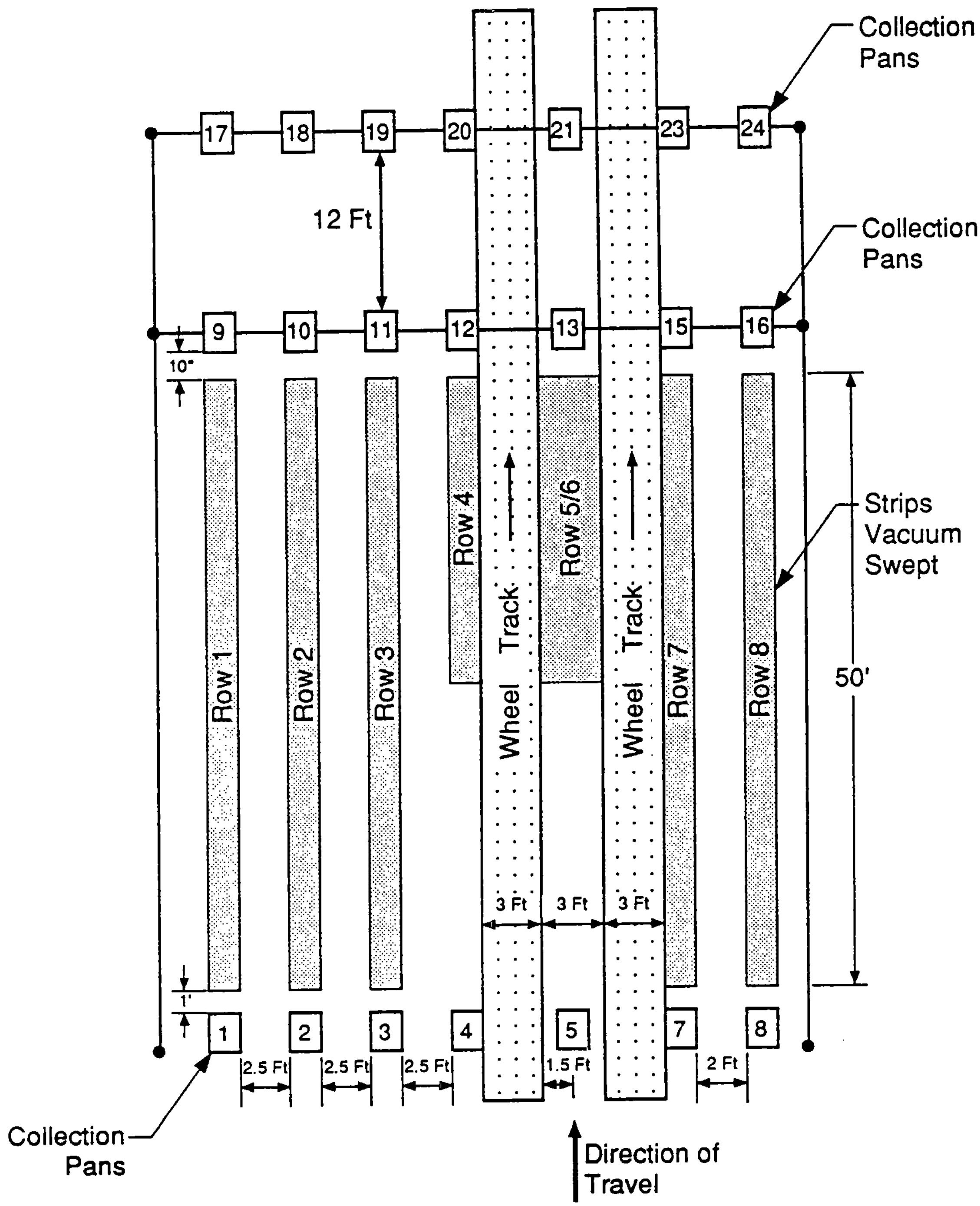


Figure 33. Arrangement for third series of spreader tests.

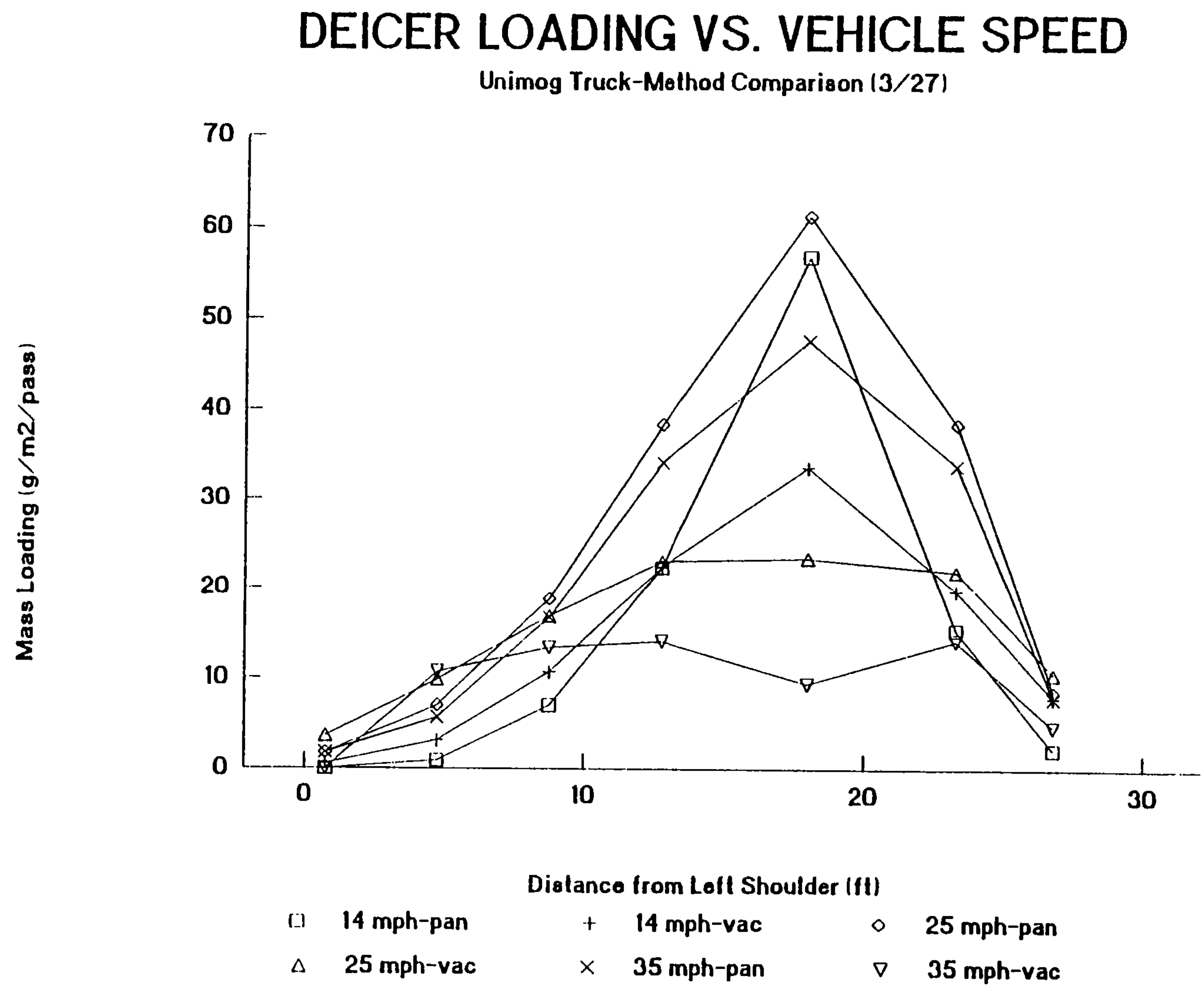


Figure 34. Comparison of deicer distribution patterns for two different collection methods (3/27/92).

European Protocols for Testing Spreader Capabilities

After determining that the U.S. highway spreader industry does not test its equipment's operating characteristics, numerous foreign sources were contacted by letter to obtain information on various types of anti-icing equipment and testing procedures. Because most research and development on spreader equipment has been conducted in Europe, follow-up interviews were held with a number of users and manufacturers in several countries.

In discussion with these manufacturers, it was noted that Europeans there are concerned about the contamination of groundwater supplies by winter salting practices. Consequently, Europeans emphasize the development and use of spreader equipment that dispenses small amounts of salt during snow and ice operations. As a result, a number of European governments require spreader equipment manufacturers to demonstrate that their equipment controls and monitors the application rate and spread pattern before the equipment can be commercially marketed.

The Federal Republic of Germany has prepared technical specifications and standards for winter spreader equipment used by its Road Maintenance and Traffic Department.[27] These standards address such factors as technical data for equipment position, equipment height, spreader attachments, safety protection, and spread-material output. Within the spread-material output standard, requirements and testing procedures are detailed for dosage rate, spread pattern, and speed. The German test protocol pertains specifically to the spread of dry material (salt and abrasives).

A version of the test protocol for prewetted salt is available currently only in draft form. However, German equipment manufacturers evaluate their equipment by testing the spread pattern for prewetted salt in a stationary position. The wetted salt is spread from a stationary position for 2 min, with the control setting at 40 g/m^2 (520 lb/lane-mile) and a spreading width of 6 m (19.7 ft). Then, the wetted salt is shoveled longitudinally into a row that is transverse to the center line of the spreader. This row is subdivided into 1-m (3.3-ft) lengths originating from the spinner location. Each subdivision of wetted salt is then collected and weighed.

The German spread pattern test for dry salt is conducted at a speed of 20 km/hr (12.4 mph) with control settings of a 4-m (13.1-ft)spread width and a coverage of 20 g/m^2 (260 lb/lane-mile). With the hopper loaded to approximately half capacity, it is driven over a marked grid system (see figure 35) spreading dry salt.

The total mass of material collected on any one transverse strip should not differ from the mean mass collected on the three strips by more than 30%. The total mass of material collected on either overspread strip (U_l, U_r) should not exceed 5% of the total mass collected. The mass of material collected on either sidestrip (R_l, R_r) should not be less than 5% of the total mass collected. The allowed deviation of the computed spread density (SD) for the inner lengthwise strips between the side strips from the average SD of all the rectangles in the grid system should not be less than 90% nor greater than 50%.

The German requirements for dosage exactness are related to the percent deviation SD between the measured and control setting value for SD. This deviation SD must be within 6%. The dosage rate of the spread material should be regulated so that the selected SD remains constant when the vehicle is operated at speeds that range between 10 and 40 km/hr (6.2 and 24.8 mph). The SD also cannot change with adjustments of the spread width between 3 and 8 m (9.8 and 26.2 ft).

The British have a standard specification and testing protocol with which all spreaders used for winter maintenance in England must comply.[28] Within the standard specification, there are five classifications for spreaders. The spreader classification depends upon the type of roadway on which the spreader is used for winter maintenance. The first two classifications (A1 and A2) are for spreaders used on highways. Class A1 spreaders have a ground-oriented control and are capable of a symmetrical and asymmetrical spread width of 11 m (36.1 ft) at speeds between 0 and 70 km/hr (0 and 43.4 mph). In contrast, the Class A2 spreaders have a ground-oriented control and are capable of a symmetrical and asymmetrical spread width of 11 m (36 ft) at speeds between 8 and 70 km/hr (5.0 and 43.4 mph).

Both spreader classes are required to have salt application rates between 5 and 40 g/m^2 (65 and 520 lb/lane-mile) in increments not exceeding 5 g/m^2 (65 lb/lane-mile). The spread width must be adjustable between 3 and 11 m (9.8 and 36.1 ft) in increments not exceeding 1 m (3.3 ft). It is necessary to make this adjustment while the vehicle is in motion. Another requirement is that the axis of the main spread pattern must be adjustable between the symmetrical and the extreme asymmetrical position in steps not exceeding 1 m (3.3 ft). When the truck is fully loaded, the height of the spinner discharge must be between 300 and 350 mm (1 and 1.17 ft) above the road surface. Other elements covered in the British protocol include general requirements, spread pattern, static discharge performance test, and travel discharge performance test.

The British spread pattern testing is conducted at two speeds: 20 km/hr (12.4 mph) and 40 km/hr (24.8 mph) for nearly empty-load and full-load runs, respectively. The total mass of salt collected from the grid system (see figure 36) at the test site for each run should not differ by more than 10%. The total mass of salt collected on any one transverse strip after a run should not differ from the mean mass collected on three strips by more than 20%. In addition, the total mass of salt collected on any one sample rectangle in the main spread zone after a run should be between 50% and 200% of the mean mass collected on all the sets of sample rectangles in the main spread zone for the nearly empty-load and full-load runs at the same speed.

The mean mass of salt collected on either margin after a run should not be less than 25% of the mean mass collected on all the sets of sample rectangles on the main spread zone for the nearly empty-load and full-load runs at the same speed. Also, the total mass of salt collected on either the nearly empty-load and full-load runs at a given speed must not exceed 0.5% of the total mass collected on both those runs. When tested by either the static discharge or road discharge performance, the calculated rate of discharge should be within 2 g/m^2

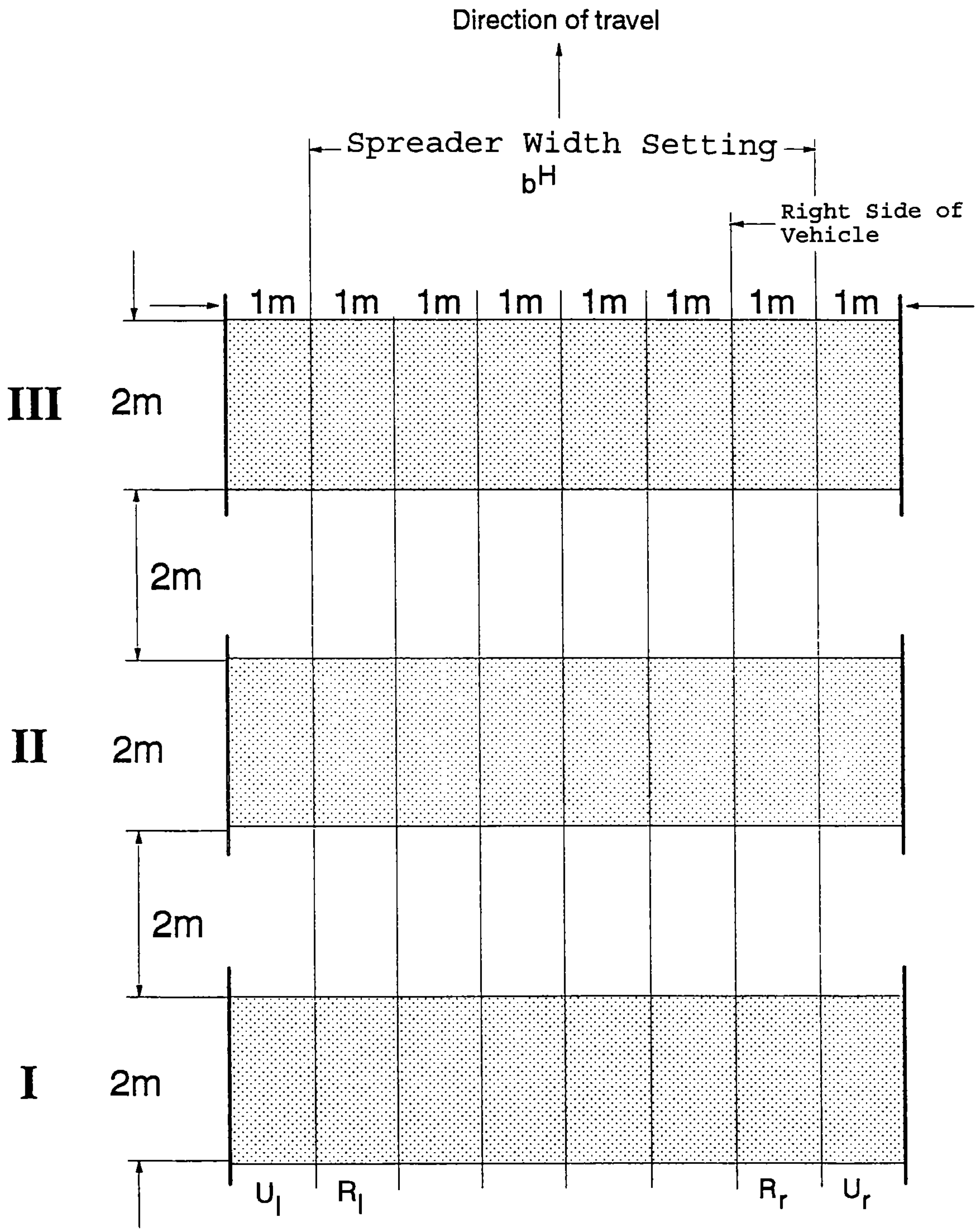


Figure 35. German spread pattern used in spreader tests.

(26 lb/lane-mile) of the nominal rate of discharge set. The nominal control setting is 10 g/m^2 (130 lb/lane-mile), the spreading width is 6 m (19.9 ft), and the speed is 48 km/hr (29.8 mph).

The Danish and Finnish road administrations have developed testing protocols to provide information for purchasing decisions and to help develop recommendations for spreader improvements. The Danish Agricultural Test Centre in Bygholm has developed and tested a new collection method for wetted salt. Earlier spread pattern test procedures consisted of collecting spread dry salt in trays with grates, which were unsuitable for wetted salt. As a result, a "wet vacuuming" procedure is used to collect the spread salt. This process also enables the test to be conducted on an asphalt surface, which is desirable, since most European pavement surfaces are asphalt.

The Danish tests consist of stationary dosage tests which examine the accuracy of the application rates with different spreader control settings while traveling at an equivalent speed of 50 km/hr (31 mph). The application rate tests were conducted with the following variables: rock salt or vacuum salt, with and without wetting, and using 6-m (9.7-ft) and 10-m (32.8-ft) spreading widths, for a total of eight combinations. Each of these combinations was conducted with salt application rates of 5, 10, 15, 20, and 30 g/m^2 (65, 130, 195, 260, and 390 lb/lane-mile). A total of 40 tests was conducted for each piece of equipment.

The spreader pattern tests were conducted on a test area with a grid pattern, which was 5 m (16.4 ft) long and had 10 1-m (3.3-ft) wide sections. In addition, there was a marginal zone on each side of the grid pattern in which the amount of salt that fell outside the range of measurement was collected.

The spreading pattern tests were conducted with the following variables: rock salt or vacuum salt, and with and without wetting, creating four combinations. Each of these combinations was carried out with a spreading width of 6 m (19.7 ft), dosage of 10 g/m^2 (130 lb/lane-mile), and a speed of 50 km/hr (31 mph) as the basic control settings. Additional spreading tests were conducted with control settings of a 10-m (32.8-ft) spreader width and 20 g/m^2 (260 lb/lane-mile) dosage. Furthermore, tests were carried out in which the speeds were changed to 30 km/hr (18.6 mph) for dry salt and to 70 km/hr (43.4 mph) for moistened salt.

The Finnish National Road Administration did not provide their testing protocols, but did provide their test results. The disc spreaders were tested in arranged test conditions so that the spread salt and sand quantities were measured at both manual and automatic control and at different driving speeds. The function of width adjustment and the spreading pattern was examined visually. The testing was conducted in a stationary position with the running speed of the truck's engine at 1,400 rpm. The following items were calculated: the standard deviation of salt amounts (g/m^2) measured at the same speed and hydraulic adjustments, and the standard deviation of salt amounts measured at the same hydraulic adjustment, but at altering speeds.

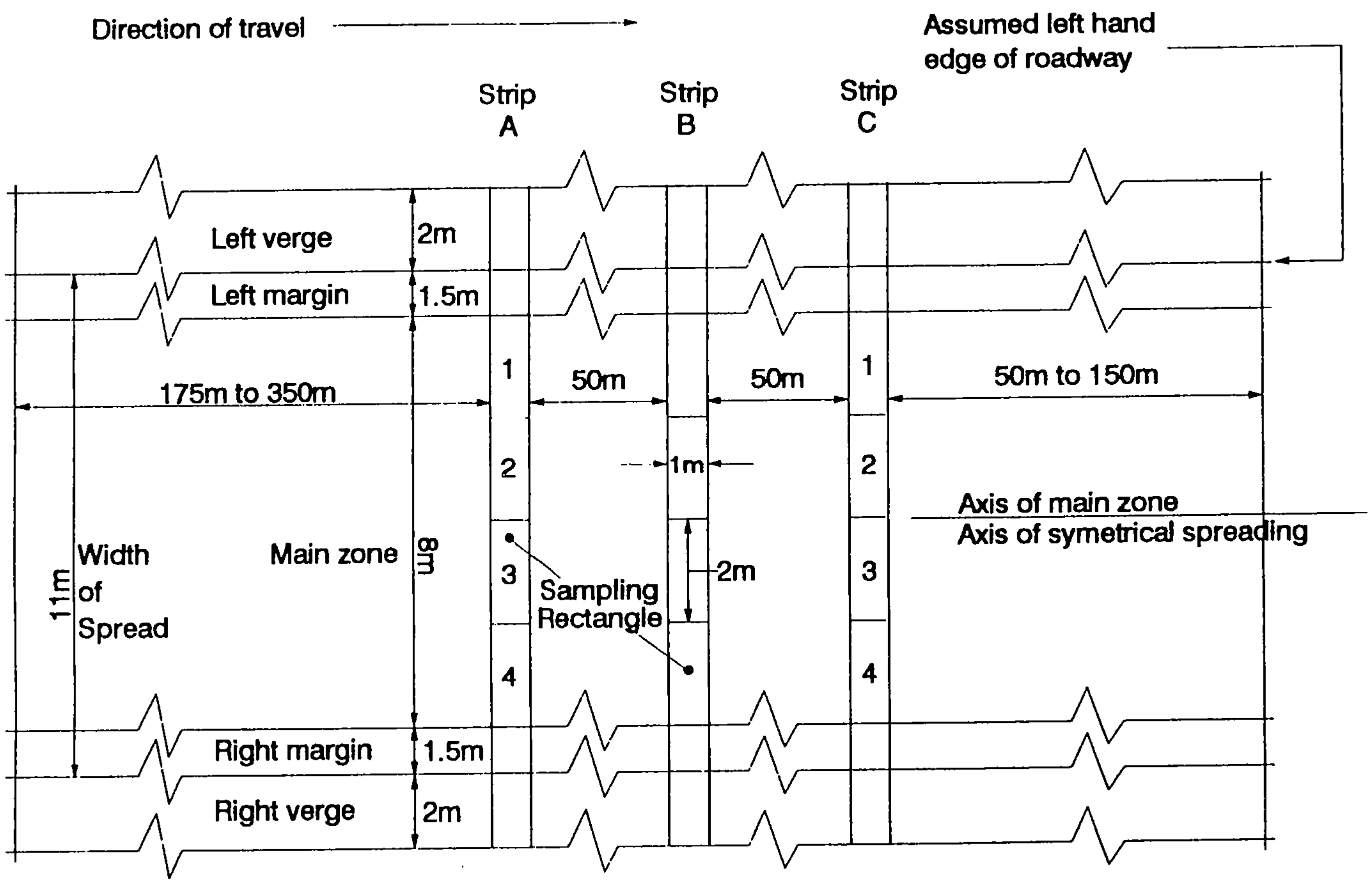


Figure 36. British spread pattern used in spreader tests.

3

Interpretation, Appraisal, and Application of Findings

Usefulness of Data from Anti-Icing Experiments

The quality and completeness of the data reported during the second winter of testing improved considerably over data from the first winter. There are three probable reasons. First, the maintenance personnel (and researchers) climbed a learning curve. The states started slowly during the first winter because of problems in getting necessary equipment and procedures in place for the experiments. Also, data were recorded for many more storm events during the second winter (110) than during the first (57). This increased number of storm events gave the maintenance forces the opportunity to attempt more anti-icing operations and to correct problems that arose.

Second, the refresher training given the maintenance personnel before the second winter's testing gave them additional support and encouragement. This training reviewed of the anti-icing testing procedures and reporting requirements as well as the findings from the first winter's testing. Problems with the first winter's field data were discussed in detail along with any particular requirements or changes the maintenance personnel wanted for the second winter's testing procedures. Changes were made in some states regarding test/control section boundary limits, application mixtures, and type of chemical used. The open discussions allowed the different levels of maintenance personnel to explain their positions on various issues and procedures and to agree on differences of opinion. The refresher training also renewed the commitment of maintenance personnel to the anti-icing operations.

The third reason for improvement was an enhanced awareness of the potential benefits of anti-icing operations on the part of maintenance management, line supervisors, and truck operators. The major installation of atmospheric, pavement, and traffic sensors on the test and control sections used on New York SR 104 in Monroe County was one example of a state's enhanced awareness. Frequent and detailed automated and manual observations, including photographic documentation of the pavement conditions, were made by New York Department of Transportation (NYDOT) field maintenance personnel throughout the storm events. These activities were proof of NYDOT's commitment to identify the benefits of anti-icing technology and sensible deicing (use of reduced amounts of deicer and abrasive materials under deicing conditions) in that region.

Another example of a state's enhanced awareness was found in Nevada. The savings achieved in chemical and abrasive use during the 1991-92 winter for the test section on US 395 in Nevada (as compared to the control section) showed the benefits of using a liquid chemical in that climatic region. The success of anti-icing and sensible deicing operations using a liquid chemical during the first winter's testing encouraged Nevada Department of Transportation (NDOT) to purchase a spreader specifically designed for dispensing liquid chemicals. The enhanced interest in observing test and control pavement conditions throughout storm events prompted NDOT to install a time-lapse video camera at the beginning of the second winter at the Road Weather Information Systems (RWIS) location on US 395. The success of the photographic coverage during the 1992-93 winter prompted NDOT to consider installing time-lapse video cameras at other locations in Nevada to monitor pavement conditions throughout the wintertime.

NYDOT and NDOT's interest in monitoring pavement conditions during storm events through photographic means is an important step in initiating more timely and appropriate winter maintenance operations. This method of monitoring pavement conditions during storm events replicates that already under way in Canada and in Scandinavian countries, especially some of the roadmaster districts in Finland.

The data received from the cooperating state highway agencies (SHAs) were also useful in describing the events that took place during the storms. Analysis of the field data provided, for each test and control section, a chronological history of the meteorological events, pavement conditions, and maintenance activities associated with each storm, including the amount of material applied to each traveled lane. The history included pavement temperature, road conditions, Coralba friction value, and SOBO-20 readings, along with the equivalent surface concentration of any chemical found. Graphs showed the weather, pavement conditions, air temperature, and pavement temperature each as a function of time for both the test and control sections. These graphical reconstructions of the storm events are extremely important. They clearly show the importance of closely monitoring pavement surface temperature, rather than only air temperature, in deciding when to apply the first and subsequent chemical treatments when precipitation is present or predicted. The plots also showed how the pavement condition responded to a combination of traffic and the frequency and amount of deicing chemicals and abrasives applied by maintenance forces. The utility of Coralba and SOBO-20 measurements in deciding when to apply or reapply chemicals is discussed in the next section.

A RWIS can provide maintenance supervisors with valuable information concerning the condition of the road and the "best" time to mobilize maintenance forces and start snow-and ice-control operations. It can also indicate when repeated material applications are needed, especially if the RWIS is capable of measuring the refreeze temperature of a brine solution on the pavement. RWIS information can also monitor road conditions when new chemicals are tried in an operational setting.

It was not always clear from much of the storm data what factor triggered the first treatment applied to the test or control section. Many of the first test section treatments were made as deicing operations rather than as anti-icing. This means the decision-making process in snow- and ice-control operations using RWIS information was not fully established and implemented.

The anti-icing experimental data were used also for various summaries of value to maintenance management, including

- a summary of the total material (chemicals and abrasives) applied to the test and control sections during the storm events;

- a summary of each storm event providing an overview of the event, the test and control section pavement conditions at the time of the first winter maintenance treatment, and a brief history of both the test and control section pavement conditions during the storm; and

- a tabulation of the maintenance activities on the test and control sections and the savings achieved on the test sections (in terms of amount of chemicals and abrasives used and passes made) during each storm.

In summary, the data obtained by the participating SHAs during the study were extremely useful in evaluating the effectiveness of anti-icing treatments. The data are adequate in both coverage and detail for SHAs to use in evaluating the effectiveness of maintenance operations during most winter storm events.

Utility of Coralba and SOBO-20 Measurements

The Coralba friction tester and the SOBO-20 units were furnished to the participating SHAs to assist maintenance personnel in determining the appropriate timing and amount of material application. The Coralba measures the friction levels of a road surface. The SOBO-20 unit measures residual deicing chemicals on pavement surfaces during winter maintenance operations. Several states provided data from both units.

Coralba Friction Tester

Five states made Coralba friction measurements during 27 storm events in the 1991-92 winter; six states did so during 62 events in the 1992-93 winter.

In theory, a friction measurement can help define the point in the development of the storm when frozen precipitation starts to bond to the pavement surface. However, the Coralba measurements did not appear to be used to time the material application, or were not reliable enough to assist in determining when bonding occurred. The data suggest that a majority of the friction measurements were made as part of the storm documentation and not for deciding when to reapply chemicals or abrasives. Two states had limited success in using the Coralba measurements to determine application timing.

Several states experienced operational problems with their units during both winters. Problems appeared to be associated either with the incorrect use of the units or with the cabling connections. Some improvement was noted in the repeatability of measurements recorded by several states during the second winter as a result of the refresher training. This indicates there is a learning curve associated with the use of the Coralba friction tester.

SOBO-20 Salinity Tester

Four states made SOBO-20 salinity measurements during 24 storm events during the 1991-92 winter; five states did so during 17 events during the 1992-93 winter.

During several storms, some states made salinity measurements before the first (anti-icing) application. Most of the time these pretreatment measurements indicated no chemical; however, in a few storms, pretreatment measurements indicated there was a low salinity level, possibly a carry-over from previous storm treatments. In some cases a low salinity measurement was followed by a treatment; in others, by no treatment. Similar mixed responses were noted after high salinity measurements were recorded. Thus, it appears that the SOBO-20 measurements were not used consistently to make decisions concerning reapplication treatments.

It was not clear if any of the states attempted to convert the SOBO-20 readings to application rates, even though conversion charts were supplied. This indicates, again, that the readings appeared to be taken to satisfy documentation requirements, rather than to assist in deciding the appropriate application.

New York made a special effort to utilize the SOBO-20 by developing unique procedures and a special form to record the measurements, along with other data. New York did attempt to use the SOBO-20 for application decisions as much as possible, especially during the first winter. Unfortunately, their SOBO-20 unit was inoperable for most of the second winter (29 out of 36 storms); therefore they did not have the opportunity to benefit from its use.

Several other states also experienced operational problems with their units during the testing. A majority of these problems were undocumented. Two states that recorded data for the 1992-93 winter did not record any SOBO-20 data for the 1991-92 winter. The lack of the first winter's experience was reflected in the in data.

One concern noted by several states was a reluctance to use the SOBO-20 on a regular basis because of safety hazards. Measurements must be taken on the road, exposing maintenance personnel to traffic during inclement weather. However, the greatest utility of the instrument is for determining residual salt concentration, and measurements to provide this information can be made during good weather.

In summary, the Coralba and SOBO-20 units, when used properly, can provide maintenance personnel with timely information needed for treatment application decisions. The Coralba appears to be more useful in winter maintenance operations than the SOBO-20. The latter is more appropriate for research and is not practical for high-volume, high-speed facilities.

Preliminary Manual of Practice for an Anti-Icing Treatment Program

The findings of the study serve as the basis for providing initial guidance to a state or local highway agency interested in implementing an anti-icing treatment program. While many agencies are aware of, and interested in, anti-icing strategies, anti-icing techniques have not been widely implemented because of the lack of information and the lack of documented performance. This research has shown that anti-icing is cost-effective for highway agencies. The field data collected are not sufficiently detailed to identify completely all the key geographic, climatic, site, traffic, pavement surface, and chemical variables that influence the successful use of anti-icing methods. However, the limited field results do offer initial insight into the conditions where anti-icing can be used effectively.

This section contains preliminary manual of practice for an anti-icing program. The elements of the manual, or guideline, include items that highway agency maintenance forces need to know for undertaking an anti-icing program:

- definitions of anti-icing and deicing operations;
- basic meteorology;
- characteristics of snow-and ice-control chemicals;
- RWIS components and functions;
- pavement temperature forecasts, their use and implications;
- decision-making process in anti-icing operations using RWIS information;

- anti-icing strategies;
- supplemental measurements of pavement surface conditions;
- role of supervisory personnel in the programs;
- role of operators in the program; and
- documentation and review of anti-icing operations and results.

Definitions of Anti-Icing and Deicing Operations

Anti-icing is the application of a chemical freezing-point depressant on a pavement surface before a bond is established between frozen precipitation and the pavement. Deicing is the application of a chemical freezing-point depressant to an accumulation of snow or ice that is bonded to the pavement in order to break the bond. In practice, the exact point at which frozen precipitation bonds to the roadway surface is difficult to establish. A friction measurement, like a Coralba reading, can help establish that point in the development of the storm. General criteria for classifying the first maintenance treatment in a storm are given in section 2 (table 15) of this report.

Basic Meteorology

Maintenance personnel can benefit from a brief introduction to basic meteorology. This introduction should cover such items as

- atmospheric heat energy balance;
- general circulation around high- and low-pressure systems;
- generalized precipitation patterns around a storm system;
- typical winter weather pattern for the geographic area of interest;
- winter precipitation types;
- weather forecasts from the National Weather Service (NWS) and private weather forecasting services;
- radar and satellite weather images; and
- pavement surface temperature versus air temperature.

Characteristics of Snow and Ice Control Chemicals

It became evident during the training of the winter maintenance personnel for the anti-icing experiments that there was a general thirst for more knowledge concerning the characteristics of snow- and ice-control chemicals. The maintenance forces also wanted to know more about the effectiveness of chemical alternatives to salt. Much of this information was included in the training manuals. Other highway agency maintenance personnel could also benefit from a brief introduction to the subject. This introduction should cover such items as

- salt used in winter maintenance operations;
- chemical properties of salt;
- physical properties of salt;
- salt as an ice melter;
- melting capacity;
- melting rate;
- salt efficiency;
- disbonding efficiency;
- forms of salt used in anti-icing and deicing operations;
- chemical alternatives to salt; and
- procedures for evaluating the characteristics of alternative anti-icing and deicing chemicals (see Report SHRP-H-332, "Handbook of Test Methods for Evaluating Chemical Deicers").

RWIS Components and Functions

Maintenance forces involved with an anti-icing program need to know that the RWIS is an extremely important technology. It can provide necessary information on key road and atmospheric conditions for deciding the appropriate treatment. RWIS consists of pavement and atmospheric sensors and associated communication equipment that gather and disseminate information from the road environment, including forecasts of road and weather conditions. The system can also include thermal mapping (the development of thermal profiles of the roadway) and professional weather advice. Each of these items is briefly discussed below. A fuller discussion of RWIS and a guide to its implementation and use is provided in two SHRP reports: SHRP-H-350, *Road Weather Information Systems - Volume 1: Research Report*[29] and SHRP-H-351, *Road Weather Information Systems - Volume 2: Implementation Guide.*[30]

RWIS Hardware

The most visible components of RWIS are usually the roadside installations of system components. A single site, which may have many sensors, is usually referred to as a remote processing unit (RPU) station. The RPU station typically consists of atmospheric sensors mounted on an instrument tower; sensors embedded in the pavement surface and beneath the surface; and an enclosure housing data processing electronics and communications equipment. From a system perspective, the RPU station is usually considered one component of the system.

Data from sensors are formatted at the RPU for transmission to a central processing unit (CPU) where they may be stored, retransmitted to other workstations or locations, or accessed directly. The CPU can be a separate computer or a workstation.

The next component is the data processing and display system used by the maintenance personnel. The actual system configuration depends on the management structure of the maintenance organization. This component can be a computer workstation in a maintenance facility or at a district or area headquarters. It can also be a portable computer that a foreman or supervisor takes home.

Whoever makes the decisions for allocating resources for snow and ice control should have access to the latest information. If decisions are made from a central office, one workstation collocated with the CPU may suffice. If decision making is decentralized, workstations or portable computers should be available for the local decision makers to access data.

RWIS Sensors

Sensors provide information from the road environment for detecting and monitoring local conditions, to be input into forecasting models. Forecasts of weather and road conditions are important for timely and efficient resource allocation decisions.

Atmospheric sensors provide data for weather forecasts and for detecting and monitoring atmospheric conditions. Pavement sensors provide information on road conditions. Pavement temperature is particularly important for making snow- and ice-control decisions. The pavement temperature is affected by solar radiation during the day, cooling at night, and by heat flow to or away from the surface, depending on the subsurface temperature.

Key parameters for forecasting pavement temperature include the current pavement and subsurface temperatures and forecasts of cloud cover, precipitation, and wind speed.

The following sections briefly describe the sensors used to acquire data and the potential uses of the data. When acquiring these sensors, care should always be taken to ensure that they are able to perform in the road environment under adverse weather conditions.

Atmospheric Sensors

Air temperature is a parameter frequently associated with atmospheric measurements. It is probably the most frequently sensed and used parameter. For years, snow- and ice-control supervisors have used air temperature to make decisions. Some mount sensors on vehicles, or thermometers on bridges and sign posts. Although pavement temperature is correlated with air temperature, the pavement temperature is a better parameter to use when making decisions.

Air temperature is measured by electronic thermometers which are shielded from solar radiation. Data are usually provided in Fahrenheit values, but can easily be reported in Celsius through software changes. The air temperature is important for monitoring existing conditions and as an input to forecasts. Air temperature should be considered mandatory RWIS data.

Wind direction and speed are also important parameters for forecasting atmospheric and pavement conditions, and for understanding what is happening (or what may happen) in the highway environment with respect to blowing snow, drifting, and accumulation of snow.

Wind direction and speed are usually measured by mechanical anemometers. A propeller or cup assembly turns at a rate proportional to wind speed. A collocated device also determines the wind direction by pointing in the direction the wind is blowing. Wind direction and speed should be considered mandatory parameters.

Dew-point temperature is the temperature at which the air would be saturated with water vapor (100% relative humidity) if cooled. It is important in forecasting visibility and precipitation. In combination with pavement temperature, it provides important information about frost or ice formation on the road surface.

The dew-point temperature is measured using electronic hygrometers. Many variations exist in hygrometer construction. Those used in a "standard" RWIS have demonstrated their durability and their ability to provide data in the road environment. The dew-point temperature is also an essential parameter..

Relative humidity is another measure of the amount of water vapor in the atmosphere. It is an expression of the actual amount of water vapor in the air compared to the amount saturated air would hold. It is a slightly more common term and is therefore better understood than dew-point temperature. The dew-point temperature is more easily related to frost when using pavement temperature. Relative humidity is useful, but not essential if the dew-point temperature is available.

Precipitation is critical information for snow and ice control. Information related to precipitation, however, comes in many forms. Each is described briefly below, along with a relative assessment of the importance of the information.

- The occurrence of precipitation is measured by either an optical or mechanical device. This is the easiest and most common measurement, essential for snow- and ice-control decisions.

- The type of precipitation is among the most difficult parameters to determine robotically. Until recently, it required human observation to distinguish between rain and snow. Precipitation type is essential, but maybe location dependent, because of the expense of the instrument.

- The rate of precipitation has usually been measured mechanically. New technologies enable optical measurements; forthcoming radar technology will provide precipitation rate data, at least for rain initially, with snow soon to follow. The rate of precipitation may be based on the climate.

- The accumulation of precipitation relates to how much precipitation has fallen, and has been measured mechanically or directly (ruler or other device). The technology, other than for manual measurements, has not been reliable. This measurement is occasionally needed

Visibility has rarely been measured in the road environment, except in locations where severe visibility problems exist. Is has been expensive, on the order of $10,000 per instrument location, requiring instruments not always suited to the harsh road environment. Recent advances in technology provide measuring capabilities which, while costing about the same as a visibility instrument, can provide important information for highway managers. A new measuring device, which combines some of the expensive sensors into one unit, has recently been introduced by one RWIS vendor. The sensor was developed to satisfy NWS requirements for automated observing systems. The sensor will provide very useful information on the existence of precipitation, its type and intensity, and horizontal visibility.

Radiation refers to measurements of both incoming solar radiation and outgoing terrestrial radiation. Relatively simple devices can provide measurements, but the utility of such data for highway operations has not been demonstrated. The important input for a pavement temperature forecast implicitly considers radiation balance through cloud-cover forecast. The data may be interesting, and perhaps useful, for a research installation.

Pavement Sensors. Surface temperature is the pavement-related measurement most often used for snow- and ice-control. It is obtained from either passive or active sensors implanted in the road surface. Sensor placement requires care to ensure that the sensor output is representative of the pavement surface temperature. Each RWIS vendor provides sensors which can measure pavement temperatures accurately when no solar radiation is incident on the sensors (i.e when it is cloudy or dark). Pavement surface temperature is an essential measurement for snow and ice control.

Surface condition sensors in the pavement determine whether the pavement surface is dry, wet, or frozen. Even though preemptive allocation of resources is based on forecasts, the pavement condition provides a check on the forecasts and added information for detecting problems, either actual or potential. Surface condition should be considered an essential parameter.

Chemical concentration is a relative measurement of the amount of deicing chemical (or other ionic substance), determined by the conductivity of a wet surface. Sensor output needs to be calibrated and correlated to the chemicals used. The information is extremely valuable for making decisions related to deicing chemical applications, and for monitoring the progress of deicing operations. The chemical concentration is essential information.

Freezing point sensors measure the temperature at which a wet surface freezes. These sensors actively cool a surface to the point a liquid deicing chemical mix freezes. Ideally, this provides the optimum information for a snow- and ice-control decision maker. In combination with pavement temperature forecasts, the freezing point of the surface assists a supervisor in deciding when to confidently allocate resources. Concern has been expressed in Europe over the repeatability or reliability of the sensors. The sensors are usually installed four to a location to increase the coverage in a roadway and to increase reliability. Freezing-point sensors should be considered essential for snow- and ice-control operations, particularly where road surfaces are prone to icing, or where snow bonding is a problem.

Subsurface temperature is usually measured at locations where pavement temperature forecasts will be made. Subsurface information is necessary for determining whether heat flows to or from the pavement surface. Sensors are typically installed about 0.5 m (1.6 ft) below the pavement surface. For forecasting at RPU stations, subsurface temperature is mandatory.

Other Hardware Data. When RWIS sensing systems are being installed along highways, opportunities may exist to gather transportation-related information for purposes other than snow- and ice-control:

- *Video* information can monitor traffic and roadway conditions.

- *Air quality* information may become a necessity in certain transportation corridors. The siting of RPU stations should consider the use of standard transportation-related air quality sensors.

- *Stream gauges* can be installed to measure water flow or height at RPU stations near critical bodies of water.

- *Traffic information can be collected,* such as traffic counts, weigh-in-motion, and perhaps even electronic license plate information.

The possibilities for gathering information in the roadway environment are enhanced the RWIS installations. The RPUs have the potential to function as data processors and communicators for information other than weather and road conditions. However, communications within closed, or proprietary, RWIS may preclude using RWIS for such data collection.

Closed RWIS have proprietary communications protocols. Neither the RPUs nor CPUs can be accessed without special software and access codes. In addition, the data formats are usually unknown and not capable of including additional sensor information without considerable reprogramming.

The American Association of State Highway and Transportation Officials (AASHTO) issued a policy in October 1992 stating that standard data formats and communications protocols should be adopted for RWIS, because of the potential for involving other data in the road environment. In particular, AASHTO noted the potential linking with Intelligent Vehicle Highway Systems.

RPU Station Locating. Usually RPU stations have three primary functions: to gather information for forecasting conditions, to detect conditions, and to monitor conditions. It is usually recommended that a combination of sites be used. Some should be suited to gather data representative of an area for forecasting purposes; some should be sited at trouble spots to detect conditions which require attention; and some should be placed at strategic locations to monitor conditions, such as the direction from which significant weather tends to come.

It is possible that some sites can cover all three functions. The site selection process should involve both maintenance personnel who are aware of the typical road conditions and meteorologists who can recognize suitable representative locations.

In general, RPU stations should not be located at a specific site simply because power or communications are nearby. It is better to locate a site which is representative of the conditions desired and to pay extra for cable trenching, solar power, or a repeater radio transmitter. In terms of return on investment, the more representative the observations, the better the information for forecasters and for snow and ice control.

Siting for forecasting purposes can also be based on a time frame of interest. Cost-effective, proactive decisions can be made anywhere from 2 to 24 hours in advance of an event. Depending on weather patterns, this can mean obtaining data from neighboring states, or just down the road.

Siting must be based on weather patterns, road conditions, and terrain. In addition, the maintenance decision process and maintenance procedures must be considered. This includes the time frame for deciding when to take action and the kinds of actions to be taken.

Placing pavement sensors requires additional analysis. Each site, even if a "detection" site, should have one pavement sensor placed in the roadway in a minimum traffic location, usually a passing lane, in order to gather representative temperature information. In rural areas with little traffic, the sensor may serve both detecting and forecasting purposes.

Also pavement sensors should also be placed just outside of a wheel track and not in the center of a lane where vehicle heat can influence the temperature. Sensors should not be located on curves or other locations where runoff from a superelevated shoulder can contaminate readings. In grooved surfaces, the sensors should be placed at the top of the grooves, isolated from grooves where liquid and chemicals can gather.

Professional Meteorological Services

Forecasts. Research has indicated that the most cost-effective weather technology which can improve decision making is weather forecasts. However, these forecasts should be specialized and tailored to the user's needs. There should be consultative interaction between the forecaster and the user. Each must understand the other's needs and capabilities. In addition, the forecaster needs to ensure that weather information and predictions are understood; the user needs to let the forecaster know what weather information is valid and appropriate for the maintenance situation.

Site-specific forecasts for snow and ice control should be acquired from private meteorological services with experience assisting highway agencies. The NWS has neither the personnel nor the mission to provide the detailed forecasts required. Meteorological services should be considered professional services and acquired as such.

Thermal Mapping. Thermal mapping, or thermography, is the process of developing thermal profiles of road surfaces using infrared devices. The original technology, developed at the University of Birmingham in the United Kingdom, use a downward-pointing radiometer mounted under a vehicle. Radiometer data are acquired every wheel revolution and recorded on a computer for later processing. The measurements are typically made in the early morning hours, when temperatures tend to be the coolest. They are also made under different atmospheric conditions, since the radiation balance at the surface is related to the atmospheric conditions, including cloud cover, wind speed, and precipitation.

A variation on thermal mapping is called road climatology. Additional data are acquired when measuring pavement temperature, including air temperature, relative humidity, and climatological characteristics of the pavement environment. The additional data are input to a short-range (up to 4 hours) forecasting model for pavement temperature.

Most thermal mapping has been conducted in Europe. The data have assisted in siting RPU stations, forecasting pavement temperature for locations where no RWIS sensors exist, and for developing snow- and ice-control strategies. Other potential locations for thermal mapping include those areas where special deicing procedures such as pretreatment are required, where reduced chemical areas exist, or where a significant number of different microclimates have been detected.

Thermal mapping may also determine representative RPU station locations that can eliminate the need for one or more sites. For example, if thermography indicates that two or three locations have similar pavement temperature characteristics, perhaps only one needs sensors. If just one less RPU station is required, the cost of the thermography is likely to be returned.

Thermal mapping profiles can be used to construct pavement temperatures between sensor locations, where the temperatures are known. An extension of this process is to use forecasts of pavement temperatures at the sensor locations. A forecast of temperatures along the roadway can then be constructed using thermography between the forecast temperatures. This process is widely used in the United Kingdom, where workstations typically display color-coded road temperature forecasts for entire road networks. This is recommended in areas where frost or ice formation on the roads is a concern.

Based on thermal mapping, better routing or allocation of maintenance personnel is possible. The data can allow staging of responses to only those road segments expected to be below freezing. It can also indicate certain areas or locations that may not need attention.

Research has indicated that thermal information from the road environment can be obtained using hand-held radiometers. Work is also in progress on developing a vehicle-mounted instrument capability for measuring pavement temperature.

Thermal mapping should be considered when variations of pavement temperature greater than 5°C (9°F) are possible, or when the road elevation changes more than about 200 m (656.2 ft).

Meteorological Data Services. Meteorological charts, meteorological data, satellite pictures, and weather radar plots can be acquired at almost any computer workstation. Most meteorological data require interpretation by a meteorologist. Some products, such as weather radar plots, can provide useful information about the development and progress of weather systems. Whether an agency acquires these products or not should be based on how decisions are made for implementing snow- and ice-control activities.

Tailored forecasting services, if carefully geared to agency needs, should provide the information needed for making decisions. The forecasters have access to the meteorological data and are trained to interpret and use the data.

Staff Weather Advisor. A staff weather advisor provides councel to an agency on the use of weather information. The advisor can be a consultant, an employee (either part time or full time), or a private meteorological services provider.

The advisor assists the agency in acquiring and using weather information and technologies, but is not normally involved in day-to-day snow- and ice-control operations. The advisor functions as a staff person who provides advice and guidance, but does not replace the provider of the tailored forecasting services. The advisor can assist in acquiring and implementing forecasting services and other RWIS components. Some of the functions an advisor can perform include

- establishing critical weather thresholds for decision making;
- determining optimum locations for RPU stations;
- preparing and evaluating Request for Proposals for the RWIS, including forecasting services;
- conducting local forecast studies to improve weather support;
- evaluating RWIS performance; and
- training maintenance personnel to incorporate weather information into the decision process.

Pavement Temperature Forecasts, Their Uses, and Implications

Sensors embedded in the pavement surface can measure temperatures representative of the surrounding pavement and can detect the presence of water or ice and a chemical freezing-point depressant. These sensors and subsurface probes give maintenance supervisors the means for observing real-time pavement conditions. Algorithms using data from these sensors can be used to reasonably predict pavement surface temperatures up to 12, or even 24, hours in advance. Improved weather forecasting targeted specifically to local or regional road conditions also allows maintenance supervisors to predict pavement surface state. These resources are important ingredients in an anti-icing program. Examples of the output available from an RWIS pavement forecasting service are detailed in the training manual developed under the contract.

Decision-Making Process in Anti-Icing Operations

The decision to initiate anti-icing operations and to continue with sensible deicing operations is an extremely important aspect of winter maintenance activities. The success in keeping roads trafficable in winter depends on how well this decision is made. A highway agency involved with anti-icing or deicing operations needs to have a clearly established process for making decisions. Individuals involved must have access to the following information:

- the locations of RWIS sites and sensors;

- data from the RWIS sites;

- a "feel" for the characteristics of the pavement surface temperature between RWIS sites, based either on operator observations and experience or on thermal mapping; and

- pavement conditions and weather forecasting information from

  - ♦ site-specific forecasts using pavement thermal algorithms;
  - ♦ NWS forecasts;
  - ♦ private vendor forecasts;
  - ♦ precipitation bands from radar images; and
  - ♦ cloud cover from satellite imagery.

The assigned individuals must determine and evaluate

- the beginning and ending time of precipitation over the geographic area of responsibility;

- the kind and amount of precipitation;

- the pavement temperature at the anticipated beginning of precipitation and the temperature trend during precipitation;

- the presence of chemicals on the pavement at the time the surface temperature reaches 0°C (32°F);

- the freezing-point temperature of any liquid on the pavement surface; and

- other roadway pavement conditions.

Finally, the decision-making process for chemical application must address

- the timing of the chemical application in advance of precipitation; and

- the subsequent reapplications of chemicals as determined by

  - ♦ freezing-point sensor data or SOBO-20 measurements;
  - ♦ friction measurements (Coralba readings); and
  - ♦ personal observations.

Anti-Icing Strategies

Some of the states conducted successful anti-icing operations during the 1991-92 and 1992-93 winters. During the successful operations, less chemical was used on the test section than on the corresponding control section. The successful operations involved the using liquid chemicals as well as prewetted salt.

Generally, the liquid chemical magnesium chloride ($MgCl_2$) was successful as an anti-icing agent when applied at the rate of about 7.7 g/m^2 (100 lb/lane-mile) and when the pavement temperature was above −5° to −4.4°C (23° to 24.1°F). The liquid chemical was less effective when applied during freezing rain or drizzle. It definitely should not be applied on compacted snow. When a liquid chemical is used with falling snow, continuous visual observations are required so that refreezing of the road surface can be anticipated and treated. For prolonged snowfall conditions, it is necessary to plow the snow accumulation repeatedly, followed by an application of the liquid chemical. Under these conditions, it may be necessary to increase the application rate to 15 g/m^2 (195 lb/lane-mile) or higher. It may be inadvisable to apply liquid chemicals during high winds or drifting snow because of droplet loss. Some designs of modern application equipment can minimize loss.

The amount of liquid chemical used in the prewetting experiments ranged from 21 to 25 L/metric ton (5 to 6 gal/ton) of salt when applied at the spinner. Twice this amount of liquid was used when the salt was prewetted in the truck bed. It is suspected that these amounts of liquid prewetting were too low and that, perhaps, 1.5 times as much liquid should have been used for better surface coating of the dry salt.

Prewetted salt appeared to be an effective anti-icing agent when applied at the rate of about 7.7 g/m^2 (100 lb/lane-mile) and when the pavement temperature was above −9° to −7°C (15.8° to 19.4°F), depending on the type of liquid used for prewetting. The use of prewetted salt during prolonged rain or freezing rain requires frequent observations and sometimes increases application rates to 15.4 g/m^2 (200 lb/lane-mile) or higher.

For prolonged snowfall conditions, it will be necessary to plow the snow accumulation repeatedly, followed by an application of prewetted salt. Under these conditions, it may be necessary to increase the application rate to 15.4 g/m^2 (200 lb/lane-mile) or higher.

Anti-icing operations should not be conducted (using liquid, prewetted, or dry salt) when the pavement temperature is at or below −9°C (15.8°F). The operation should also not be conducted during high winds or under severe drifting snow conditions.

Supplemental Measurements of Pavement Surface Conditions

Maintenance personnel can make supplemental measurements of pavement surface conditions forces during a storm event to aid in determining the appropriate timing for chemical applications. These measurements relate to the friction available between a vehicle tire and the traveled surface and to the surface concentration levels of an ice control chemical. Devices such as the Coralba friction tester and the SOBO-20 salinity tester can be used to make these measurements. Of the two, the Coralba appears to be most useful as a winter maintenance tool.

Role of Supervisory Personnel in an Anti-Icing Program

The role of supervisory personnel in an anti-icing program is similar to the role performed in conventional snow- and ice-control operations, with a few exceptions summarized below:

- Inform all personnel involved with the anti-icing operations of the boundaries of the treatment area.
- Identify the equipment to be used during the anti-icing operations and ensure that the spreaders are calibrated both before the beginning of the winter and periodically during the winter.
- Provide a chain of command that establishes
    - ♦ who makes the decisions;
    - ♦ who carries out the decisions; and
    - ♦ how the is information communicated.
- determine when chemicals should be first applied.
- determine the timing and application rates of the second and subsequent chemical treatments, as needed.
- ensure that all proper safety measures are followed during the field operations.
- ensure that all data associated with the anti-icing operations are assembled for a poststorm review.

Role of Operators in an Anti-Icing Program

- Calibrate spreader equipment at the direction of supervisory personnel.
- Inform supervisory personnel of spreader calibration results.
- Follow instructions of supervisory personnel regarding the application and timing of chemical treatments.

- Complete activity logs for each chemical, abrasive, or plowing treatment of the assigned highway segments.

- Inform supervisory personnel of road and weather conditions.

- Make note of any traffic accidents on the assigned highway segments.

Documentation and Review of Anti-Icing Operations and Results

Assessing the effectiveness of an anti-icing operation can best be done in a poststorm review of the maintenance and other field data generated during the storm. These data come from several sources, including weather forecasts and records, pavement condition information, RWIS data, operator information, spreader data, and Coralba and SOBO-20 readings. Forms useful for recording much of this information are contained Appendix C. The types of analysis that can be performed on the maintenance field data are discussed in Section 2 of this report.

Proposed American Testing Protocol for Winter Maintenance Spreaders

Applying small amounts of a chemical freezing-point depressant to a road surface prior to the development of compacted snow or ice prevents formation of a strong bond and facilitates removal. It is necessary to apply a precise quantity (such as 10 g/m^2 or 130 lb/lane-mile) uniformly across the road. This research project undertook to identify the capabilities of winter maintenance spreader equipment for achieving low application rates and controlling the spreading pattern over a wide range of rates.

In late summer of 1991, all potential sources of spreader equipment used for applying deicing chemicals in small quantities were contacted in an effort to learn "if" and "how" U.S. highway spreader manufacturers test their equipment's performance. This information was to be used to develop the necessary testing protocols for proposed American testing standards for winter maintenance spreaders. It was determined, however, that the highway spreader industry does not test its equipment's operating characteristics under actual field conditions. One exception was the Salt Institute, which has developed a procedure to measure the application rates of a spreader in a stationary mode. This standard was not useful to this study, however, because information was needed on spreader equipment tested in a dynamic mode.

The only standard test method found in the literature of American made spreader equipment literature was that developed by the American Society of Agricultural Engineers, the ASAE Standard S341.2 "Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders." However, this procedure is used with fertilizers, which have a narrow gradation band in comparison to salt. Furthermore, this standard does not pertain to application on a hard surface, such as pavement.

Therefore, the team contacted numerous foreign sources to obtain information on various types of spreader equipment used for anti-icing and their respective testing procedures. Follow-up interviews were conducted with a number of users and manufacturers in various European and Scandinavian countries. Denmark, the United Kingdom, and Germany use testing procedures to evaluate spreader equipment. Using these testing protocols as background information, a proposed testing protocol was developed to evaluate spreaders in the United States.

The proposed "American Testing Protocol for Winter Spreaders" measures the ability of the spreader to control the distribution pattern and the application rate of spread material. The distribution pattern should be evaluated at speeds of 20 km/hr (12.4 mph) and 40 km/hr (24.8 mph), with controls set to deliver 20 g/m^2 (260 lb/lane-mile) of spread material over a 6-m (19.7-ft) width. This application rate is equivalent to applying 194 kg (427.7 lb) of material over a 6-m (19.7-ft) wide roadway surface 1.6 km (1 mi) in length. The spreader should be driven over a marked grid system spreading dry salt. Next, the salt samples should be vacuumed into paper filters from the surface of the grid system and the mass of the salt vacuumed from each sampling rectangle should be weighed and recorded. The data should then be analyzed to determine the characteristics of the longitudinal and transverse distribution pattern.

The application test measures the accuracy of the spread material released in accordance with the normal operational range of the spreader. This test reflects the actual amount of material applied to the roadway. The testing should be conducted using the following combinations:

- 20 g/m^2 (260 lb/lane-mile) at 30 km/hr (18.6 mph)
- 5 g/m^2 (65 lb/lane-mile) at 10 km/hr (6.2 mph)
- 20 g/m^2 (260 lb/lane-mile) at 40 km/hr (24.8 mph)
- 40 g/m^2 (520 lb/lane-mile) at 30 km/hr (18.6 mph)
- 40 g/m^2 (520 lb/lane-mile) at 40 km/hr (24.8 mph)

The testing protocols that have been developed for spread pattern performance and application rate performance follow.

Spread Pattern Performance Test

General. The spread pattern test should be conducted at a speed of 20 km/h (12.4 mph) and 40 km/hr (24.8 mph) with controls set to deliver approximately 20 g/m^2 (260 lb/lane-mile) of spread material and the spinner setting dispersing the spread material over approximately two lanes (6 m or 19.7 ft).

With the hopper loaded to approximately half capacity, the spreader should be driven over a marked grid system spreading dry salt. The salt samples should be vacuumed into paper filters from the surface of the grid system, and the mass of the salt vacuumed from each sampling rectangle should be weighed to an accuracy of 0.1 g (.004 oz) and recorded. The data should then be analyzed to determine the characteristics of the longitudinal and transverse distribution pattern. The tests should consist of two runs at each speed.

Test Site. The test should be conducted on a straight length of roadway. The roadway should be as flat as possible, with a cross slope not exceeding 1 in 40, to avoid distortion and the rolling of large particles. The recommended minimum length of the roadway is 320 m (1,049.9 ft). The roadway should be long enough for the spreader to accelerate to and maintain test spreads of 20 and 40 km/hr (12.4 and 24.8 mph) before entering the first test strip. The roadway should also be long enough for the spreader to stop after leaving the third test strip. The surface of the test area should be made of asphalt-concrete, exhibiting a macroroughness such as that experienced in the middle of the roadway.

A grid system consisting of strips should be marked out on the test area in accordance with figure 35. The width of the strips should be 6 m (19.7 ft) for the nominal spread width and 1 m (3.3 ft) for the overspreading rectangles, for a total width of 8 m (26.2 ft). Capture walls (with a dimension of 2.5 m long by 300 mm high [8.2 ft by 1 ft]) should be placed along the outer edge of the overspreading rectangles. The breadth of the strips should be 2 m (6.6 ft).

Test Material. The testing material should be rock salt which meets ASTM D632 Grade 1 at a moisture content of less than 3%.

Procedure.

1. Mark out the test site as indicated in figure 35. Erect capture walls along the outer edges of the overspreading rectangles (U). Ensure that the surface of each test strip is dry.

2. Sweep the transverse strips and adjacent areas until a negligible amount of salt is left on the surface, and then vacuum the transverse strips.

3. Set the spread controls for a delivery rate of 20 g/m^2 (260 lb/lane-mile) and a spread width of 6 m (19.7 ft). Fill the hopper to approximately half capacity. With tailgate spreaders, fill the auger box completely.

4. The spinner displacement setting (asymmetry) should be set so that when the vehicle's right side is driven along the left edge of the rectangle designated as (R_r), the spread material is covering the right-edge stripe (R_r).

5. Drive the spreader vehicle straight along the test area with the vehicle's right side along the left edge of the right-edge stripe (R_r) of the grid layout at the speeds of 20 km/hr (12.4 mph) and 40 km/hr (24.8 mph).

6. The amount of spread material deposited in the individual rectangles should be carefully removed by vacuuming the material into paper filters. Weigh the material to the nearest 0.1 g (.004 oz), and record the weights on a form similar to that shown in figure 37.

7. Perform the various computations to measure the spreader performance for the following capabilities:

   - Accuracy of longitudinal coverage

     Compare the total mass of material collected on any one transverse strip to the mean mass of material collected on all three strips. Also, the total mass of material collected from all three strips should be compared for each of the speeds, 20 km/hr (12.4 mph) and 40 km/hr (24.8 mph).

   - Accuracy of coverage on side strips

	Collected spread material amount (g)								Lateral strip $\Sigma\ \Omega$	Deviation from average value (%)
	O_l	R_l	i..	i..	i..	i..	R_r	O_r		
Column	1	2	3	4	5	6	7	8	9	10
Strip width (m)	1	1					1	1	–	–
Lateral strip III										
Lateral strip II										
Lateral strip I										
Σ_{Total}									:3 →	
Percent of the total amount (Σ_{Total} Column 9)			–	–	–	–				
(1) Spread density$_{ix}$ [g/m^2)	–	–					–	–		
(2) A_{Qix} (%)	–	–					–	–		

(1) Spread thickness in the test longitudinal strip ix

(x = 1; 2; 3... Number of the test longitudinal strip as per selected number)

$$SD_{ix} = \frac{\Sigma_{Total}\ (\text{Col. } 3...6)}{6 \cdot b_{Tix}\ \dagger} = [\text{g/m}^2]$$

(2) Deviation of spread thickness in the test longitudinal strip ix

$$A_{Qix} = \frac{(SD_{ix} - SD_m)}{SD_m} \cdot 100 = [\%]$$

SD_m is the mean spread density in the nominal spread track including overspread amount

$$SD_m = \frac{\Sigma_{Total}\ (\text{Col. } 9)}{6 \cdot b_H\ \dagger} = [\text{g/m}^2]$$

† Factor 6 is the total length of the test longitudinal strip 3 · 2 m.

Figure 37 Computation form.

Compare the mass of material collected on either side strip (R_l, R_r) to the total mass collected.

- Accuracy of coverage on inner test strips

  Compare the computed spread density for the inner lengthwise strips (those between the side strips) to the average spread density of all the rectangles in the grid system.

- Wastage

  Compare the total mass of material collected on either overspread strip (U_l, U_r) to the total mass collected.

Discharge Performance Test

General. The amount of spread material released from the spreader vehicle in a unit of time depends on the setting that controls the auger or belt speed and on the speed of the vehicle. The discharge test measures the accuracy of releasing material in accordance with the normal operational range of the spreader. This test also attempts to reflect the actual amount of material applied to the roadway.

For dry salt, the values of the operating ranges for output and speed follow:

Output	Amount discharged	Speed
Lowest	30 kg/km (106 lb/mile)	10 km/hr (6.2 mph)
Most frequent	120 kg/km (426 lb/mile)	30 km/hr (18.6 mph)
Highest	240 kg/km (852 lb/mile)	40 km/hr (24.8 mph)

The tests should be conducted under the following conditions developed from the above tabulations:

- 30 kg/km (106 lb/mile) at 10 km/hr (6.2 mph)
- 120 kg/km (426 lb/mile) at 30 km/hr (18.6 mph)
- 120 kg/km (426 lb/mile) at 40 km/hr (24.8 mph)
- 240 kg/km (852 lb/mile) at 30 km/hr (18.6 mph)
- 240 kg/km (852 lb/mile) at 40 km/hr (24.8 mph)

Discharge Test

1. Fill the spreader to half capacity with dry salt.

2. Start and end the measurement by activating the on and off control.

3. The control setting values should correspond to the test conditions given above.

4. Establish a distance for the spreader vehicle to travel during the discharge test operation. The recommended quantity of spread material collected during each test is 24 kg (52.9 lb). The minimum quantity collected should not be less than 10 kg (22.1 lb).

5. Remove the spinner from the truck bracket. Relocate the spinner to a position that is not hazardous to the operator, the truck, or itself. Mount a drum and bracket assembly, similar to that in figure 38, on the truck in the area previously occupied by the spinner.

6. Allow the vehicle to idle long enough to warm the hydraulic oil to a normal working temperature with the spreader system running. Set the spinner controls to a midrange setting to allow hydraulic fluid to flow.

7. Drive the spreader vehicle over the test distance and collect the discharge material in the barrel. At least two separate discharge tests should be made for each test condition. The maximum and minimum weights of the discharge material collected for each test condition must satisfy the following expression:

$$\frac{\text{Maximum} - \text{Minimum}}{0.5\ (\text{Maximum} + \text{Minimum})} \leq 0.1$$

8. Evaluate the discharge results for the various truck speeds to determine the accuracy of released material.

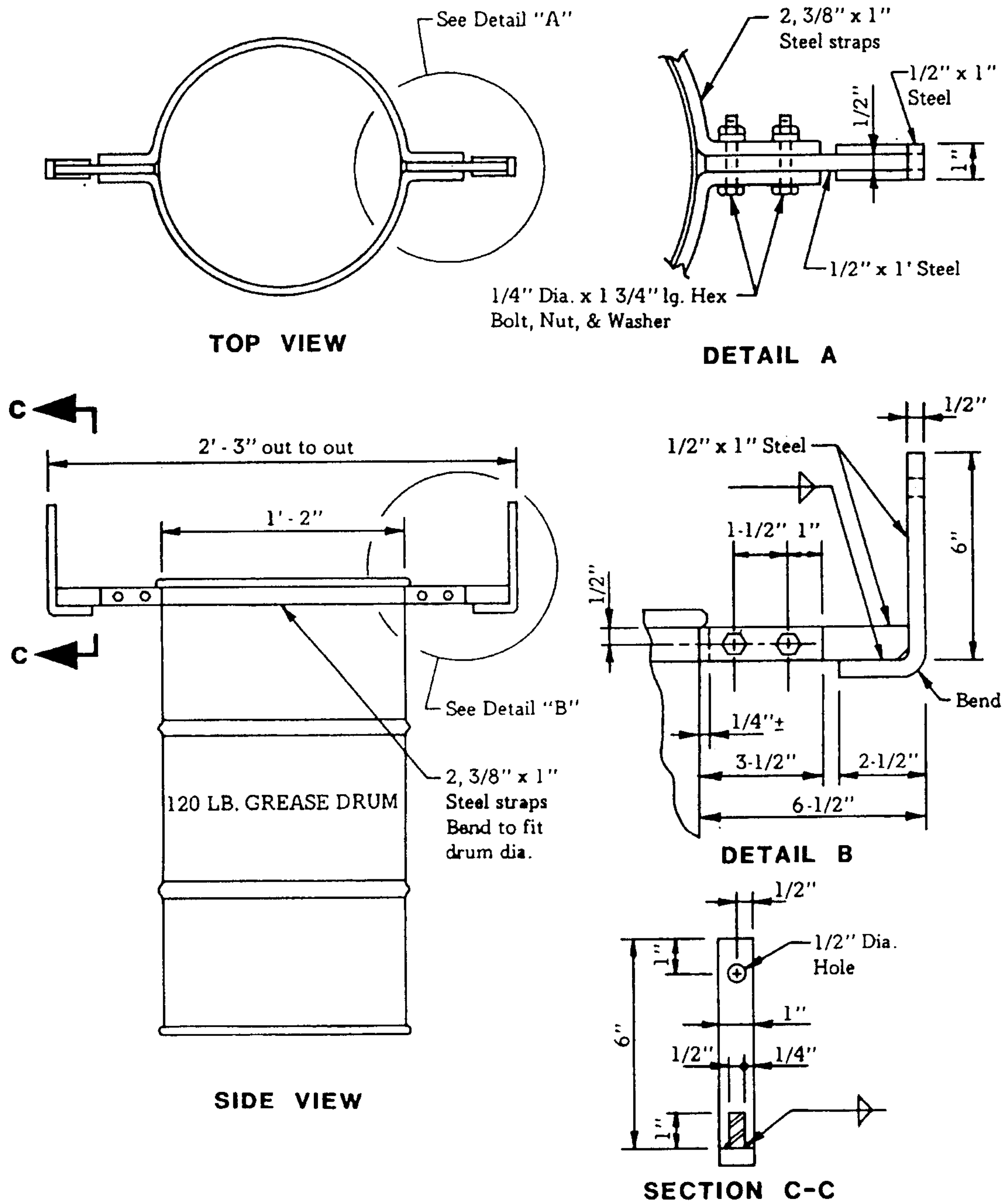


Figure 38 Drum and bracket assembly (replaces spinner).

4

Conclusions and Recommendations

Conclusions

- A variety of anti-icing treatment strategies, including chemicals and treatment timing, are used by different states.
- No U.S. manufacturers were found that make spreaders specifically designed to distribute prewetted solid material or liquid chemicals.
- Attempts to retrofit existing spreaders with on-board prewetting equipment were not satisfactory.
- It was difficult to get timely service and repairs for the Coralba and SOBO-20 measurement devices, as well as the complete Road Weather Information System (RWIS) installation.
- Training of maintenance personnel in anti-icing operations is essential. The retraining for the second winter of the test program was valuable and helped solve problems identified during the first winter testing.
- Frequent communications with maintenance supervisors during the anti-icing trials were necessary to solve problems and provide encouragement.
- Weather forecasting specific for highway segment areas is important to the success of anti-icing operations.
- No standard test methods are used in the United States to evaluate chemical or abrasive spreader capabilities.

- Calibration of spreader application rates, prior to the beginning of the winter and periodically throughout the winter, is necessary for full achievement of the savings possible with anti-icing.

- Some of the participating state highway agencies conducted successful anti-icing operations during the 1991-92 and 1992-93 winters. Less chemical was used on the test section than on the control section during 40% of selected storm events of the 1991-92 winter. This percentage increased to 62% during the 1992-93 winter. There is a definite learning curve associated with the use of anti-icing technology.

- The Coralba friction tester and the SOBO-20 salinity tester, when used correctly, can provide winter maintenance personnel with timely information needed for chemical treatment application decisions.

- Initial application rates of about 7.7 g/m^2 (100 lb/lane-mile) appear to be adequate for anti-icing operations using a liquid chemical, if applied at the appropriate time on pavements with a temperature not below -5°C (23°F) and in the absence of high winds.

- The use of liquid chemicals and prewetted salt in anti-icing operations was successfully demonstrated during several storm events.

- The beneficial effects of anti-icing operations were not noted for all storm events. Increased amounts of chemicals may be necessary after the first (or subsequent) anti-icing application.

- The success of anti-icing operations was strongly enhanced by the willingness of the various levels of maintenance personnel to work cooperatively and learn from the collective experience.

- Cost-benefit analysis indicates that anti-icing operations can result in cost savings to both highway agencies and motorists. For highway agencies, the primary cost savings is the reduced material costs resulting from both the lower application rates and fewer truck passes. For motorists, the cost savings result from fewer accidents due to fewer hours of exposure to snow- and ice-covered pavements.

- European and Scandinavian maintenance forces have more experience than their U.S. counterparts in the use of anti-icing technology.

- Spreader equipment currently manufactured in European and Scandinavian countries is designed for anti-icing operations. The equipment can dispense small amounts of salt and can control the distribution pattern of the applied material. Some of the equipment is capable of dispensing all three types of material: dry, prewetted solids, and straight liquid.

Recommendations

- Additional winter testing of anti-icing technology should be conducted in the United States to supplement the knowledge gained from the two winters of testing. The additional data collected should be used to help improve the initial estimates of the effectiveness of anti-icing technology.

- Additional anti-icing experiments should be conducted using liquid chemicals under a variety of winter storm and traffic conditions.

- Anti-icing experiments should be conducted with salt gradations similar to those used in foreign countries, and prewetted with a liquid chemical in proportions similar to those used in foreign countries.

- The role of traffic volume in affecting the response of an anti-icing chemical treatment should be assessed further.

- A reliable pavement surface freezing-point detector should be included as part of a RWIS installation.

- Software should be developed that will present graphical information to decision makers concerning weather and pavement conditions during anti-icing and conventional deicing operations. Graphical information similar to that presented in this study should be considered.

- The extensive data bases generated during the New York Department of Transportation anti-icing experiments in the 1992-93 winter should be further analyzed for additional measures of effectiveness.

- The use of time-lapse video equipment to monitor pavement conditions before, during, and after winter storm events should be considered.

Appendix A

Summary of State Visits

Table A-1 Summary of state visits—California.

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Mountain state	California I-80 at Donner Pass	Edward B. Delano, Chief District Liaison—Branch A Office of Highway Maintenance Sacramento Tel: (916) 445-4649 Richard J. Melim Deputy District Director Maintenance & Equipment District 3 Marysville Tel: (916) 741-4318 John Qualls Caltrans Superintendent III Regional Manager District 3 Maintenance Nevada City Tel: (916) 265-4290 Ken Wilson CT Highway Superintendent II Donner Pass Area Kingvale Maintenance Station Solda Springs Tel: (916) 426-3621	Reactive deicing	Treatment at beginning of storm	Straight sand is applied at 1,000 lb/lane-mile when precipitation begins. 50% sand and 50% salt is applied at 1,000 lb/lane-mile when snow begins to stick on shoulders. Liquid Freezgard is also applied at 0.005 gal/yd^2 when snow begins to stick on shoulders. Liquid Freezgard is applied at 0.03 gal/yd^2 to compacted snow. No salt will be used this winter.	Salt: 500 Freezgard: Fogging—0.005 gal/yd^2 Drilling—0.03 gal/yd^2
	California SR 88 at Kit Carson Pass	Same as above except Qualls & Wilson replaced by: Earl Williams Pine Grove Area Superintendent District 10 Pine Grove Tel: (209) 296-1353	Same as above	Same as above	80% volcanic cinders and 20% salt by volume. No bare pavement policy—public drives on compacted snow at times. Cinder/salt mix: Nominal—1,000 lb/lane-mile Maximum—2,700 lb/lane-mile (1990-91 season)	Salt: Nominal: 200 Maximum: 540 (1990-91 season)

Table A-1 (Continued).

Geographic area	State/ route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Mountain state	California I-80 at Donner Pass	Divided, limited access	DGA and PCC	DGA surface was placed in 1991; PCC surface is worn and polished.	4	31,100	Rural	~ 40	National Weather Service—Reno, NV (Blue Canyon has NWS Station). 12 Surface Systems, Inc. surface sensors plus 2 subsurface probes being installed. CPU is located at Kingvale Station.	8-10 yd^3 Swenson spreaders; 6 or 7 trucks equipped with Dickey-Johns Model 2000 controls. 15 spreader/plows plus 6 plow trucks available from 3 facilities.
	California SR 88 at Kit Carson Pass	2-lane, 2-way	DGA	Good with some transverse cracking	2	2,200	Rural	120	No weather fore-casting (Caples Lake Maintenance Facilities has NWS Station).	4-yd^3 chassis-mounted hoppers with ground-oriented spreader controls. At Woodfords site, one truck equipped with 8-yd^3 Swenson hopper, ground-oriented control and prewetting at spinner (rated at 14 gal/mile at vehicle speed of 25-30 mph).

Table A-1 (Continued).

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Mountain state	California I-80 at Donner Pass	Reluctance of district to use straight deicing chemicals.	Use one of two prestorm treatments: Spray $MgCl_2$ on bare pavement, or use rock salt prewetted at spinner with Freezgard Plus.	Friction tester	1,800
				Salinity measuring instrument	2,700
	California SR 88 at Kit Carson Pass	Need atmosphere and pavement sensors.	Use rock salt prewetted at spinner with magnesium chloride as a prestorm treatment.	2 RPUs with associated atmospheric and roadway sensors	51,000-54,000
				Friction tester	1,800

Table A-2 Summary of state visits—Maryland (mountainous area).

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Mountain state	Maryland SH 495	Martin J. Knecht, III Assistant Chief Maintenance Management Baltimore Tel: (301) 333-1605 Paul D. McIntyre Resident Maintenance Engineer Garrett County Accident Tel: (303) 746-8141 Robert C. Rowan Assistant Resident Maintenance Engineer Garrett County Accident Tel: (301) 746-8141 James A. Smith Highway Maintenance Superintendent Garrett County Accident Tel: (301) 746-8141	Reactive deicing	Treatment at beginning of storm	Three mixtures used depending on conditions: 90% sand/10% salt (night patrol and reapplications); 75% sand/25% salt (dry snow); 50% sand/50% salt (wet snow); or 100% salt (freezing rain). Sand is a 90%/10% mixture of fine crushed sandstone (100% < No. 4; large amounts < No. 100 screen) and coarse (1/4-in) crushed limestone. Mixture applied at 400-500 lb/lane-mile directly down centerline of 2 lanes.	Night patrol and reapplications: 40-50 Dry snow: 100-125 Wet snow: 200-250 Freezing rain: 400-500

Table A-2 (Continued)

Geographic area	State/route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Mountain state	Maryland SH 495	2-lane, 2-way	OGA	Unspecified	2	1,600-2,000 (1989)	Rural	~ 40	Baltimore office of NWS for "zone forecast" plus Channel 4 in Pittsburgh. State contracts with a private weather forecasting group, Weather Data Network. Also monitors "NOOR" weather information on the state radio channel. No RWIS available.	Oshkosh trucks with spreaders and plows. Also, 20 single-axle trucks equipped with 6-yd^3 dump boxes and tailgate spreaders. Spreaders are Swensons with single auger and steel spinner. Controls are Dickey-Johns Model 47 (ground-oriented). Spinners cannot be turned off during windrowing along centerline.

Geographic area	State/ route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Mountain state	Maryland SH 495	1. Abrasive material is of poor quality. 2. No RWIS available.	Use straight rock salt at beginning of storm. Monitor pavement surface temperature prior to storm using hand-held radiometer.	One Raytek radiometer	-0- (unit to be borrowed from participating H-207 states)
				Friction tester	1,800
				Salinity measuring instrument	2,700

Table A-3 Summary of state visits - Colorado.

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Standard treatment strategy: Treatment timing	Standard treatment strategy: Deicing material used and associated application rate	Standard treatment strategy: Net deicer application rate (lb/lane-mile)
High plains state	Colorado I-25 near Berthoud Interchange C-470 at SH 121	David B. Woodham Highway Engineer Denver Tel: (303) 757-9506 David N. Fraser Staff Highway Maintenance Superintendent Denver Tel: (303) 757-9536 Gordon Bell Assistant District Superintendent Denver Tel: (303) 757-9514 Orville Rhoades Denver Tel: (303) 757-9514 M. L. "Mike" Anderson Highway Maintenance Superintendent III Greeley Tel: (303) 350-2119 Steven M. Carlson Deputy Maintenance Superintendent Greeley Tel: (303) 350-2120	Reactive deicing	Treatment at beginning of storm (patrols alert maintenance personnel—material already on patrol vehicles)	Abrasives applied with 0%-18% (vol) salt added. In Greeley area the salt content of the sand/salt mixture is 3%-6%. In Denver area, the mixture is 15%-18% salt. Sand/salt mixture is purchased from local vendor. In 1990-91, 120,000 tons of sand/salt applied to 3,130 lane-miles.	Not specified.

Table A-3 (Continued)

Geographic area	State/route	Highway type	Pavement type	Pavement condition	No. lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
High plains state	Colorado I-25 near Berthoud Interchange	Divided, limited access	PCC with PCC shoulders	Good	4	29,500-30,100	Rural	~ 25	RPU at site with two roadway sensors and an extra precipitation sensor on the met tower. NWS forecast monitored in trucks.	Patrol No. 5: (North of site on I-25) • Three single-axle trucks with 4-yd^3 dump boxes and drum spreaders. • One tandem-axle truck with 7-yd^3 dump box with tailgate drum spreader. Patrol No. 15: (South of site on I-25) • Four single-axle trucks with 4-yd^3 dump boxes with tailgate drum spreaders. • One tandem-axle truck with 7-yd^3 dump box with tailgate drum spreaders. One special unit located in Grand Junction area. This unit consists of a 7-yd^3 slide-in hopper with prewetting capability at spinner, 200-gal liquid tank, and ground-oriented control (fifth wheel). There is a weak possibility that this unit might be made available for either Colorado site.
	C-470 at SH 121	Divided, limited access	DGA	Good	4	33,000	Sub-urban	~ 25	RPU at site with three pavement sensors. Two RPUs are located on C-470 at interchanges of proposed site. NWS forecast monitored in trucks.	Trucks have 4-yd^3 dump boxes with tailgate drum spreaders.

Table A-3 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
High plains state	Colorado I-25 near Berthoud Interchange	1. Reluctance of district to use straight deicing chemicals. 2. Drum distributors do not provide adequate control of spread pattern. 3. No prewetting equipment for dump trucks. Use of special truck unit from Grand Junction uncertain.	Use liquid NaCl or $MgCl_2$ solution to prewet rock salt after truck loading.	Fixed liquid spray system and associated storage tanks	10,000
			Prewetted salt will be applied to pavement at beginning of storm.	Friction tester	1,800
	C-470 at SH 121	Same as above	Same as above	Fixed liquid spray system and associated storage tanks	10,000
				Friction tester	1,800

Table A-4 Summary of state visits - Nevada.

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
High plains state	Nevada I-80 near California state line	Jim Dodson Assistant Director—Operations Carson City Tel: (702) 687-5440	Reactive deicing	First deicing application made when roadway turns white	Outside Tahoe Drainage Basin: Mixture of 83% sand and 17% salt by volume. Application rate is ~ 1,100 lb/lane-mile.	Salt: 110 to 187, depending on area.
	US 395 at Panther Valley	Richard J. Nelson District Engineer Reno Tel: (702) 688-1250 Bill Young Equipment Engineer Reno Tel: (702) 688-1330			In Tahoe Drainage Basin: Mixture of 90% sand and 10% salt. Application rate is ~ 1,100 lb/lane-mile. Freezgard may be used on trial basis on I-395 from McCarran Boulevard to California state line.	Freezgard: • Fogging — 0.005 gal/yd^2 • Drilling — 0.05 gal/yd^2

Geographic area	State/ route	Highway type	Pavement type	Pavement condition	No. lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
High plains state	Nevada I-80 near California state line	Divided, limited access	DGA	Good	4	5,000 (weekdays) ~ 20,000 (weekends)	Rural	~ 6	NWS used for updates. Also, weather channel from Reno television is monitored. An RPU has been relocated at this site with two roadway sensors. The RPU was used for the first time at this site during winter of 1991-92.	Slide-in hoppers with drag conveyors, spreaders, and ground-oriented controls. Controls are Dickey-Johns or Hydra-Tech. Old oil distributor truck being modified to apply liquid Freezgard similar to Caltrans' units.
	US 395 at Panther Valley	Divided, limited access	DGA	Good	4	39,000	Sub-urban	~ 6	Same as above.	Same as above. NDOT plans to equip two trucks with Freezgard prewetting capability at the spinner. Plans are to use these trucks at this site during 1991-92 winter to pretreat the pavement as an anti-icing strategy.

Table A-4 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
High plains state	I-80 near California state line	1. Reluctance of state and district to use straight salt because of environmental concerns. 2. Low frequency of storm events. 3. RPU installation questionable and has not been operated since being relocated. 4. Route becomes closed at California State Line when Donner Pass is closed.	Site not recommended for use.	None	-0-
	US 395 at Panther Valley	Same as 1, 2, and 3 above.	Use rock salt prewetted with Freezgard at spinner and applied to pavement surface at beginning of storm.	Coralba friction tester	1,800

Table A-5 Summary of state visits - Missouri

Geographic area	State/ route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Plains state	Missouri I-29 at KCI Airport	Bob Girard Director of Research Jefferson City Tel: (314) 751-1040 Tom Borgmeyer Jefferson City Tel: (314) 751-1157 Roger Schwartze (Primary Contact) District Maintenance & Traffic Engineer Kansas City Tel: (816) 921-7104 Dan Miller Kansas City Tel: (816) 921-7104 Bob Chappell Kansas City Tel: (816) 921-7104	Reactive deicing	Variable. Crews are called out when $\geq$ 70% probability of precipitation in forecast; spotters are used at 30%-70% probability.	In areas with curbs and gutters, 100% salt is prewetted with either $CaCl_2$ (32% concentration) or $MgCl_2$ (28% concentration) at 6 gal liquid/ton salt. In other areas a mix of salt, sand, and boilerhouse cinders is used. Composition of mixture is unknown. Straight salt is used down to 20°F. Below 20°F, prewetted salt is used.	Prewetted salt: ~ 200
	Missouri US 71 over Grand River	Same as above	Same as above	Same as above	Same as above	Same as above

Table A-5 (Continued)

Geographic area	State/ route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Plains state	Missouri I-29 at KCI Airport	Divided, limited access	DGA	Worn with many filled cracks	4	39,500	Rural—near major airport	~ 15	Weather forecasts provided by Murray and Trettel of Northfield, IL. Nine RPU sites available in K.C. metro area. One RPU is located on I-29 near Cookingham Road. Access to SCANCAST through St. Louis—no forecast available through local CPU.	Slide-in hopper, chain drag and lime-type spinner. No ground-oriented controls used. Drag and spinner operates at only one rate.
	Missouri US 71 over Grand River	Divided, limited access	DGA over PCC	Good	4	11,800	Rural	~ 15	Same as above except RPU is located at US 71 over Grand River.	Same as above

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Plains state	Missouri I-29 at KCI airport	1. SCANCAST information for site not automatically available through local CPU.	Use rock salt prewetted at spinner with either $MgCl_2$ or $CaCl_2$ and applied to pavement at beginning of storm.	Ground-oriented spreader control for one truck	2,600
		2. Application rate used not precisely known.		Friction tester	1,800
	Missouri US 71 over Grand River	Same as above	Same as above except use as prestorm treatment.	Same spreader control as above	2,600
				Salinity measuring instrument	2,700
				Friction tester	1,800

Table A-6 Summary of state visits - Ohio

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Plains state	Ohio I-70 and SR 29	Keith C. Swearingen Engineer of Maintenance Columbus (Tel: (614) 466-3264 Keith T. Hinshaw Research Evaluation Engineer Columbus Tel: (614) 466-2916 Steven R. Hart Maintenance Engineer Delaware Tel: (614) 363-1251 Howard F. Stone Equipment Superintendent Bureau of Equipment Management Columbus Tel: (614) 275-2824 M. John Main General Superintendent Delaware Tel: (614) 363-1251 Arnie Holley Maintenance Supervisor West Jefferson Outpost	Reactive deicing	Treatment at beginning of storm	Mixture used by ODOT consists of 50% coarse limestone and 50% salt by volume. First application on interstates is 100% salt with reapplications of 50/50 mix. All applications to state highways are the 50/50 mixture.	First application: Salt: ~ 250-300 Reapplications: Salt: ~ 125-150 State highways: Salt: ~ 125-150 (Note: driver estimates how much material is loaded)
	Ohio US 40	Same as above	Same as above	Same as above	Same as above	Same as above
	Ohio I-71 and US 62	Same as above	Same as above	Same as above	Same as above	Same as above

Table A-6 (Continued)

Geographic area	State/ route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Plains state	Ohio I-70 and SR 29	Divided, limited access	PCC with DGA overlay	Good	6	34,000-45,000	Sub-urban	~ 30	Each district contracts its own forecasting service. The district has used Special Weather Service in Chicago for the last three to four seasons. NWS located in Columbus—ODOT does not use their forecasts. A RPU with four pavement sensors is located at this site.	Single-axle 4-yd^3 dump boxes, tailgate augers and spinner. Controls are Dickey-Johns, Swenson, Hydro Teck, or Pengwyn. Pengwyn system is computerized and provides up to 15 application rates for a given set of programmed conditions.
	Ohio US 40	Divided, limited access	DGA	Good	4	15,000-44,000	Rural	~ 30	Same as above except would need to use data from RPU at I-70 and SR 29.	Same as above
	Ohio I-71 and US 62	Divided, limited access	PCC with DGA overlay	New overlay	4	23,000-58,000	Rural	~ 30	Same as above. A RPU with four pavement sensors is located at this site.	Same as above

Table A-6 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Plains state	Ohio I-70 and SR 29	None	Use rock salt prewetted at spinner with either liquid NaCl or $CaCl_2$ as a treatment at beginning of storm.	Prewetting equipment for one truck plus storage tanks, pump and liquid chemical	3,900
				Friction tester	1,800
	Ohio US 40	None	Same as above except use as a prestorm treatment.	Prewetting equipment for one truck	1,400
				Salinity measuring instrument	2,700
	Ohio I-71 and US 62	None	Same as I-70 above.	Same prewetting equipment as I-70 above	3,900
				Friction tester	1,800

Table A-7 Summary of state visits - Minnesota.

			Standard treatment strategy			
Geographic area	State/route	State contacts	Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Lake effect state	Minnesota US 53 northwest of Duluth I-35 in Duluth at Mesaba Avenue	Bruce Larson Area Maintenance Engineer Duluth Tel: (218) 723-4809 Dean Cummings District Maintenance Superintendent District 1A Duluth Tel: (218) 723-4816 Kelvin Smith Shop Supervisor Duluth Tel: (218) 723-4825 Duane Butterfass Highway Maintenance Supervisor Nopeming Tel: (218) 624-3211 Alvin Bostrom Intermittent Highway Maintenance Supervisor Nopeming Tel: (218) 624-3211 Wayne Compton Highway Maintenance Supervisor Duluth Tel: (218) 723-4820	Reactive deicing	Apply mixtures of abrasives and salt at beginning of storm	Mixture of 90% sand and 10% salt by volume. Some additional salt added at time trucks are loaded. For some areas, 100% salt may be used. In downtown Duluth, first application is 100% salt and second application is a 50/50 mixture of sand and salt. Liquid chemicals will be tried this year. These include liquid $CaCl_2$ (32% solution); liquid CMA (24% solution); and possibly liquid potassium acetate. Also, a 20/80 mixture (by weight) of CMA and NaCl will be tried. Application rates include 150 lb/lane-mile (salt only); 300 lb/lane-mile (50% sand/50% salt mix); or 400-600 lb/lane-mile (75% sand/25% salt mix).	~ 150

Table A-7 (Continued)

Geographical area	State/route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Lake effect state	Minnesota US 53 northwest of Duluth	Divided, unlimited access	PCC and DGA	Good	4	~ 5,800	Rural	18	Tried using a private forecasting service (Metro Weather Service) with little success. Now uses "zone forecast" from NWS. Also used weather radar from Kavouras, Inc., in past. A Climatronics RPU with pavement and freezing-point sensors is located at this site.	MNDOT has single-axle (Class 33) and tandem-axle (Class 35) trucks equipped with a dump box, tailgate auger spreader, and spinner. Class 33 trucks are 5-yd^3 capacity and Class 35 trucks are 10-yd^3 capacity. Dickey-Johns controls are used which are not ground-oriented. Two plow trucks (Class 33 and Class 35) and two other vehicles set up for prewetting. The two plow trucks have Swenson equipment, another vehicle has Bristol equipment, and the Unimog truck has the Schmidt system with microprocessor. The Class 33 and 35 trucks will be used on US 53 and the Unimog truck on I-35 section.
	I-35 in Duluth	Divided, limited access	PCC and DGA	Good	4	35,000	Urban	18	Same as above except the RPU at this site is a SSI unit with three pavement sensors. Site has been thermally mapped but data are not used.	Same as above

Table A-7 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Lake effect state	Minnesota US 53 northwest of Duluth	None	Use rock salt prewetted at spinner with liquid $CaCl_2$ and apply to pavement as a prestorm treatment.	Local weather forecasting from Acu-Weather.	12,000
				Modified electronic meter to use with existing state owned Salinity measuring instrument. Will also use state-owned friction tester.	1,000
	I-35 in Duluth	None	Same as above except use either liquid CMA or potassium acetate and apply at beginning of storm.	Share equipment with US 53 site.	-0-

Table A-8 Summary of state visits - New York.

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Lake effect state	New York SR 104 east of Irondequoit Bridge	Duane E. Amsler, Sr. Program Engineer for Snow and Ice Control Albany Tel: (518) 457-9501 Gerald T. Kerwin Assistant Region Highway Maintenance Engineer Region 4 Rochester Tel: (716) 272-3400 Louis R. Bechle Resident Engineer East Rochester Tel: (716) 586-4514 Gene M. Taillie Highway Maintenance Supervisor East Rochester Tel: (716) 586-4514 Mark Fuller Highway Maintenance Engineer Webster	Reactive deicing	At the beginning of the storm event	At temperatures <20°F, a mixture of 80% sand and 20% salt (by volume) is applied. Alternately, an 83/17 mix can be used at other times during a storm. 100% salt is normally the first application after initiation of a storm event. Application rate of sand/salt mix is ~ 115 lb/lane-mile.	First application: 225 Reapplications: 20-23

Table A-8 (Continued)

Geographic area	State/route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Lake effect state	New York SR 104 east of Irondequoit Bridge	Divided, limited access	DGA from Wayne County line to Five Mile Line Road; PCC from Five Mile Line Road to east of Irondequoit Bridge	Top 1 inch of DGA pavement recycled summer 1991; PCC surface somewhat worn	6	19,900-45,700 on DGA pavement segment; 45,700-53,500 on PCC pavement segment	Sub-urban	40-50	NYDOT contracts with private forecasting service but this information is generally not used by Regional Office. Also, Regional Office has contract with local TV station (channel 13) to provide local weather forecast, including updates as needed and the interpretation of weather data. One RPU is located at east end of Irondequoit Bridge with three pavement sensors. Another RPU is located at west end of Bridge with four pavement sensors.	Single axle vehicles equipped with 6-7 yd^3 slide-in hoppers and metal spinners. Dickey-Johns Model 47 ground-oriented controls are used to regulate application. The spreader equipment normally used is manufactured by Swenson, Frink, or Henderson.

Table A-8 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Lake effect state	New York SR 104 east of Irondequoit Bridge	None	Use rock salt prewetted with liquid $CaCl_2$ at spinner to treat pavement at beginning of storm.	Equipment to prewet rock salt at spinner plus storage tanks, pumps, and liquid chemical	3,900
				Friction tester	1,800
				Ground-oriented control for one truck	2,600

Table A-9 Summary of state visits - Maryland (maritime area)

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Maritime state	Maryland SR 313, SR 349, US 50	Martin J. Knecht, III Assistant Chief Maintenance Management Baltimore Tel: (301) 333-1605 Ray G. Bailey Resident Maintenance Engineer Wicomico County Salisbury Tel: (301) 543-6710 Howard Robinson Highway Maintenance Supervisor Salisbury	Reactive deicing	Treatment after storm begins	100% salt used for all applications. On routes with open-graded bituminous paving, lighter applications are used but more frequently.	250-300 (snow) 100 (ice)

Geographic area	State/ route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Maritime state	Maryland SR 313	2-lane, 2-way	DGA	Good	2	1,100-2,500	Rural	12-14	Channels 16 and 47 in Salisbury are used plus "zone forecast" from NWS. Rely on drawbridge operators as spotters. No RWIS available.	Swenson tailgate auger spreaders with spinner and ground-oriented controls (Dickey-Johns). Single-axle trucks used with 8-ton hoppers. State Highway Administration District has a total of 13 trucks plus contract vehicles.
	Maryland SR 349	2-lane, 2-way	DGA	Poor with many filled cracks	2	1,600-33,000	Rural to Urban	12-14		
	Maryland US 50	Divided, unlimited access	OGA and DGA	Good	4	~ 14,000 -17,000	Rural	12-14		

Table A-9 (Continued)

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Maritime state	Maryland SR 313, SR 349, US 50	District and local maintenance forces have never considered using anti-icing technology because of negative preconceptions. Area also has low frequency of storm events.	Sites not recommended for use.	None	-0-

Table A-10 Summary of state visits - Washington.

Geographic area	State/route	State contacts	Standard treatment strategy: Treatment type	Treatment timing	Deicing material used and associated application rate	Net deicer application rate (lb/lane-mile)
Maritime state	Washington I-90 near SR 18	James R. Spaid, Jr. Road Maintenance Engineer Olympia Tel: (206) 586-4352 Thomas E. Lentz Road Maintenance Engineer District #1 Bellevue Tel: (206) 562-4271 Richard A. Bickle Maintenance Superintendent Area 5 Bellevue Tel: (206) 822-4161 Philip George Assistant Maintenance Superintendent Area 5 Bellevue Pat Moylan Maintenance Supervisor Eastern Area 5 Bellevue Jim McBride Lead Worker Preston	Reactive deicing	Apply mixtures of abrasives and salt at beginning of storm	A mixture of 95% sand and 5% salt (by weight) is used. Liquid "Ice Stop" is used on floating bridges in the Seattle area after ice has formed. Maintenance area at Preston having jurisdiction over site will sweeten the sand-salt mix with straight salt when necessary. Historically, chemicals have been applied only to wet pavements and not to dry pavements. During 1991-92 winter, Preston used a special mix of 90% sand, 8% salt, and 2% CMA. Sand consumption is 2,000 to 3,000 tons/yr in Preston and 1,000 to 1,500 tons/yr in Bellevue.	Application rate not specified but regulated by truck operators. Preston: 300 tons salt/yr Bellevue: 150 tons salt/yr

Geographic area	State/route	Highway type	Pavement type	Pavement condition	Number of lanes	ADT	Area type	Frequency of winter events	Local met support and RWIS available	Spreader equipment available
Maritime state	Washington I-90 near SR 18	Divided, limited access	Portions are DGA and others are PCC	Good	4	~ 21,000	Rural	10 (snow) 30-40 (frost)	WADOT contracts with private forecasting service (Northwest Weathernet). NWS forecasts are not used. RPU located on I-90 east of junction with SR 18 and has one pavement sensor. Site has been thermally mapped but data are not used.	Three plow trucks available at Preston site. These are one tandem truck with 10-yd^3 slide-in hopper and custom spinner; one 6-yd^3 single-axle truck with tailgate auger spreader; and one 6-yd^3 single-axle truck with a Fink front-end dump box. Controls are not ground-oriented.

Geographic area	State/route	Obstacles in way of meeting study goals	Planned procedure	Equipment/support needs from SHRP	Estimated equipment cost ($)
Maritime state	Washington I-90 near SR 18	Reluctance of state and district to use straight salt because of mandate to limit salt usage.	Use rock salt prewetted at modified spinner with either liquid NaCl or mixture of liquid NaCl and CMA. Mixture to be applied to pavement surface at beginning of storm.	Prewetting attachment at modified plastic spinner for Fink equipment, associated storage tank, and pump for liquid deicing chemicals	4,000
				Ground-oriented control	2,600
				Friction tester	1,800
				Salinity measuring instrument	2,700

Appendix B

Individual ASTM E-274 Skid Trailer and Coralba Friction Tester Measurements

Individual Skid and Coralba Measurements

Obs.	Site	Pvt type	Speed (mph)	Device	Lockup ?	Friction	N	Mean	Standard Deviation	CV[1] (100%)
1	NBL[2] TH 53	Asphalt	30	Coralba	yes	0.47				
2	NBL TH 53	Asphalt	30	Coralba	yes	0.43	2	0.45	0.03	6.29
3	NBL TH 53	Asphalt	30.2	Skid	yes	54.9				
4	NBL TH 53	Asphalt	29.2	Skid	yes	55.5				
5	NBL TH 53	Asphalt	29.5	Skid	yes	57.1				
6	NBL TH 53	Asphalt	29.9	Skid	yes	60.3				
7	NBL TH 53	Asphalt	30.3	Skid	yes	60.5	5	57.66	2.63	4.56
8	St. Cloud	Asphalt	30	Coralba	yes	0.26				
9	St. Cloud	Asphalt	30	Coralba	yes	0.28				
10	St. Cloud	Asphalt	30	Coralba	yes	0.26				
11	St. Cloud	Asphalt	30	Coralba	yes	0.22				
12	St. Cloud	Asphalt	30	Coralba	yes	0.23	5	0.25	0.02	9.80
13	St. Cloud	Asphalt	30	Skid	yes	18.4				
14	St. Cloud	Asphalt	30	Skid	yes	18.6				
15	St. Cloud	Asphalt	30	Skid	yes	18.3				
16	St. Cloud	Asphalt	30	Skid	yes	16.8				
17	St. Cloud	Asphalt	30	Skid	yes	16.6	5	17.74	0.96	5.40
18	NBL TH 53	Concrete	30	Coralba	yes	0.41				
19	NBL TH 53	Concrete	30	Coralba	yes	0.32				
20	NBL TH 53	Concrete	30	Coralba	yes	0.39				
21	NBL TH 53	Concrete	30	Coralba	yes	0.36				
22	NBL TH 53	Concrete	30	Coralba	yes	0.36				
23	NBL TH 53	Concrete	30	Coralba	yes	0.39				
24	NBL TH 53	Concrete	30	Coralba	yes	0.37				
25	NBL TH 53	Concrete	30	Coralba	yes	0.32				
26	NBL TH 53	Concrete	30	Coralba	yes	0.36				
27	NBL TH 53	Concrete	30	Coralba	yes	0.41				
28	NBL TH 53	Concrete	30	Coralba	yes	0.31				
29	NBL TH 53	Concrete	30	Coralba	yes	0.29				
30	NBL TH 53	Concrete	30	Coralba	yes	0.33				
31	NBL TH 53	Concrete	30	Coralba	yes	0.28	14	0.35	0.04	12.12
32	NBL TH 53	Concrete	30.8	Skid	yes	60.2				
33	NBL TH 53	Concrete	30.4	Skid	yes	56.4				
34	NBL TH 53	Concrete	30.5	Skid	yes	55.9				
35	NBL TH 53	Concrete	30.1	Skid	yes	58.7				
36	NBL TH 53	Concrete	30.3	Skid	yes	59.5	5	58.14	1.90	3.27
37	I-35	New conc.	30	Coralba	yes	0.43				
38	I-35	New conc.	30	Coralba	yes	0.49				
39	I-35	New conc.	30	Coralba	yes	0.40				
40	I-35	New conc.	30	Coralba	yes	0.51				
41	I-35	New conc.	30	Coralba	yes	0.49	5	0.46	0.05	10.06
42	I-35	New conc.	30.6	Skid	yes	67.3				
43	I-35	New conc.	30.1	Skid	yes	66.9				
44	I-35	New conc.	30.5	Skid	yes	66.0				
45	I-35	New conc.	30.5	Skid	yes	64.2				
46	I-35	New conc.	29.7	Skid	yes	65.2	5	65.92	1.26	1.91

[1] CV = Coefficient of variation = 100 x standard deviation / mean
[2] NBL = Northbound lane
[3] Measurements made on dry pavement

Individual Skid and Coralba Measurements

Obs.	Site	Pvt type	Speed (mph)	Device	Lockup ?	Friction	N	Mean	Standard Deviation	CV[1] (100%)
47	NBL TH 53	Asphalt	40	Coralba	yes	0.46				
48	NBL TH 53	Asphalt	40	Coralba	yes	0.47				
49	NBL TH 53	Asphalt	40	Coralba	yes	0.51				
50	NBL TH 53	Asphalt	40	Coralba	yes	0.45	4	0.47	0.03	5.57
51	NBL TH 53	Asphalt	39.7	Skid	yes	56.6				
52	NBL TH 53	Asphalt	39.7	Skid	yes	58.8				
53	NBL TH 53	Asphalt	39.5	Skid	yes	60.6				
54	NBL TH 53	Asphalt	39.5	Skid	yes	62.6				
55	NBL TH 53	Asphalt	39.0	Skid	yes	58.0	5	59.32	2.33	3.94
56	St. Cloud	Asphalt	40	Coralba	yes	0.22				
57	St. Cloud	Asphalt	40	Coralba	yes	0.21				
58	St. Cloud	Asphalt	40	Coralba	yes	0.26				
59	St. Cloud	Asphalt	40	Coralba	yes	0.19				
60	St. Cloud	Asphalt	40	Coralba	yes	0.21	5	0.22	0.03	11.87
61	St. Cloud	Asphalt	40	Skid	yes	14.8				
62	St. Cloud	Asphalt	40	Skid	yes	14.7				
63	St. Cloud	Asphalt	40	Skid	yes	14.0				
64	St. Cloud	Asphalt	40	Skid	yes	14.6				
65	St. Cloud	Asphalt	40	Skid	yes	16.4				
66	St. Cloud	Asphalt	40	Skid	yes	16.1	6	15.10	0.94	6.21
67	NBL TH 53	Concrete	40	Coralba	yes	0.37				
68	NBL TH 53	Concrete	40	Coralba	yes	0.28				
69	NBL TH 53	Concrete	40	Coralba	yes	0.31				
70	NBL TH 53	Concrete	40	Coralba	yes	0.31				
71	NBL TH 53	Concrete	40	Coralba	yes	0.30				
72	NBL TH 53	Concrete	40	Coralba	yes	0.31				
73	NBL TH 53	Concrete	40	Coralba	yes	0.25				
74	NBL TH 53	Concrete	40	Coralba	yes	0.39				
75	NBL TH 53	Concrete	40	Coralba	yes	0.37				
76	NBL TH 53	Concrete	40	Coralba	yes	0.35	10	0.32	0.04	13.74
77	NBL TH 53	Concrete	39.8	Skid	yes	49.7				
78	NBL TH 53	Concrete	39.8	Skid	yes	54.7				
79	NBL TH 53	Concrete	39.6	Skid	yes	56.6				
80	NBL TH 53	Concrete	40.3	Skid	yes	50.0				
81	NBL TH 53	Concrete	40.9	Skid	yes	55.4	5	53.28	3.21	6.02
82	I-35	New conc.	40	Coralba	yes	0.49				
83	I-35	New conc.	40	Coralba	yes	0.57				
84	I-35	New conc.	40	Coralba	yes	0.47				
85	I-35	New conc.	40	Coralba	yes	0.45				
86	I-35	New conc.	40	Coralba	yes	0.53				
87	I-35	New conc.	40	Coralba	yes	0.51	6	0.50	0.04	8.58
88	I-35	New conc.	39.2	Skid	yes	64.3				
89	I-35	New conc.	39.6	Skid	yes	62.9				
90	I-35	New conc.	40.3	Skid	yes	61.6				
91	I-35	New conc.	39.8	Skid	yes	61.6				
92	I-35	New conc.	40.4	Skid	yes	60.9	5	62.26	1.35	2.17

[1] CV = Coefficient of variation = 100 x standard deviation / mean
[2] NBL = Northbound lane
[3] Measurements made on dry pavement

Individual Skid and Coralba Measurements

Obs.	Site	Pvt type	Speed (mph)	Device	Lockup ?	Friction	N	Mean	Standard Deviation	CV[1] (100%)
93	NBL TH 53	Concrete	20	Coralba	yes	0.40				
94	NBL TH 53	Concrete	20	Coralba	yes	0.17				
95	NBL TH 53	Concrete	20	Coralba	yes	0.23				
96	NBL TH 53	Concrete	20	Coralba	yes	0.39				
97	NBL TH 53	Concrete	20	Coralba	yes	0.32	5	0.30	0.10	33.23
98	NBL TH 53	Asphalt	30	Coralba	no	0.43				
99	NBL TH 53	Asphalt	30	Coralba	no	0.45				
100	NBL TH 53	Asphalt	30	Coralba	no	0.52				
101	NBL TH 53	Asphalt	30	Coralba	no	0.42				
102	NBL TH 53	Asphalt	30	Coralba	no	0.49				
103	NBL TH 53	Asphalt	30	Coralba	no	0.40				
104	NBL TH 53	Asphalt	30	Coralba	no	0.40				
105	NBL TH 53	Asphalt	30	Coralba	no	0.46				
106	NBL TH 53	Asphalt	30	Coralba	no	0.44				
107	NBL TH 53	Asphalt	30	Coralba	no	0.45				
108	NBL TH 53	Asphalt	30	Coralba	no	0.43	11	0.44	0.04	8.13
109	NBL TH 53	Concrete	30	Coralba	no	0.28				
110	NBL TH 53	Concrete	30	Coralba	no	0.38				
111	NBL TH 53	Concrete	30	Coralba	no	0.30				
112	NBL TH 53	Concrete	30	Coralba	no	0.41				
113	NBL TH 53	Concrete	30	Coralba	no	0.39				
114	NBL TH 53	Concrete	30	Coralba	no	0.41	6	0.36	0.06	15.78
115	I-35	New conc.	30	Coralba	no	0.45				
116	I-35	New conc.	30	Coralba	no	0.51				
117	I-35	New conc.	30	Coralba	no	0.49				
118	I-35	New conc.	30	Coralba	no	0.55				
119	I-35	New conc.	30	Coralba	no	0.47				
120	I-35	New conc.	30	Coralba	no	0.56	6	0.51	0.04	8.65

[1] CV = Coefficient of variation = 100 x standard deviation / mean

[2] NBL = Northbound lane

[3] Measurements made on dry pavement

Individual Skid and Coralba Measurements

Obs.	Site	Pvt type	Speed (mph)	Device	Lockup ?	Friction	N	Mean	Standard Deviation	CV[1] (100%)
121	NBL TH 53	Asphalt	40	Coralba	no	0.46				
122	NBL TH 53	Asphalt	40	Coralba	no	0.41				
123	NBL TH 53	Asphalt	40	Coralba	no	0.34				
124	NBL TH 53	Asphalt	40	Coralba	no	0.45				
125	NBL TH 53	Asphalt	40	Coralba	no	0.44				
126	NBL TH 53	Asphalt	40	Coralba	no	0.40				
127	NBL TH 53	Asphalt	40	Coralba	no	0.35				
128	NBL TH 53	Asphalt	40	Coralba	no	0.40				
129	NBL TH 53	Asphalt	40	Coralba	no	0.46				
130	NBL TH 53	Asphalt	40	Coralba	no	0.44				
131	NBL TH 53	Asphalt	40	Coralba	no	0.46				
132	NBL TH 53	Asphalt	40	Coralba	no	0.41				
133	NBL TH 53	Asphalt	40	Coralba	no	0.45	13	0.42	0.04	9.63
134	NBL TH 53	Concrete	40	Coralba	no	0.35				
135	NBL TH 53	Concrete	40	Coralba	no	0.43	2	0.39	0.06	14.50
136	I-35	New conc.	40	Coralba	no	0.56				
137	I-35	New conc.	40	Coralba	no	0.54				
138	I-35	New conc.	40	Coralba	no	0.57				
139	I-35	New conc.	40	Coralba	no	0.51				
140	I-35	New conc.	40	Coralba	no	0.52				
141	I-35	New conc.	40	Coralba	no	0.60	6	0.55	0.03	6.08
142	NBL TH 53	Concrete	20	Coralba	no	0.26				
143	NBL TH 53	Concrete	20	Coralba	no	0.39				
144	NBL TH 53	Concrete	20	Coralba	no	0.35	3	0.33	0.07	19.97
145	NBL TH 53	Asphalt	40	Coralba[3]	no	0.46	1	0.46		
146	NBL TH 53	Asphalt	40	Coralba[3]	yes	0.44				
147	NBL TH 53	Concrete	40	Coralba[3]	yes	0.34	2	0.39	0.07	18.13

[1] CV = Coefficient of variation = 100 x standard deviation / mean

[2] NBL = Northbound lane

[3] Measurements made on dry pavement

Appendix C

Forms and Instructions for Anti-Icing Experiments

WEATHER AND PAVEMENT CONDITION LOG

NAME: ______________________ AGENCY: ______________________

Date	Time	Type of Precipitation								Section Observed		Location (Route and Milepost)	Lane No. and Direction	Type of Pavement*	Observed Pavement Condition														Friction Value
															Wheel Track							Outside Wheel Track							
		Drizzle	Rain	Fr. Rain	Sleet	Lt. Snow	Snow	Blowing Snow	None	Test	Control				Dry	Wet	Slush	Snow	Ice	Snow/Ice Pack	Other	Dry	Wet	Slush	Snow	Ice	Snow/Ice Pack	Other	

* Indicate as either PCC, DGA, or OAG. PCC-Portland Cement Concrete; DGA-Dense-Graded Asphalt; OGA-Open-Graded Asphalt

Figure C-1 Example weather and pavement condition log.

WEATHER AND PAVEMENT CONDITION LOG

- Date
- Time — Military Time 2400 hours
- Type of Precipitation (check applicable type)
  - Drizzle
  - Rain
  - Freezing Rain
  - Sleet
  - Light Snow
  - Snow
  - Blowing Snow
  - None
- Section Observed — Test or Control (check applicable)
- Location — Route and Milepost
- Lane No. and Direction of Travel (e.g., Northbound)
  - Driving Lane (DL)
  - Center Lane (CL)
  - Passing Lane (PL)
- Type of Pavement — PCC, DGA or OGA
- Observed Pavement Condition (check applicable) — Wheel track and-outside wheel track

Dry	Snow
Wet	Ice
Slush	Snow/Ice Pack
	Other

- Friction Value (Coralba reading)

Figure C-2 Instructions for weather and pavement condition log.

Anti-Icing Operation Aborted

Date ____

Time ____

OPERATOR ACTIVITY LOG (TEST SECTION)

STATE OF ____

Name of Operator: ____ Truck I.D. No. ____

Location of Highway: ____

Spreader Make and Model ____ Type of Spreader Control ____

Was spreader calibrated prior to use (Yes or No): ____ If so, when: ____

Date	Treatment Start Time	Section Treated		Type of Material Applied	Pump/or Conveyor-Auger Settings	Spinner Setting	Pass No.	Lane Being Treated[1]	Method of Treatment[2]	Approx. Speed (mph)	Comments or General Weather/Pavement Conditions
		Test	Control								

1 *Indicate DL, CL, PL, DL + CL, or CL + PL. DL = Driving Lane; CL = Center Lane; PL = Passing Lane; DL + CL = Driving and Passing Lanes; or CL + PL = Center Lane and Passing Lanes.*
2 *Indicate P, C, A, S, P+C, or P + A. P = Plowing; C = Chemical; A = Abrasives; S = Sweeping; P+C = Plowing + Chemical treatment; or P + A = Plowing + Abrasives.*

Figure C-3 Example operator activity log (test section).

Anti-icing Operation Aborted

Date ______

Time ______

OPERATOR ACTIVITY LOG (CONTROL SECTION)

STATE OF ______________________

Name of Operator: ______________________ Truck I.D. No. ____________

Location of Highway: ______________________

Spreader Make and Model ____________ Type of Spreader Control ____________

Was spreader calibrated prior to use (Yes or No): ______ If so, when: ____________

Date	Treatment Start Time	Section Treated		Type of Material Applied	Pump/or Conveyor-Auger Settings	Spinner Setting	Pass No.	Lane Being Treated[1]	Method of Treatment[2]	Approx. Speed (mph)	Comments or General Weather/Pavement Conditions
		Test	Control								

1 Indicate DL, CL, PL, DL + CL, or CL + PL. DL = Driving Lane; CL = Center Lane; PL = Passing Lane; DL + CL = Driving and Passing Lanes; or CL + PL = Center Lane and Passing Lanes.

2 Indicate P, C, A, S, P+C, or P + A. P = Plowing; C = Chemical; A = Abrasives; S = Sweeping; P+C = Plowing + Chemical treatment; or P + A = Plowing + Abrasives.

Figure C-4 Example operator activity log (control section).

OPERATOR ACTIVITY LOG

- Date
- Treatment Start Time — Military Time 2400 hours
- Section Treated — Test or Control (check applicable)
- Type of Material Applied — Salt, Sand/Salt %
- Pump/or Conveyor — Auger Setting (1-11 or lbs)
- Spinner Setting
- Pass No. (First, Second, Third, etc.)
- Lane Being Treated [Driving Lane (DL), Center Lane (CL), Passing Lane (PL), or any combination of the three (e.g., DL + CL)]
- Method of Treatment
    - Plowing (P)
    - Chemical (C)
    - Abrasives (A)
    - Sweeping (S)
    - Plowing + Chemical Treatment (P + C)
    - Plowing + Abrasives (P + A)
- Approximate Speed (mph)
- Comments or General Weather/Pavement Conditions
- Point at which anti-icing operation was aborted

Figure C-5 Instructions for operator activity log.

SOBO/CORALBA DATA RECORDING FORM 2

Name: ____________________ Agency: ____________________ Date: __________

Time: ________ Hours Test Location: ______________________________

General Weather Condition: ______________________________

General Pavement Condition: ______________________________

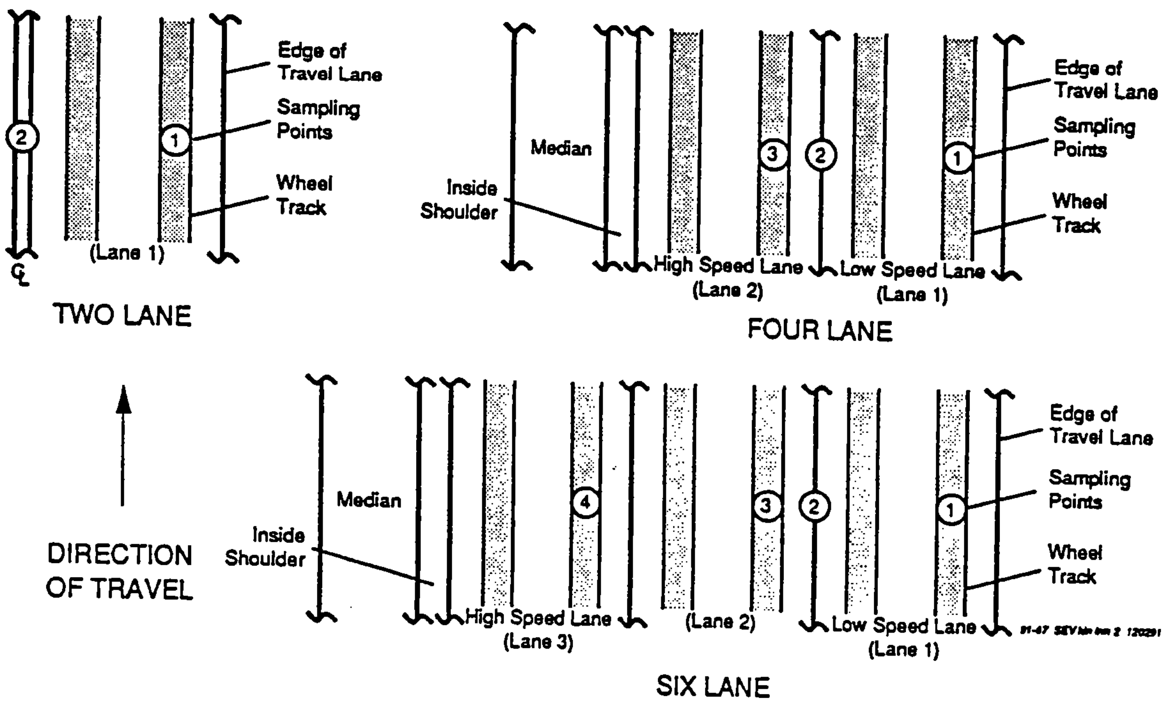
Type of Pavement: _____ Open Graded Asphalt _____ Dense Graded Asphalt _____ Concrete

No. of Lanes _____ Direction of Travel: Test Section ________ Control Section ________

Direction of Cross Slope: ______________________________

Test Location Relative to Nearest RWIS Site: ______________________________

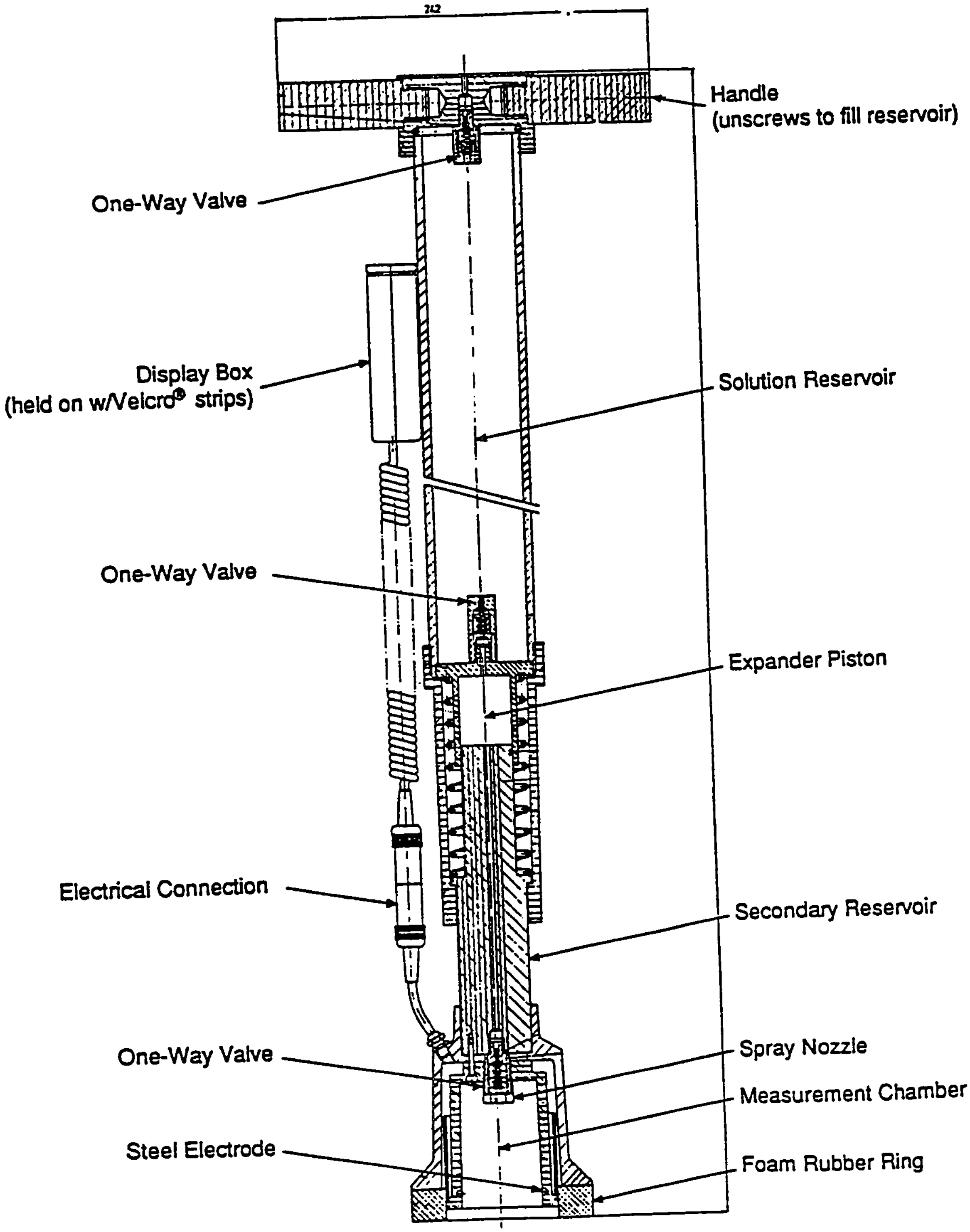
TEST SECTION			CONTROL SECTION			COMMENTS
Sampling Point	Scale Factor	Sobo Reading	Sampling Point	Scale Factor	Sobo Reading	
1			1			
2			2			
3			3			
4			4			
5			5			
Coralba Reading: Lane 1: _____; Lane 2: _____; Lane 3: _____			Coralba Reading: Lane 1: _____; Lane 2: _____; Lane 3: _____			



SAMPLING POINTS FOR DIFFERENT ROAD CONFIGURATIONS

Figure C-6 Example SOBO-20 data form.

SOBO 20 CHLORIDE MEASURING INSTRUMENT



Schematic courtesy of Boschung Co., Inc. U.S.A.

Figure C-7 Schematic of SOBO-20 instrument.

OPERATING INSTRUCTIONS FOR SOBO 20 CHLORIDE MEASURING INSTRUMENT

1. Unscrew handle of instrument and fill reservoir with acetone solution. (Note: solution is prepared by mixing 15 parts technical grade acetone with 85 parts distilled or deionized water.) Reservoir holds approximately 1.5 L of solution which is adequate for about 35 measurements.

2. Install 9 volt battery in electronic display box, attach box to body of instrument, and connect display to electrical lead located at bottom of instrument.

3. Prime the system by depressing and releasing the expander piston twice in succession and allow the waste liquid to discharge from bottom of instrument.. This fills the secondary reservoir and prepares the instrument for use.

4. Activate the instrument by sliding the on-off switch (lowest switch on the display box) to the on position.

5. Slide the measure-test switch (upper switch on the display box) to the test position, slide oz/yd^2 switch to the x1/2 scale, and note reading on display. Repeat for x1 scale.

6. If display reading on x1/2 scale is not "10" or x1 scale is not "5" replace battery in display box.

7. Switch the instrument off, slide the measure-test switch to the measure position, and turn the meter on. The display should read "0".

8. Move the oz/yd^2 (middle) switch to the x1/2 scale.

9. Place the bottom of the instrument firmly on the surface to be measured keeping it as level as possible. (Note: measurements can be made on wet or slushy surfaces but <u>do not install instrument over ice or compacted snow</u>.)

10. Keeping instrument vertical and firmly sealed, slowly depress the expander piston until it stops.

Figure C-8 Operating instructions for SOBO-20.

OPERATING INSTRUCTIONS (CONT'D)

11. Decrease pressure on the instrument slightly, hold in position for approximately 5 seconds, and record reading on display.

12. If display reads "15" after 5 sec holding period, change oz/yd^2 switch to x1 scale and record reading. **(Note: if two lights are illuminated, the reading should be recorded as 1/2 unit above lowest of the two.)** During this period, make sure seal between bottom of instrument and surface remains intact with no liquid loss.

13. Release pressure on instrument and move to next measurement location. Repeat steps 8 through 12.

14. After completing the test series, move the on-off switch to the off position to conserve battery power. Flush measurement chamber with distilled or deionized water and discard.

15. After each storm event maintain and recalibrate instrument as provided in separate **MAINTENANCE AND CALIBRATION INSTRUCTIONS.**

Figure C-8 (Continued)

MAINTENANCE AND CALIBRATION INSTRUCTIONS FOR SOBO 20 CHLORIDE MEASURING INSTRUMENT

(Note: Maintenance must be performed after each storm event. Calibrations must be performed upon receipt of instrument and during post-storm maintenance.)

1. Remove foam rubber ring from bottom of instrument, soak ring in distilled or deionized water, and allow to dry.

2. Flush the measurement chamber with distilled or deionized water and discard.

3. Using brass wire brush, clean each of the two steel electrodes. (NOTE: DO NOT TOUCH THE BLUE DOT-SHAPED PROBE WITH THE WIRE BRUSH--THIS DAMAGES INSTRUMENT AND MAKES IT UNUSABLE.) See Sobo Instruction Manual for details.

4. Flush the measurement chamber with distilled or deionized water and discard.

5. Check battery in display box (see **OPERATING INSTRUCTIONS**) and replace, if necessary.

6. Check each of the three one-way valves in the instrument periodically and replace components, as necessary. See Sobo Instruction Manual for details.

7. Reinstall foam rubber ring on bottom of instrument. The Sobo is now ready for calibration.

8. To calibrate instrument, dispense 3 drops of chloride calibration solution using eye dropper (provided by MRI) into bottom of plastic pan (provided by MRI) making sure all liquid is contained within the same "drop".

9. Place Sobo instrument over "drop" of calibration solution in pan and conduct measurement in the usual manner (see OPERATING INSTRUCTIONS). Record display reading.

Figure C-9 Maintenance and calibrations for SOBO-20.

10. Compare display reading to that obtained immediately after receipt of the instrument. If the reading varys by more than 1 unit from the "new" value, notify MRI immediately.

11. The instrument should now be ready for use in the field.

Figure C-9 (Continued)

MEASUREMENT CRITERIA FOR THE SOBO 20 INSTRUMENT

1. A series of measurements should be made at each of the locations shown on the Sobo/Coralba Data Form: well in advance of the storm (i.e., **dry pavement**); and after the initial application of anti-icing chemicals **at the point when the pavement first becomes wet.** Additional measurements should be made at **Sampling Points 1 and 2 only** when: partially melted precipitation (i.e., **slush**) **covers the pavement** surface; and the **pavement first becomes bare** after the second (or subsequent) applications of anti-icing chemicals.

2. Each measurement series must be made **at the same location along the test and control section** of the roadway and **at the same point across each travel lane.** Some type of identification (e.g., paint marks, marker poles, etc.) should be used to assure that this is accomplished **every time a series of measurements is made.**

3. Carefully select each measurement point to assure that the pavement is relatively flat and in good condition with no cracks, holes, patches, etc. The site should also have good sight distance for safety.

4. Measurements must be made on dry pavement, wet pavement, or pavement with a layer of partially melted precipitation (i.e., slush). **Measurements cannot be made on pavement with a layer of ice or compacted snow.**

5. Select one measurement location near the RWIS site and carefully document the position of the sampling points relative to the RWIS pavement sensors.

6. Visually compare the pavement condition to RWIS sensor indications and note on the separate form provided.

7. Copy each data form and mail to MRi for processing. **Do not mail original data.**

Figure C-10 Measurement criteria for the SOBO-20.

INSTRUMENT CALIBRATION FORM

STATE OF ________

LOCATION OF HIGHWAY ____________________________

Operator Name	Calib. Date	Type of Instrument	Serial No.	Calibration Data

Figure C-11 Example instrument calibration form.

OPERATING INSTRUCTIONS FOR THE CORALBA C-u FRICTION METER

1. Install Coralba C-u Friction Meter on vehicle according to manufacturers specifications (see Coralba Manual for details).

2. Calibrate instrument according to separate calibration instructions immediately upon installation of the unit and after each storm event. Permanently record calibration results and submit photocopies of the data to MRI.

3. To make a friction measurement, press FRICT key. Display value should not change.

4. Press RESET key to clear register. Display should indicate a value of "0.00". (Note: measurement will continue even if you select another register.)

5. At beginning of roadway section to be measured, accelerate vehicle to approximately 40 mph (or maximum safe speed--specify any difference from 40 mph on appropriate data form), depress clutch pedal (or move automatic transmission shift level to NEUTRAL), and allow the vehicle to roll freely approximately 10 m (30 ft).

6. Brake firmly for a maximum of 6 seconds allowing wheels to lock. (Note: maximum braking potential must be used during the measurement process.)

7. If vehicle comes to a complete stop, brakes must be released immediately after stopping to indicate such to the instrument.

8. Read value of friction coefficient on display and record on data form.

Figure C-12 Operating instructions for the Coralba.

OPERATING INSTRUCTIONS (CONT'D)

9. Press the HALT key, note the value on the display, and record on the data form. Press HALT again--value on the display should be the same as in No. 8 above.

10. Repeat measurement for each travel lane on both the test and control sections by pressing RESET after each determination. Record data accordingly.

Figure C-12 (Continued)

CALIBRATION INSTRUCTIONS FOR THE CORALBA C-u FRICTION METER

1. Calibrate instrument during initial installation and after every storm event. Calibration should be performed on DRY pavement.

2. Check tire pressure and inflate, as necessary, to manufacturers specifications.

3. Select a known distance of road greater than 1 mile in length (e.g., the distance between several calibrated mile markers) and note distance on calibration form. Also select a reference point on vehicle (e.g., window post, etc.).

4. Before proceeding, select TRIP 1 on key pad. Display should read "TRIP 1."

5. Press CAL. Display will read current calibration constant--ignore reading during first instrument calibration.

6. Press SET (display will flash), enter known length in four significant figures (e.g., 2.000 miles), and press SET again.

7. Select TRIP 1 and press RESET to clear trip register. (Note: you must select the (+) mode and should not press the SPLIT key.)

8. Drive the known distance of roadway, stop, note the display reading and record on calibration form. This is your new calibration constant (four significant figures).

9. Store new calibration constant by selecting TRIP 1, press CAL then SET, and enter calibration constant from data form.

10. Press SET again to store new constant.

Figure C-13 Calibration instructions for the Coralba.

CALIBRATION INSTRUCTIONS (CONT'D)

11. Select TRIP 1 and drive known road distance again. Note display and compare to known distance. If all factors are correct, the length should correlate exactly.

12. If display and known distance vary by more than 3%, repeat calibration procedure above.

Figure C-13 (Continued)

RAYNGER PM-4 DATA FORM

Name: ______________________________

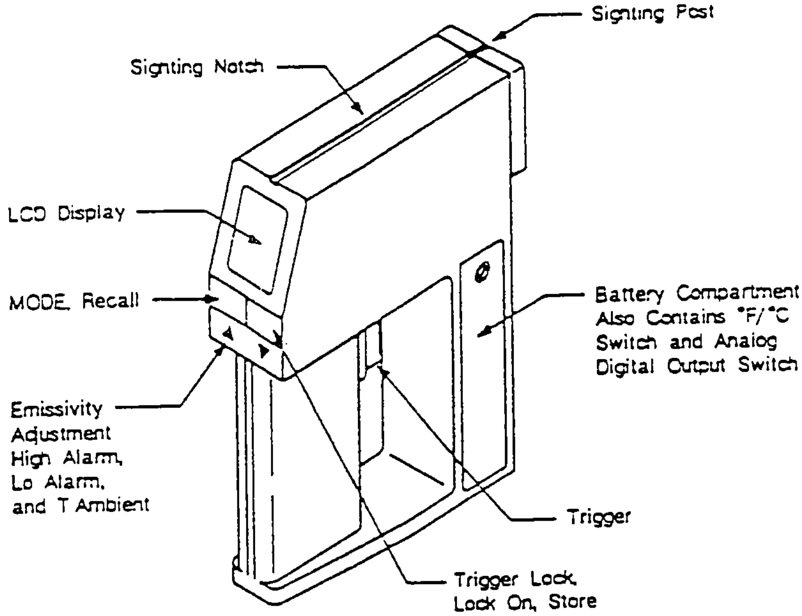
Agency: ______________________________

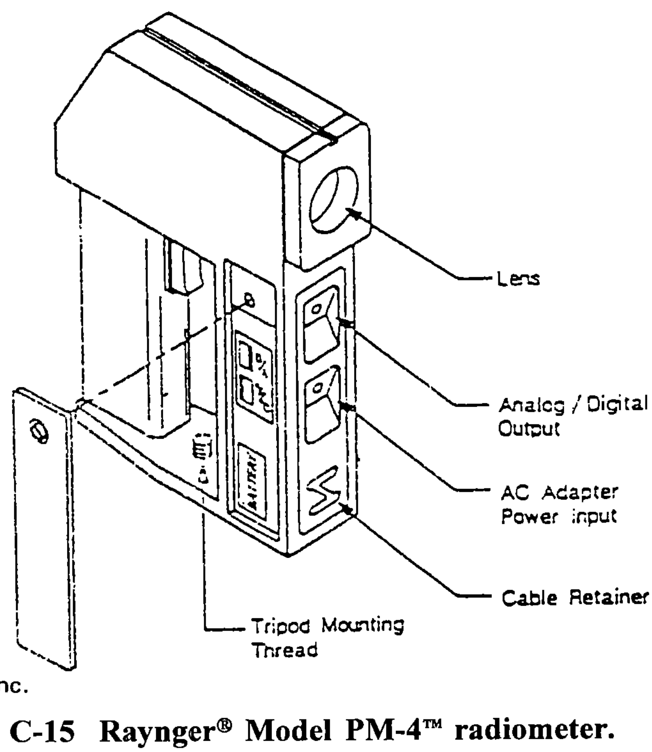
Location of Highway: ______________________________

Date	Time	Section Measured	Measurement Location	Average Pavement Temperature (° F)

Figure C-14 Example radiometer data form.

RAYNGER MODEL PM-4 RADIOMETER





Drawings courtesy of Raytech Inc.

Figure C-15 Raynger® Model PM-4™ radiometer.

OPERATING INSTRUCTIONS FOR THE RAYNGER PM-4 RADIOMETER

1. To set emissivity, press and hold trigger.

2. Press MODE key and select either MAX, MIN, DIF, or AVG. Lower left portion of display should read MAX, MIN, DIF, or AVG.

3. Using arrow keys set emissivity reading to 0.95 (for dry asphalt and concrete). Display should read e = .95.

4. To set audible alarm, press and hold trigger.

5. Using MODE key, select LAL in lower left corner of display.

6. Set low alarm temperature to 32 using arrow keys.

7. Activate alarm by pressing LOCK. Display should read LO ALARM in left middle of readout. (Alarm will now sound if pavement temperature is ≤ 32° F.)

8. Set automatic temperature compensation by selecting an emissivity of 1.0 as indicated in steps 1 to 3 above.

9. Using MODE key, select AVG in lower left corner of display.

10. Pan the unit over the area surrounding the roadway several times. Note the value displayed next to the AVG readout on the display--this is your compensation value.

11. Press MODE key, select TAM, and set ambient temperature value to that obtained in step 10 above using arrow keys.

12. Press LOCK to activate temperature compensation. Display should read TAMB.

13. Readjust emissivity to 0.95 as indicated in steps 1 to 3 above.

14. Using MODE key, set lower display to AVG. The unit is now ready to operate.

Figure C-16 Operating instructions for the Raynger® PM-4™ radiometer.

OPERATING INSTRUCTIONS (CONT'D)

15. Determine average pavement temperature by pointing the unit downward at arms length.

16. If pavement is wet reset emissivity to 0.93. If pavement is snow covered or slushy reset emissivity to 0.9. Display should indicate e = .93 or e = .90, respectively.

17. Press trigger and push LOCK key to take continuous measurements.

18. Swing the instrument in a circular motion in approximately a 2 ft radius.

19. Walk across the width of the travel lanes while swinging the instrument.

20. Repeat the above by returning back across the travel lanes to the starting point. Do not push LOCK key or release trigger.

21. Record average pavement temperature on data form. Repeat measurement at other locations, as desired. (Note that alarm will sound if pavement temperature is $\leq$ 32° F.)

Figure C-16 (Continued)

Appendix D

Meteorological Criteria and Support for Anti-Icing Operations at Potential Test Sites

Meteorological Service to Department of Transportation Maintenance

General Discussion

Specialized weather service to the road-maintenance field has not yet developed in the United States to the level needed to accomplish significant gains in traffic safety, efficient and cost-effective maintenance procedures, or increased traffic flow when weather events are the determining factor.

Most winter snowfalls result in accumulations of 25 to 76 mm (1 to 3 in). Forecasts of these events do not have a good statistical verification record—the early indications are too subtle. The general forecast procedure in these cases is to use probabilities in the range of 20% to 40%, numbers with little value for maintenance decisions.

Significant events—those with heavy snow and accompanying complications—are more accurately anticipated by the meteorological community. Mathematical models used by the National Weather Service rarely fail in these cases, and experts at the National Meteorological Center enhance these indications by various corrective procedures. However, these significant events occur only about three times per season at most locations, while the lesser events referred to above are frequent. Ways must be found to deal effectively with the lesser events.

There are providers in the field who have developed complete road-weather systems, from road-weather stations to meteorological forecast services. But the systems used are proprietary and can be costly. In addition, they rely too heavily on automation, reducing interaction between the provider and an informed user.

Significant gains in winter maintenance can be achieved by the proper provision and use of weather information. Most of those gains can be realized in short-term reaction to imminent weather events. Following are systems and procedures designed to produce that result.

Road-Weather Meteorology

Providers and Developments

There are numerous providers of local weather forecasting services. Except for two or three proprietary systems, there has been little effort in the United States to develop road-weather meteorology as a specialty within the general field of meteorology. The criteria for selection of private forecasting services that follow and the requirements for actual forecast elements are intended to aid such a development.

Problems To Be Overcome in the Development of Road-Weather Meteorology

Most meteorological work is done on the macro (large) scale, while the road-weather regime is in the meso (small) or micro (very small) scale. The finer meteorological scales require greater attention to detail, good communication, and cooperation between the provider and the user. Special techniques and tailored meteorological products will be required for each application.

General forecasting fits expected weather events into periods of time, usually 6-hr increments. Often, however, a 48-hr period is divided into four increments (e.g., tonight, tomorrow, tomorrow night, and the following day). Forecasts for the aviation community are more specific, calling for expected events within 30 min in a 2-hr time frame.

In order to meet the needs of a fully responsive road-weather service, the time between the forecast and the event should be reduced to about 15 min. At the current level of development, this calls for almost constant dialogue between the forecaster and a knowledgeable decision maker at the operational level.

In addition to the scale and time requirements of weather service to Department of Transportation (DOT) maintenance personnel, the individual nature of each locality as well as variations within each locality must be considered. This suggests that weather service for road-weather support must be site-specific.

Guidelines for Selecting a Private Meteorological Service Provider for Road-Weather Forecasts

The usual practice has been to select a service on the basis of the lowest bid. If bidders certify that they meet certain basic criteria, their bids are valid. Generally, no inspections of the facilities for adherence to professional standards are made and no effort undertaken to develop the site-specific procedures needed in road-weather forecasting.

The "lowest bidder" requirement may be a costly error when used in the selection of a forecast provider. The funding used for this service maybe wasted if it does not buy the level of service required by the goals established for a specific maintenance program.

It is sometimes said that there should be little or no geographical requirement in the selection of a forecast provider. However, the following factors should be considered:

- Shorter lines of communication ensure more frequent and fruitful interchange between the provider and user.
- A provider in the same geographical area may be more familiar with special problems and has a vested interest in doing well in that area.
- Nearby providers are accessible for inspection and aid in developing special techniques and products for site-specific weather service.

Procedures for Selecting a Forecast Provider

Most state and local governmental agencies do not have an expert to advise them when selecting a meteorological provider. Contrast that with the procedures used in selections made in many other professional fields. This situation can be addressed by the following:

- Engage a professional meteorologist to aid in writing each Request for Proposal for site-specific weather forecasting services.
- Have the meteorologist review the bidders and establish a qualified review panel.
- Have the meteorologist make an on-site inspection of each bidder, using criteria for level of professionalism, adequate staff, etc.
- Use the meteorologist's advice in making the final selection. Although cost must be a factor, overriding considerations may eliminate it as the final deciding factor.

Specific Criteria for a Road-Weather Forecast Service

The selected road-weather forecast service should have

- a professional staff of sufficient size to provide the level of support needed;
- knowledge of road-weather forecasting problems, including scale and time;
- a willingness to engage in the development of site-specific services;
- a comprehensive bias-correcting verification system;
- a willingness to work with DOT maintenance personnel in the development of interactive service systems;
- rapid and reliable communication systems and a practice of utilizing new technologies as they come on-line; and,
- if possible, an office in the same geographical area.

Specific Forecast Requirements

General forecasts should be issued and transmitted to the user in the same format and frequency as those from the National Weather Service. These include three-times-daily forecasts out to 72 hr as well as all extended routine issuances.

When forecasts call for a 40% or greater probability of accumulating ice or snow, a special forecast should be issued and transmitted 4 hr in advance of the expected time of occurrence, updating regularly scheduled forecasts.

The forecaster should use inputs from the user, utilizing telephone or other means of interactive communication, in order to deal with weather events on a real-time basis.

Forecast Format

The following forecast information should be provided on an hour-by-hour breakdown for an upcoming 24-hr period and appended to the regularly scheduled and updated forecasts specified above.

- In graphic format
  - Ambient air temperature

- ♦ Road-surface temperature
- ♦ Dewpoint temperature

- In table format

  - ♦ Precipitation probability
  - ♦ Precipitation type
  - ♦ Precipitation amount
  - ♦ Precipitation rate
  - ♦ Wind direction and speed
  - ♦ Expected road condition, including the potential for frost formation on roadways

- In a general discussion format

  - ♦ Estimated snow/water ratio
  - ♦ Comments on how that ratio may change during a particular event
  - ♦ Specific starting and ending times for precipitation
  - ♦ Probable cloud cover for the next 24 hr
  - ♦ Changes that may occur in wind direction and speed
  - ♦ Chance of blowing snow and possibility of snow sticking to road surfaces

Updates

Updates should be initiated by the provider or in response to information from the user whenever changes in any of the following occur

- time of likely precipitation or frost;
- type of precipitation, expected or actual;
- amount of precipitation, expected or actual;
- road condition, expected or actual;
- actual road-surface temperature deviation of 1.7°C (3°F) from expected state highway agency monitors (in any case, road-surface temperatures should be updated every 3 hr); and
- any other parameter that affects, or is expected to affect, road condition.

Communication

All current forms of communication should be employed, including hard copy by fax or computer terminal and interactive discussions by telephone or other means of voice communication.

Summary

The requirements for a forecast service and the criteria for actual forecast services in the foregoing are somewhat stringent. The purpose of this is to engage a selected provider in the development of road-weather meteorology as a specialty and to facilitate the development of an interactive service system for maintenance support.

Utilization of Weather Forecasts and Information by Maintenance Offices

In order to respond properly to weather inputs of all types, the decision maker at the operational level must achieve some degree of practical meteorological expertise. This need not be a comprehensive training course but should provide that person with enough knowledge to recognize weather phenomena; to observe, analyze, and recognize the significance of various reports and depictions; and to apply that knowledge to ongoing events. Experience will make it possible to initiate strategies quickly without losing time in consultation with a forecaster.

A good working knowledge of meteorology at the operational level is a key to the desired level of efficiency needed. It is a working part of "nowcasting," discussed below.

Appendix E

Scandinavian/European Trip Report

Introduction and Purpose of Trip

The Organization for Economic Cooperation and Development report titled "Curtailing Usage of Deicing Agents in Winter Maintenance"[7] indicated that a number of Scandinavian and other European countries were experimenting with new and highly promising techniques and systems that would lead to substantial savings in deicing agents. Some of these new and highly promising techniques include preventive salting, use of liquid salt, and prewetted salt spreading.

A number of road administrations in the Scandinavian and other European countries were identified as having successfully practiced these techniques. Also, it was determined that a number of European spreader manufacturers sell equipment that can be used in these new techniques.

Therefore, the project team traveled to a number of these countries to discuss their approaches and the equipment used in their operations. The information which was sought included both successes and failures and any unpublished maintenance operational data on the effectiveness of the anti-icing operations. The team planned to obtain operating and performance data on a firsthand basis without the delays and disadvantages associated with international communication.

The information and data collected from various road administrations during the visit were used to help guide the analysis of the 1991-92 winter maintenance data as well as plan the field test for the 1992-93 winter. The data obtained from the equipment manufacturers were used to finalize the equipment testing protocols and develop a profile of available equipment and its expected performance in anti-icing operations.

The project team interviewed road administration supervisors in the United Kingdom, Finland, Denmark, and the Netherlands and equipment manufacturers in Finland, Denmark, the Netherlands, and Germany.

Experience with Anti-Icing Operations

In the countries visited by the project team, preventive salting with liquid salt brine and/or prewetted salt are considered as anti-icing operations in the United States. Findings included the practice of applying salt before ice or snow occurs, thereby requiring considerably less salt to keep roadways clear. This concept was reported repeatedly in the following countries: the United Kingdom, Finland, Denmark, and the Netherlands.

United Kingdom

In the United Kingdom, the project team met with Mark Ponting, Contracts Manager of Hereford and Worcester Contracting, who had conducted extensive research and had traveled extensively in Europe in pursuit of the development of anti-icing methodology for the United Kingdom. At the present time, he administers the maintenance activities in Hereford and Worcester counties.

Having been awarded the Winston Churchill Traveling Fellowship in 1982, he spent 5 weeks in Northern Europe. He visited more than 100 establishments, and at the end of that tour, he concluded that no measure of excellence or accountability had been achieved and no one line of research could be identified as being completely satisfactory. In retrospect, he believes that he should have traveled to the Scandinavian countries instead of to Northern Europe. He noted that the road administrations in various Scandinavian countries have conducted a number of winter maintenance operation studies.

Ponting concluded that the only way to reduce salt usage and other resources was to improve weather forecasting and monitoring. A joint research project was developed with Dr. John Thornes, head of Meteorological Services at Birmingham University and the Transport Research Laboratory, Crowthorne, to establish the usefulness of thermal mapping and its viable application for permanent installation of road sensors.

In 1983, thermal mapping was conducted on 25 routes in Hereford and Worcester counties. In analyzing the findings, it was determined that the number of potential problem areas was twice the number identified by experienced maintenance personnel. As a result of thermal mapping, 12 road weather information system (RWIS) sites were installed in 1986. As a result, during the winter of 1986-87, the accuracy for anti-icing weather forecasting increased from 57% to 91%. Since the installation of the RWIS stations and the increase in accuracy of weather forecasting, the managing contractor has realized a savings of approximately $240,000. Currently, there are 14 RWIS stations alone in the Hereford area.

The weather forecasting service is provided by the British Meteorological Office. This office also makes a 24-hr pavement forecast at noon each day during the winter months. The Meteorological Office uses the "Ice Prediction System," which was developed by Thornes. As a result of the forecasting model, which is used to predict minimum road surface temperatures during the winter, highway authorities are improving information used to base decisions on whether to apply salt on a given night. Many highway authorities in the United Kingdom are claiming that salt consumption has been reduced by about 20% as a result of improved weather forecasting.

The Hereford and Worcester counties typically have three different winter climate areas. The Birmingham area is considered a moderate type with up to six freeze-thaw cycles per day. The western area has a colder climate, while the southern is warm and moist due to the flow of air up from the British Channel.

The salt used in the area is from a single mine in the United Kingdom. The gradation of British salt is much finer than the material used in the United States. Salt gradation requirements are listed in the British Standard (BS 3247). The United Kingdom's salt has 5% marl content, which causes it to have a reddish color. In addition, the normal moisture content of the salt is 5% or greater. Therefore, British winter maintenance services do not prewet their salt during spreading operations.

British application rates are as follows:

Anti-icing (wet road and drying)	> −5°C (23°F) > −10°C (14°F)	10 g/m² (130 lb/lane-mile) 20 g/m² (260 lb/lane-mile)
Deicing		20 g/m² (260 lb/lane-mile)
Light snowfall, −2°C (28.4°F)	> 1/2 in (1.25 cm) > 2 in (5 cm)	20 g/m² (260 lb/lane-mile) 40 g/m² (520 lb/lane-mile)

The salt is used until a minimum pavement temperature of −8°C (18°F) occurs. Urea is used on special structures in the Birmingham area. No calcium chloride is being used in the United Kingdom due to corrosion.

The contracting firm has performed equipment evaluations and found that the Epoke spreaders, which are manufactured in Denmark, were the optimum equipment for their use.

Ponting has authored two papers: "A Cost Benefit Study of the Need for Improved Forecasting and Communications for Effective Highway Maintenance," dated 1989, and "Hereford and Worcester County Council - Ice Prediction System," dated September 1986.

The project team also visited the Transport Research Laboratory at Crowthorne. Ian Lancaster and Marilyn Burtwell of the Road Performance Section were interviewed.

Their section, which has an annual budget of £2,000,000, researches winter maintenance, surface treatments, and trench reinstatement. In the area of winter maintenance, research has been conducted or is ongoing on the following:

- improved weather forecast ("Open Road");
- assessment of the effectiveness of prewetted salt;
- development of improved spreading methods;
- measurements of residual salt levels on roadway surfaces; and
- assessment of alternative deicing chemicals.

The British Meteorological Office provides site-specific weather forecasting. The forecast also contains the pavement temperature forecast. The product is called "Open Road" forecast and is provided to approximately 96% of the districts. The Meteorological Office charges for their services and must compete with the other private vendors in providing weather forecasting. The computer forecasting model for pavement temperatures resides at the Meteorological Office.

Maintenance managers in the United Kingdom consider thermal mapping an important tool in establishing RWIS sites and in estimating pavement temperature distributions between RWIS locations. The pavement temperature forecast is updated when the pavement temperature varies by more than 3°C (5.4°F) from the projected values. The team was provided a report on thermal mapping titled "The Use of a Computer Model to Predict the Formation of Ice on Roadway Surfaces" by B. S. Parmenter and J. E. Thornes, Research Report 71, dated 1986.

Helmut Scharsching of Austria is developing a microwave radar to detect water and ice on the roadway surface. The success of the project has not yet been determined. (The results were reported at the Transportation Research Board's September 1992 meeting.)

In addition, Surmo Electrics, a French company located at Mels, France, is developing a pavement sensor to determine the freezing point of the brine. The company had contacted the Transport Research Laboratory to participate in the cost and development of the sensor, which they consider to be an active type.

Parmenter of the Road Performance Section has identified theoretical salt spread rates for particular circumstances. On a well-drained road during and after rain, the thickness of the water film in a typical instance may vary between 0.5 and 0.08 mm (0.019 to 0.003 in). Thin films of ice formed by water freezing on road surfaces are usually less than 0.25-mm (0.009-in) thick, which is equivalent to approximately 0.25 kg (0.55 lb) of ice per square meter of surface.

From tables of concentrative properties of aqueous solutions, freezing-point depression has been plotted against anhydrous compound weight percent (i.e., grams solute per 100 g [3.5 oz] of solution) for sodium chloride. An application of salt of 10 g/m^2 (130 lb/lane-mile) is sufficient to effect complete melting of an ice film less than 0.25 mm (0.009 in) thick at temperatures above −2.4°C (28°F). Application of this quantity before the onset of freezing will prevent the formation of ice. The freezing-point depression has been tabulated for a range of different water film thicknesses and for different quantities of salt (see table E-1).

The Transport Research Laboratory has awarded a contract to Silsoe Research Institute, Silsoe, to develop a spinner to be used for spreading salt. In the past, the design has been empirical. The study is to be completed by the latter part of December 1993. At the time of the visit, the firm had developed a mathematical model for a spinner and was developing a prototype. They were charged with examining the fundamentals of the spinner, including energy of the salt and the friction between the disc and the salt particles. Preliminary findings indicate that curvature of the vanes appears unimportant. It is very important, however, where the salt lands on the disc. The institute hopes to improve the distribution pattern at low application rates.

During salt application, the particles are subjected to air turbulence and air suction behind the vehicle. To minimize this disruption, the concept of using a fiberglass airfoil is being tested by the Motor Research Industry Association. This fiberglass airfoil projects above and out on each side of the rear of the spreader box. Air is forced at the rear, reducing the air suction.

Finland

The project team visited four roadmaster districts in southern Finland. During this visit, discussions were held on the use of liquid salt and prewetted salt in anti-icing operations. The various maintenance personnel shared their experiences with liquid salt, equipment, and mixing units. Also, various spreader equipment was demonstrated.

The Finnish National Road Administration (FinnRA) has established winter maintenance standards, which determine the level of service that is provided to each highway in Finland. These standards were reviewed to provide the project team with a perspective of the Finnish maintenance personnel's experience with liquid salt and prewetted salt. Their winter maintenance level of service is based on traffic volume, time of day, and whether snow plowing or deicing operations are required. Each highway is given a classification according to traffic volume (ADT) as follows[19]:

	Highway classification	ADT
I	Super divided (SK)	Freeways
I	Super (S)	≥ 6,000
I		1,500–6,000
II		200–1,500
III		≤ 200
IV	Pedestrian and bicycle paths	

Table E-1 Freezing-point depression (°C) for different thicknesses of water film and different salt concentrations.

Quantity of salt (g/m^2)*	Water film thickness (mm)					
	0.08	0.10	0.20	0.25	0.30	0.50
1	0.7	0.6	0.3	0.3	0.2	0.2
2	1.5	1.2	0.6	0.5	0.4	0.3
3	2.2	1.8	0.9	0.7	0.6	0.4
4	3.0	2.4	1.2	1.0	0.8	0.5
5	3.8	3.0	1.5	1.2	1.0	0.6
6	4.7	3.7	1.8	1.4	1.2	0.7
7	5.5	4.4	2.1	1.6	1.4	0.9
8	6.5	5.0	2.4	1.9	1.6	1.0
9	7.5	5.8	2.7	2.1	1.8	1.1
10	8.6	6.5	3.0	2.4	2.0	1.2
12	10.9	8.1	3.6	2.9	2.4	1.4
14	13.5	9.9	4.3	3.4	2.8	1.7
16	16.4	11.9	5.0	3.9	3.2	1.9
18		14.0	5.7	4.5	3.7	2.1
20		16.4	6.5	5.0	4.1	2.4

* 1 g/m^2 = 13 lb/lane-mile.

Water film thickness of 0.08 mm is equivalent to 80 g of water per square meter.
Water film thickness of 0.25 mm is equivalent to 250 g of water per square meter, etc.

Example

(a) A water film thickness of 0.08 mm with 10 g/m^2* of salt will freeze at $-8.6°C$.

(a) A water film thickness	of 0.08 mm	with 10 g/m^2* of salt will freeze	at $-8.6°C$.
"	of 0.10 mm	"	at $-6.5°C$
"	of 0.20 mm	"	at $-3.0°C$
"	of 0.25 mm	"	at $-2.4°C$
"	of 0.30 mm	"	at $-2.0°C$
"	of 0.50 mm	"	at $-1.2°C$

(b) If the temperature is expected to fall to $-5°C$, then the following quantity of salt will be required for water film thicknesses of

Water film thickness	of 0.08 mm	will require	7 g/m^2 salt*
"	of 0.10 mm	"	8 g/m^2 salt*
"	of 0.20 mm	"	16 g/m^2 salt*
"	of 0.25 mm	"	20 g/m^2 salt*

(c) Crossfall and super-elevation on motorways usually ensure that the road is well drained. Once rain has ceased to fall, traffic quickly reduces the water film on the road. Assuming, therefore, that the water film thickness will generally not be greater than 0.25 mm when precautionary salting is being considered, it would be possible to specify application rates for temperature bands, e.g.

If the temperature is expected to fall to	$-2.5°C$,	the required spread rate	= 10 g/m^2*
"	$-4.0°C$,	"	= 16 g/m^2*
"	$-5.0°C$,	"	= 20 g/m^2*

When ice has formed, an application rate of 10 g/m^2 (130 lb/lane-mile) will not be sufficient to achieve the required increase in skid resistance in a reasonable time. Under this condition, a deicing application rate of 40 g/m^2 (520 lb/lane-mile) should be used.

The density of fresh untrafficked snow is about one-tenth that of ice, so that a 10-mm depth of snow over a 1-m^2 area is therefore roughly equivalent to 1 kg/m^2 of ice. In practice, it is found that one-half the quantity of salt required for complete melting will reduce the snow to a state in which it can be dispersed by traffic, and about 6 g/m^2 (78 lb/lane-mile) of salt is required per 10 mm of fresh snow for each degree Celsius that the air temperature is below the freezing point. When snowfalls of 10 mm or more occur, the temperature is usually higher than $-3.0°C$.

* 1 g/m^2 = 13 lb/lane-mile.

For each highway classification, the Finnish National Road Administration assigns a condition standard. When the road condition does not meet this standard, it must be restored within a certain time period to the level required by the condition standard. Slipperiness, snowiness, and evenness are regarded as variables of the standards. The various condition standards are given in table E-2.

Table E-2 Definition of condition standards[19].

Quality class variable	1	2	3	4	5
Variable I, slippery condition					
Skid number	0.00−0.15	0.15−0.25	0.25−0.30	0.30−0.45	0.45−0.10
Road surface/ texture	Very icy driving or otherwise very slippery	Dry ice or snow path	Coarse ice or snow path in cold weather	Bare and wet or paths between traffic ruts	Bare and dry
Variable II, snow condition					
Dry frozen snow	> 50 mm (1.96 in)	≤ 50 mm (1.96 in)	≤ 30 mm (1.18 in)	≤ 20 mm (0.78 in)	
Thawing snow	> 40 mm (1.57 in)	≤ 40 mm (1.57 in)	≤ 25 mm (0.98 in)	≤ 15 mm (0.59 in)	
Slush	> 30 mm (1.18 in)	≤ 30 mm (1.18 in)	≤ 20 mm (0.78 in)	≤ 10 mm (0.39 in)	
Drifting snow	Easy passage or may be difficult in some places; car may become stuck in snowdrifts.	Projections over the road or moderate snow layer at the road edges; driving speed must be reduced in some cases.	Projections over the road; driving speed has to be reduced in some cases.	Projections exist to the middle of the outermost traffic lane; generally no need to reduce driving speed.	
Variable III, evenness					
Ruts	> 30 mm (1.18 in)	≤ 30 mm (1.18 in)	≤ 20 mm (0.78 in)	≤ 10 mm (0.39 in)	
Other roughness	Path very uneven and possible projecting bumps; driving speed must be reduced and uneven spots avoided.	Plenty of worn spots or disturbing holes; driving speed must be reduced in some cases.	Path even; possible unevenness does not actually disturb driving.	Thickness of path strips on the road portion under traffic, ≤ 10 mm (0.39 in).	

Note: The skid numbers shown are measured using a Coralba friction meter. The vehicle conducting the friction measurements uses studded tires. Thus, the values given are higher than would be experienced using non-studded tires.

Table E-3 shows the target condition values for each highway classification and presents cycle times. Cycle time is defined as the time elapsed between when a road first falls short of the condition standard to when it is restored to the level of its "target condition" using appropriate maintenance measures.

Table E-3 Target condition values and cycle time.

Highway classification	Target condition		Cycle time (hr)		
	Daytime	Nighttime	Deicing	Snow removal	Slush removal
I (SK), I (S)	4	4	2	2.5	2
I	4	3	2	3	3
II	3	2	4	4	4
III	2	1	6	6	6
IV	3	2	4	4	4

The following statistics show the total road salt usages in metric tonnes for Finland from 1985 to 1992. The reported tonnage includes sand mixed with salt. In the mid-1980s, the mixture rate was 30 to 50 kg (66 to 110 lb) of sand per cubic meter of salt. Currently, the recommended rate is 15 to 20 kg (33 to 44 lb) of sand per cubic meter of salt.

Winter	Tonnes
1985-86	69,000
1986-87	68,000
1987-88	130,000
1988-89	150,000
1989-90	157,000
1990-91	129,000
1991-92	130,000

The new winter maintenance standards were instituted in Finland in the 1987-88 winter season. Finland also began to experience very warm winters starting with 1987-88. As a result, salt usage increased substantially. However, it has been estimated that only 25% to 30% of the increase in the salt usage was caused by the new standards. It was reported that the 1986-87 winter was a long, severe cold season (around −30°C [−22°F]). With this extreme cold temperature, no salt was used. In addition, Finland began experimenting with prewetted salt during this same period of time. In 1990-91, they began to experiment with liquid salt as a means to reduce salt usage. Today, the goal is to use only liquid salt and prewetted salt.

The first district visited was the Hyvinkää Roadmaster District, which is Finland's second largest district by area and has the fourth highest amount of traffic in the Uusimaa Road District. This district has 438 km (272 miles) of public roads, 80% of which are paved, and 37 km (23 miles) of four-lane highways (freeways). Only 200 km (124.27 miles) are treated with salt during snow and ice operations during winter. However, all paved roads are treated with salt during fall and spring, especially for black ice.

The Hyvinkää Roadmaster District has developed a method of liquid salt application to a degree further than the other Finnish road master districts. They emphasized that it is important to apply only small amounts of liquids (typically, 10 g/m^2 [130 lb/lane-mile]) and then to allow traffic action to dry the pavement. If the road surface remains wet during low periods of traffic, such as at night, the risk for refreezing is great. In this optimum manner, it is possible to use liquid salt even at such low temperatures as −7° to −10°C (19° to 14°F). During the winter of 1991-92, the Hyvinkää District used about 1,600 tons of salt for about 115 events. In contrast, during the winter of 1992-93, the salt usage was reported at 730 tons for approximately the same number of events. During both periods, more than 90% of the total salt usage was in the form of liquid salt.

At that time, the district had only three liquid salt spreaders but planned to purchase two liquid spreaders in the future. In addition, the district owns six trucks, two motor graders, and three tractors, and also hires five to nine additional units to help the district with their snow and ice operations.

The Finnish National Road Administration has developed a procedure for producing a 23% salt brine solution from dry salt at each of their truck barns. This salt brine is used as a liquid salt application or as a prewetting agent with dry salt. When they are prewetting salt, the 23% solution of salt brine is mixed with dry salt at the rate of 30% by weight. This produces a mixture that has a consistency of a thick soup or cooked oatmeal. Sometimes, they will reduce the rate of salt brine to 15% or 20% because of the trucks' limited tank capacity.

Next, the project team visited the Riihimäki Roadmaster District where they heard a presentation on a groundwater study that was being conducted in the Kymi Road District. It was reported that average annual salt usage in that district was 20 tons/km. The peak usage at certain road sections was 30 tons/km. Due to prewetting and new salting policy (more consideration was given to efficiency of salt application), the District reduced its salt usage last year to an estimated 10 tons/km.

The Finnish National Road Administration has begun a program of testing and monitoring water wells for both private homes and public water treatment plants. The Administration tests to determine the levels of chlorides, nitrate, and ferrous ions in the water wells. For private wells, the limit for chlorides is 100 ppm, and 100 household wells in the district have values over the 100-ppm limit. The municipalities in Finland have recommended that the chloride limit for public water supplies be less than 25 ppm. The water works standard established by the Finnish Health Administration is a maximum level of chloride content in drinking water of 100 mg/L for water works that provide water to more than 200 consumers. According to one example, it will take 25 years for the chloride level to decrease once the district stops using salt.

The Riihimäki Roadmaster also outlined his experience with liquid salt application and prewetting salt. The district has one road weather information station in operation, which uses data from five other stations from surrounding districts. These data are used to provide information on when to apply salt to the roadway. This district has used the road weather information data for 4 years.

In the Riihimäki District, there are 624 km (388 miles) of public roads, of which only 123 km (76.4 miles) receive salt. During the winter of 1991-92, about 2,060 tons of salt were applied. From that quantity, 1,010 m^3 (267,000 gal) of 23% of liquid salt was manufactured and used on roadways.

Liquid salt is most effective when used for black ice and during preventive operations in the fall and spring. It can be used as a preventive when the pavement temperature is around 0° to −3°C (32° to 27°F). Liquid salt has been applied up to 3 hr before the beginning of freezing or precipitation. It was indicated that when using liquid salt, there is a decrease in the total amount of salt used. Also, there is an instant melting action of the liquid salt. The small amount of liquid salt used does not splash against car windshields. The salt stays on the roadway and does not spread to the shoulders.

Liquid salt is not recommended for use when the pavement temperatures are lower than −5°C (23°F) nor for application on compacted snow. Normally, liquid salt should not be used with freezing rain, but at times, the application rate has been increased up to 40 to 60 g/m^2 (520 to 780 lb/lane-mile). Also, it was reported that liquid salt is less effective on roadways with low traffic volume (less than 2,000 ADT). Traffic is needed to dry the pavement after the application of the liquid.

One of the major drawbacks identified with using liquid salt is that continuous visual observations are required so that refreezing of the road surface will not occur, which may increase the work of operators. Also, the salt brine corrodes the spreading equipment more than granular salt; electrical connections are particularly susceptible.

Another concern expressed when working with liquid salt is the attitude of the equipment operator. The operators must learn to accept reduced application rates and to reapply after dilution.

The district has two years of experience using liquid salt in snow and ice operations. Operators demonstrated two types of liquid spreaders. One uses two spinners, while the other has a spray bar with nozzles. The operators indicated a preference for the spinner spreader because it has a faster application speed (up to 70 km/hr [43 mph]), a higher application capability (60 g/m^2 [780 lb/lane-mile] as compared to 25 g/m^2 [325 lb/lane-mile] with nozzles), and is easier to mount onto trucks. The operators stated that the spinner equipment was more reliable than the spray-bar type. Because of the large amounts of impurities in salt brine, they have experienced problems with nozzle spreader plugging.

For the 1993 winter season, the Riihimäki District purchased a spray-bar spreader. The operators were able to make comparisons at the district level. The operators reported that the spray-bar type has been more efficient because it provides sufficient pressure to break up the ice/snow. The spray-bar spreader uses a greater speed than the spinner type. But its filter and nozzles need to be kept clean to prevent plugging. The cost of liquid spreader equipment has become more inexpensive each year.

During the visit to the Raisio Roadmaster Station, it was reported that of the 679 km (422 miles) of public roads in the district, 174 km (108 miles) are classified as Class I highways and about 50 km (31 miles) are divided highways (four to six lanes). The station has seven trucks, six motor graders, and three light trucks in their fleet with a staff of 48 people. Normally, only 28 personnel are used for snow and ice operations. The station has two Kupper-Weisser, one Epoke, and one Salo 1500 spreader with prewetting facilities. In addition, the district has three liquid salt spreaders.

During the winter of 1991-92, they experienced 80 events of ice, in contrast to an average winter of 60 events. The District rarely has no snow events. Based on salt usage reports, it was determined that the District used 6.45 tonnes/road-km for those 80 events, or a total of 1066.6 tonnes of salt. For the last winter, during 60 of the 80 events, liquid salt applications of 952 m^3 (251,000 gal) were utilized. The district has found that when using dry salt, only 10% to 20% of the material remains on the icy roadway due to traffic action and spreader turbulence.

For black ice or when the pavement temperature is down to −3°C (27°F), the recommended application rate for liquid salt is 16 g/m^2 (208 lb/lane-mile), which is equivalent to 4 g/m^2 (52 lb/lane-mile) of dry salt. When the pavement temperature is approximately 0°C (32°F), the application rate can be cut back to the equivalent dry salt application of 2 g/m^2 (26 lb/lane-mile). During snowfall, it is recommended that 25 g/m^2 (325 lb/lane-mile) of liquid salt be applied for each centimeter of snow. However, they do not recommend the use of liquid salt for snow operations.

When the pavement temperature drops below −3°C (27°F), there is a tendency for the liquid salt to refreeze. In this temperature range, the station uses prewetted salt, which has been wetted with salt brine at the rate of 30% by weight. Generally, no salt is applied to the roadway when the temperature falls below −7°C (19°F).

This district uses both spray-bar and spinner slide-in spreaders for liquid salt application. Spreader tank capacity varies from 10 to 12 m^3 (2340 to 2800 gal). The pump which is used has a capacity of 260 L/min. With this pump capacity, the operators are able to obtain a maximum application rate of 65 g/m^2 (845 lb/lane-mile) at a spread width of 8 m (26 ft) and speeds up to 60 km/hr (37 mph). Typically, the units feature speeds of 50 to 60 km/hr (31 to 37 mph), although some units may obtain speeds of 70 km/hr (43 mph). The district reported that with speeds above 30 km/hr (19 mph), turbulence occurs and some loss of material is experienced.

One operator in the Turku Road District, which is part of the Raisio Roadmaster District, is responsible for the calibration of all the spreaders. This operator visits the various roadmaster areas within the district each fall to conduct the calibration.

For the spinner spreaders, the pump is ground-speed oriented, but the spinner is rotated at a constant speed. Generally, a spinner can obtain a spread width of approximately 5 m (16 ft). It was noted that all the spinner spreaders use two spinners. These spinners have the ability to adjust the spread pattern asymmetrically or symmetrically.

During the visit to the Kirkkonummi Roadmaster District, the project team was advised that from November 1991 to April 1992 maintenance personnel made 91 salt applications to the roadways. If the district had had enough liquid salt available, 80% of those applications would have been with liquid salt. They also noted that the equipment to make liquid salt did not become operational until December 1991.

The District Supervisor indicated that Kirkkonummi District has followed the general temperature range recommendations for the use of liquid salt to a pavement temperature of −3°C (27°F). When the pavement temperatures are lower than −7°C (19°F), the operators do not apply chemicals and plow the snow. For this district, the air temperature typically drops down to −20°C (−4°F), with the average being −7°C (19°F), and precipitation occurs when the temperature is below −5°C (23°F).

During the project team's visit, the Kirkkonummi District had four liquid spreaders: one Weisser spinner spreader and three nozzle spreaders. Of the three nozzle spreaders, one is a simple nozzle and the others are a first generation of Epoke liquid nozzle spreaders. This district also has a Weisser spreader, which is used to prewet salt. Based on equipment test studies conducted by the Finnish National Road Administration this past year, the district plans to buy a Salo 5000 Combi spreader. The testing has shown that this spreader is the optimum type for the FinnRA needs.

The Finnish National Road Administration has approximately 160 road-weather information stations, with the greatest network density located along the coastline. This provides approximately 1.5 road-weather information stations for each road master district. Each roadmaster has access to data from all stations in Finland on an hourly basis. The Kirkkonummi District had just received one station last winter and thus had not yet developed the level of confidence that is needed to fully utilize the station in the timing salt applications. However, they indicated that besides the road-weather information system, they also use weather forecasts.

Summary

The Finnish National Road Administration had 80 liquid salt spreaders last winter and is purchasing more each year. Two types are used, including one which features a spray bar with nozzles for the driving lane and three nozzles that apply chemical to the adjacent lane. With this equipment, either lane or both lanes can be treated. The other type is a spreader that uses two spinners. From the equipment that was observed and demonstrated, it appears that the administration's fleet has approximately equal numbers of each type.

The use of liquid salt appears to be the method of choice for salt application to roadways by the road masters in Finland. Small quantities (10 to 20 g/m^2 [130 to 260 lb/lane-mile]) of salt solution can be applied under controlled conditions. The material is not blown off by traffic and works immediately. Also, the liquid salt can be applied at a higher rate of speed (60 to 70 km/hr [37 to 43 mph]) compared with dry or even prewetted salt. In addition, liquid spreader equipment is less costly than solid spreaders.

The limitation of liquid salt is the very limited temperature range (0° to −3°C [32° to 27°F]) at which it can be used. To prevent refreezing when temperatures drop or the brine diluting and freezing on the roadway, it is necessary to keep plowing slush off the roadway. The effect of liquid salt is minimal where there is low traffic volume (less than 2,000 ADT) or on packed snow. Also, there is more corrosion on liquid spreaders than on equipment that spreads granular salt.

When the pavement temperature is lower than −3° to −5°C (27° to 23°F), the Finnish National Road Administration recommends that prewetted salt be used to temperatures down to −7° to −10°C (19° to 14°F). The wetting solution is a 23% salt brine solution, which is manufactured at each truck station. The salt is prewetted at the spinner at the rate of 30% by weight. This mixture has the consistency of thick soup, which makes the material stay in place on the road surface. Again, the need for traffic is required in the use of prewetted salt for preventive or anti-icing operations. The use of prewetted salt reduces the amount of salt required because it does not blow away and starts to work more quickly than dry salt.

In Finland, when the pavement temperature reaches −7°C (19°F), no chemicals typically are applied to the roadway. The snow and ice operation consists only of plowing snow and sanding at the most critical spots.

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Denmark

The project team visited the Knabberup Road Maintenance Station, which is the road maintenance headquarters of the County of Vajen, Denmark. The roadmaster, Mr. Jensen Kristeian (telephone 75-83-5333), was interviewed regarding Danish winter maintenance operations. Denmark has a network of more than 200 road-weather stations throughout the country, of which the County of Vajen has 26. Each of these road-weather stations provides real-time data every 10 minutes. The data include road surface temperature, air temperature, humidity, and relative amount of residual salt.

Each county has direct access to data from its own road-weather station. The data are presented to the roadmaster by various computer screen images. In addition, the roadmaster has access to very short range weather forecasts, issued every 2 hr, which are valid for 3 hr. Each forecast is limited to the area of the specific county. The forecast includes measurements of road surface temperature, dew point temperature, air temperature (at 2 m [7 ft] height), cloudiness, precipitation, and wind velocity, which are valid for 3 hr upon issuance. The forecasts, as well as the latest radar images, are available to the roadmaster on a computer.

In Denmark, a conductivity sensor is used to measure the amount of residual salt. This instrument expresses the road surface condition as the resistance of electric current between two electrodes in the road surface. A resistance reading of 10 indicates a wet surface and no salt. A reading of 2 indicates a wet surface with some salt, while a reading of less than 2 indicates a wet surface with more salt. All the road-weather station equipment used in Denmark is manufactured by Malling Kantrol of Denmark.

Winter weather for the County of Vajen typically includes only about 10 nights per year where the temperature falls below −6°C (21°F). The county experiences approximately 60 occurrences of snow or ice per year that require winter maintenance services. Most of the time, however, the temperature during winter will fluctuate just above and below 0°C (32°F).

According to the roadmaster, it costs approximately 100,000 Danish Krone for each winter maintenance service performed. A large percentage of the station's snow and ice control equipment is rented. In the event of substantial snow or ice, personnel are required to report to the road master within 1 1/2 hr of being contacted by telephone. The Knabberup Road Maintenance Station features a system that automatically calls the operators. The roadmaster has a large switchboard, that indicates which operators have been called and which operators are responding. By reviewing the switchboard, the roadmaster knows immediately how many and which operators are reporting for work.

The roadmaster determines the application rate for salt. The amount is dependent on pavement temperature and forecast of the pavement temperature. The application rate is normally the equivalent to 10 g/m^2 (130 lb/lane-mile) with a maximum of 25 g/m^2 (325 lb/lane-mile). It was determined that 5 g/m^2 (65 lb/lane-mile) was too small a quantity to work effectively. The road-weather station system provides an alarm to the road master 2 hr before a storm event. Operators apply liquid salt up to 2 hr before the beginning of a storm. Generally, one application is required for frost and/or black ice at the rate of 7.5 to 10 g/m^2 (98 to 130 lb/lane-mile) of equivalent dry salt. During a snowstorm, no salt is applied and only plowing is performed. After the snow stops, 15 to 20 g/m^2 (195 to 260 lb/lane-mile) is applied. The maintenance personnel use liquid and prewetted salt for their operations.

At the end of each winter season, a report is sent to the Danish Road Administration, providing the agency with the number of times snow and ice maintenance operations were performed and the total amount of salt used in the county.

The Netherlands

The project team visited Mr. Deuss, Minister of Roads and Waterways, at Wolfhezeto, to learn about preventive salting operations in the Netherlands. In the Netherlands, slipperiness is caused mainly by the freezing of wet sections of the roadway surface and the formation of a layer of ice through condensation or frozen fog. Precipitation in the form of glaze ice or snow occurs only on a limited scale.

Prewetted salt is applied on Dutch national highways. The Dutch reported that this technique ensures better adhesion of the salt to the roadway surface and thus a minimum of salt is blown away. The prewetted salt technique also speeds up the melting process. With this technique, solid sodium chloride (NaCl) is generally prewetted with a 16% $CaCl_2$ solution. In some areas, the solid NaCl is used with a 20% NaCl solution.

Preventive salting using prewetted salt is practiced when snow is forecast in order to prevent the snow from adhering to the roadway. Once this preventive action has been taken, the snow can be removed easily by plowing. During plowing, further spreading takes place using the dry salt method.

The highway authority is able, with the help of the National Weather forecasting, private weather forecasting services, and local road weather stations, to establish the amount of precipitation and the time at which a snow front is due to arrive in its area. This permits preventive salting to be particularly effective before an expected snowfall.

In the Netherlands, a distinction is made between three different causes of slipperiness when discussing application rates and timeliness:

- slipperiness caused by the freezing of wet sections of road;
- slipperiness caused by a small amount of moisture (condensation, freezing fog); and
- slipperiness caused by precipitation.

If the temperature falls following a period of precipitation, the areas of the roadway that are still wet may freeze. Preventive salting is carried out using a quantity of 7 g/m^2 (91 lb/lane-mile) of prewetted salt. This is composed of 5 g/m^2 (65 lb/lane-mile) of dry NaCl and 2 g/m^2 (26 lb/lane-mile) of liquid solution (16% $CaCl_2$ solution or 20% NaCl solution). Therefore, if the solvent (water) is not counted, about 5.5 g/m^2 (72 lb/lane-mile) of prewetted salt will be spread on the road.

Under certain temperatures and humidity conditions, ice may form on the roadway surface as a result of condensation and freezing. Following a cold period in particular, condensation forms rapidly, owing to the cold buffer that has built up in the subgrade. If air saturated with moisture contacts road surface temperatures below freezing when the air temperature is just above freezing, a considerable quantity of moisture may condense and freeze on the roadway surface.

This type of slipperiness will occur at unexpected moments and is also difficult for drivers to see. Preventive salting using the prewetted method (7 g/m^2 [91 lb/lane-mile]) is used on highways with sufficient traffic. The spreading is repeated depending on the quantity of freezing fog or condensation. In addition, if traffic volumes are low, such as at night, it is generally necessary to carry out spreading operations more often.

In the event of snowfall, preventive salting action is taken to prevent the snow from adhering to the roadway by applying 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of thawing agent using prewetted salt techniques. During the snowfall, the roadway is kept as clear as possible by snow plowing and by spreading 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of salt using the dry salt method. After the snowfall, the remaining snow generally is easy to remove with snow plows and by spreading 15 to 20 g/m^2 (195 to 260 lb/lane-mile) of salt. Conditions such as traffic intensity, the quantity of salt, and the quantity of precipitation determine the surface conditions of the roadway. In applying the prewetted salt, the maximum application speed is 40 km/hr (25 mph) so that air turbulence does not blow the material off the roadway. It was also noted that the maintenance forces use prewetted salt down to a temperature of −15°C (5°F) and dry salt down to −7°C (19°F).

The road weather stations employed in the Netherlands have sensors that measure air temperature, pavement temperature, wind speed and direction, humidity, a sub-probe temperature, and the conductivity of the brine on the roadway surface. Each station has four pavement sensors, two per each direction, which are located in the wheel tracks. The sensors are polled for data every 15 minutes.

The conductivity measurements have a range of readings from 0 to 500. Readings less than 4 indicate that no action is required. Readings between 4 and 100 indicate humidity or moisture presence, but no salt presence. Readings over 100 indicate wet pavement and the presence of salt.

The road weather stations feature screen displays where pavement temperature and dew point curves are displayed for the past 8-hr period for each sensor. The road weather system can be programmed to warn the road master of possible problems. The alarm situation is determined by the slope of the pavement temperature curve in the area of 0°C (32°F).

There are 10 road weather stations in the area of Wolfhezeto, which have access to the data from the adjacent areas. This provides the road master with real-time information. In addition, a private weather forecasting vendor provides radar images. The road master can download 100 frames, which can be used for looping. This information is useful in scheduling preventive salting operations.

The Dutch began using thermal mapping in 1991 on a number of kilometers of roadway. Since the temperature is usually in the range of 0°C (32°F), thermal mapping is used to indicate the sections of roadway that should receive preventive salting.

Most of the equipment used in their snow and ice operations is manufactured by Nido, a Dutch firm. Thus, the road master has an equipment contract with the manufacturer to do all their required equipment repairs. Nido does preventive maintenance on the equipment during the summer months, which eliminates excessive downtime due to equipment failure during the winter season. This method helps the road master limit the number of mechanics needed to keep his fleet operational.

Sweden

The project team met Kent Gustafson and Gudrun Oberg of the Swedish Road and Traffic Research Institute and Lennart Axelson of the Swedish National Road Administration. Because of scheduling conflicts, the project team was not able to visit Sweden. The Swedish National Road Administration has conducted the MINSALT project, in which they determined ways of reducing salt usage. This meeting provided information on the Swedish anti-icing approach and methods used in conducting the MINSALT project.

In Sweden, anti-icing operations are called preventive salting. This operation uses either liquid salt brine or prewetted salt. Liquid salt brine is best used for anti-icing involving black ice and for highways with large traffic volumes (over 6,000 ADT). Liquid salt brine application generally is performed during night hours when traffic volume is low. The Swedes also did not recommend using liquid salt brine during precipitation. The Swedish National Road Administration has 100 units that can spread liquid salt brine.

With a storm approaching, they recommend using prewetted salt instead of liquid salt. The salt can be wetted by either of two methods: at the spinner with a 30% amount of the dry salt, or by applying water to a salt load when loading the truck. The rate of applied water is 80 to 100 L (19 to 24 gal/ton) per ton of salt. The recommended maximum size of the load is 2 to 3 m^3 (3 to 4 yd^3).

The application rate for preventive salting is 5 to 10 g/m^2 (65 to 130 lb/lane-mile). During a storm, the rate can increase up to 40 to 60 g/m^2 (520 to 780 lb/lane-mile) with the normal application rate of 20 g/m^2 (260 lb/lane-mile) for each application. The Swedes determined that rates above 60 g/m^2 (780 lb/lane-mile) are not effective and are wasteful. The minimum effective working temperature range for prewetted salt is between −8° and −10°C (18° to 14°F). At times, they have used prewetted salt effectively with temperatures as low as −12°C (10°F). Various gradations of salt were tested in Sweden. They found that a maximum size of 3 mm (0.12 in) is the best. They also tried a gradation with a maximum of 2 mm (0.08 in), which was unsuccessful. Salt with maximum gradation of 2 mm (0.08 in) exhibited problems with tunneling above the auger(s) in the spreaders.

Different SOBO-20 readings were obtained when measuring chemical residues containing either NaCl or $CaCl_2$. The residual chemical must be in solution in order to obtain an appropriate measurement. The Swedish operations personnel noted that the measuring location is very important in determining the amount of chemical residue and that a large number of measurements should be taken to determine the amount of residue. They also found that measurements cannot be made on rough surfaces.

Friction measurements are used only for research purposes and are not used by operations personnel. Swedish operations personnel noted that it is difficult to set values that can be used as an operation standard. Although the Coralba friction meter has been researched and developed in Sweden, operations personnel stated that too many variables exist when using the device. A Saab friction tester car or a BU 11 trailer has been used to measure skid resistance on various pavement conditions at various speeds. These data have been compiled in a report.

The maintenance personnel use RWIS equipment in their decision-making process. Pavement temperature trends are important in indicating application rates to be used during salting operations. This information helps reduce salt usage. They recommend the calibration of the spreader equipment to control salt usage. Still, Swedish public opinion is that the Swedish National Road Administration is oversalting.

Salt Gradations Used in Various Foreign Countries

Salt is the major chemical used in snow- and ice-control operations. It is used as a salt brine in liquid application and as a prewetting agent with dry salt. Dry salt is also used, but its use is decreasing as the method of using prewetted salt becomes better understood.

Three different procedures are used in salt extraction. Solar salt is extracted from seawater using the combined action of the sun's heat and wind. The concentration is gradually increased in ponds where the salt crystallizes and settles. The salt is collected mechanically, then washed and stored. Rock salt is extracted from salt deposits by conventional mining methods, then crushed. Vacuum salt is extracted on site by dissolving rock salt in water injected into narrow wells bored into the salt deposit. The recovered brine is evaporated, causing the salt to crystallize into small, regular, rounded grains.

Typical characteristics of solar salt include large and irregular grain size with high to very high moisture content and an average amount of impurities. Rock salt's grain size has a wide distribution (up to 5 mm [0.2 in]) with very low moisture content (< 0.1%) and low to high amounts of impurities, depending on the type of deposit. Vacuum salt's grains are small and even (around 0.6 mm [0.02 in]) with average amount of moisture (approximately 2.5%) and low amounts of impurities.

Grain size distribution has a marked effect on the effectiveness of salt spreading. Fine grains cause rapid melting at the surface, but their penetration is inadequate. Large grains penetrate to the road surface, causing the snow and ice to soften under traffic loads. The large grains (3 to 5 mm [0.12 to 0.2 in]) take longer to dissolve and therefore require a longer time to take effect. This is shown in figure E-1. In addition, there is more loss during spreading operations because some large grains bounce onto the road shoulder. Likewise, very small grains (below 0.16 mm [0.006 in]) are also unsuitable because they blow off the pavement in passing traffic and wind.

During the numerous interviews with the winter maintenance personnel in Scandinavia, it was reported that almost all salt is prewetted before being applied. A liquid salt brine is mixed with dry salt at the rate of 30% by weight. This produces a mixture that has an oatmeal consistency. With this consistency, the salt is spread more uniformly with less waste along the shoulders of the roadway. Also, the material adheres better to the roadway surface. The prewetted salt has a quicker effect and can be used at lower temperatures. In addition, the spreading speed can be increased because the material does not appear to be affected as much by spreader air turbulence. In some cases, the roadway surface dries out more quickly.

However, when MNDOT attempted to moisten salt at the rate of 30% , a large amount of free liquid resulted. Therefore, a review was made of the Finnish salt specification to determine its difference from the U.S. specification.

Recently, the Finnish National Road Administration revised its specifications for rock salt after conducting studies in 1989 on the effect of gradation. The administration found that a finer gradation provided a better result with prewetting operations. The existing standard required 100% passing a 6-mm (0.24-in) sieve, while the revised standard requires 100% passing a 5-mm (0.20-in) sieve, as given below:

5 mm	4 mm	3 mm	2 mm	1 mm	500 μm
100%	90%–100%	70%–100%	40%–90%	15%–55%	3%–25%

As a comparison, the U.S. (ASTM D632, Type I) specification for salt gradation is

19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	600 μm
100%	100%	95%–100%	20%–90%	10%–60%	0%–15%

The British Salt Standard (BS 3247) has specifications for two different grades. The road authority feels that compliance with the gradation will enhance the spreadability of the salt for spreading for the treatment of snow and ice. The gradation requirements are expressed as percentage passing:

	10 mm	6.3 mm	2.36 mm	300 μm
Rock salt				
Coarse	100%	75% to 95%	30% to 70%	0% to 20%
Fine		100%	30% to 80%	0% to 20%

	10 mm	6.3 mm	1.18 mm	150 μm
Vacuum salt				
Coarse	100%		0% to 80%	0% to 10%
Fine	100%		100%	0% to 30%

The moisture content of the salt on delivery should not exceed 4%. Due to the high humidity in the southern part of the United Kingdom, the salt, when held in covered storage compounds, obtains an optimum moisture content of 5% at the time of spreading.

The Swedish have conducted studies that demonstrate that the salt's origin has little influence on its melting effect. The grain size distribution, on the other hand, is of more importance. With preventive spreading on thin ice and layers of rime frost, a larger proportion of fine-grained salt is probably more advantageous while more coarse salt could be more efficient in producing slush during a snowfall and on less-compacted layers.

Based on the aforementioned information and other reports from various European countries, an ideal salt grain size used in winter maintenance ranges from 0.16 to 3 mm (0.006 to 0.12 in), with a low percentage (maximum 5%) of the fraction below 0.16 mm (0.006 in) and of the fraction from 3 to 5 mm (0.12 to 0.2 in). It is not advisable to use grains larger than 5 mm (0.2 in). Given the deep-acting effect of large grains (3 to 5 mm [0.12 to 0.2 in]), however, some countries impose a mandatory fraction of at least 5% of these large grains.

Foreign Testing Protocols

Numerous foreign sources were contacted by letter to obtain information on various types of anti-icing equipment and their testing procedures. Follow-up interviews were then held with a number of manufacturers in various European and Scandinavian countries. A number of these governments require spreader equipment manufacturers to demonstrate that their equipment can control and monitor the application rate and spread pattern before the equipment can be marketed.

The testing protocols have been paraphrased for better understanding. The British, Danish, and German protocols are as follows.

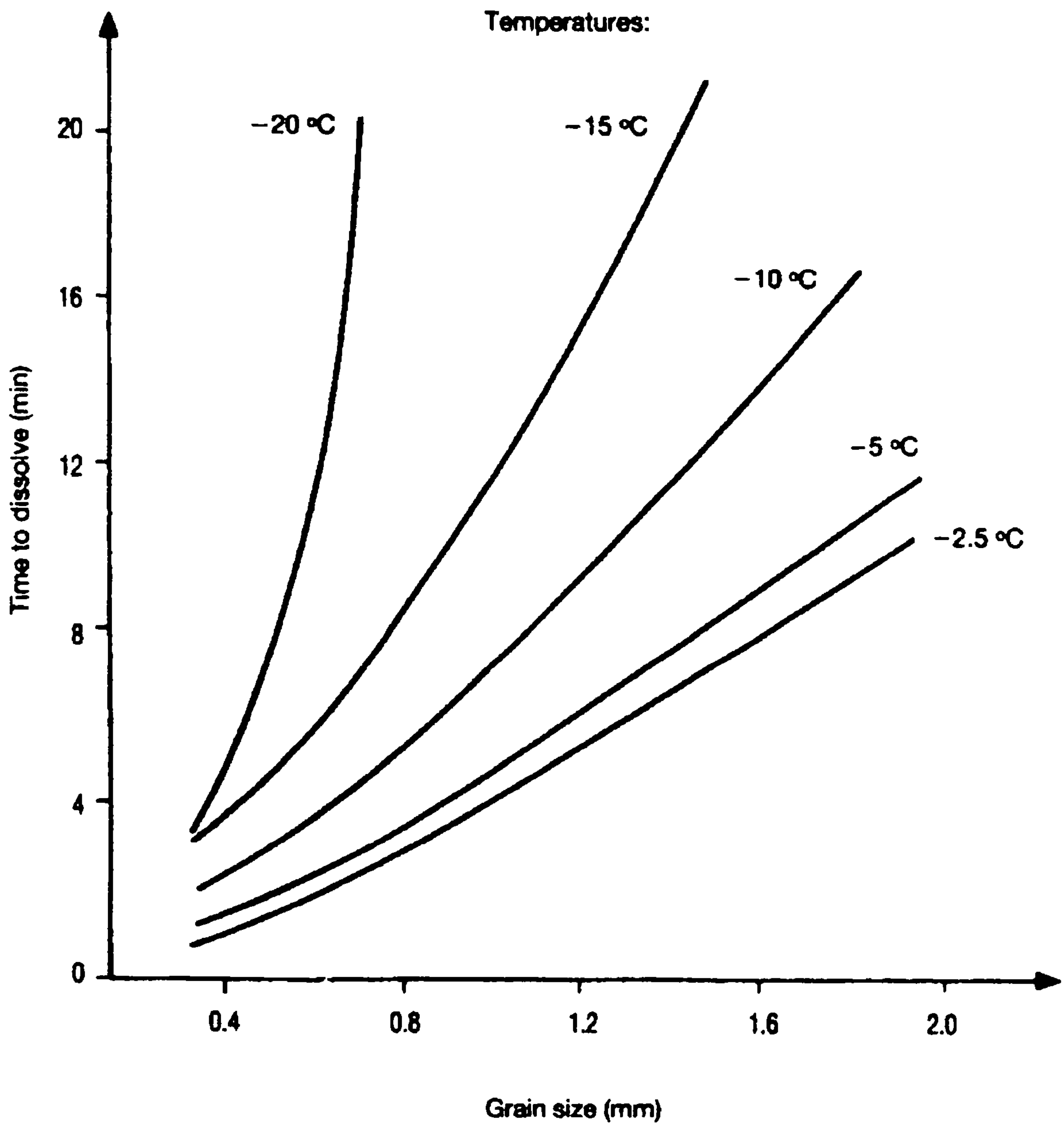


Figure E-1 Time taken by salt grains to dissolve in contact with ice at different temperatures.

British Standards for Spreaders

The British have a standard specification[28] with which all spreaders used for winter maintenance in England must comply. Within the standard specification, there are five different classifications for spreaders. The particular classification is dependent upon where the spreaders are used for winter maintenance. The first two classifications of spreaders are for those used on highways. Class A1 spreaders are capable of a symmetrical and asymmetrical width of spread of 11 m (36 ft) at all speeds up to 70 km/hr (43 mph) and have a speed-related drive. Class A2 spreaders are capable of a symmetrical and asymmetrical width of spread of 11 m (36 ft) at all speeds between 8 and 70 km/hr (5 to 43 mph) and have a speed-related drive. Both classes of spreaders are required to be capable of nominal coverage of salt between 5 and 40 g/m^2 (65 to 520 lb/lane-mile) in increments not exceeding 5 g/m^2 (65 lb/lane-mile) and are required to be appropriately marked at the control point. The width of spread is required to be adjustable between 3 and 11 m (10 to 36 ft) in steps not exceeding 1 m (3 ft). It is necessary to make this adjustment while the vehicle is in motion. Another requirement is that the axis of the main zone be adjustable between the symmetrical and the extreme asymmetrical position in steps not exceeding 1 m (3 ft). The height at point of distribution, when fully laden, must be between 300 and 350 mm (12 to 14 in) above road surface.

Requirements for Spread Pattern Performance

Accuracy of Nominal Coverage. The total mass of salt collected on the main zone, margins, and verges (i.e. shoulders) for the nearly empty-load and full-load runs at the same nominal speed should not differ from the calculated total by more than ±10%. The total mass of salt collected on the main zone, margins, and verges shown in figure E-2 during the nearly empty-load and full-load runs at 20 km/hr (12 mph) are not to differ from the total mass collected on the runs at 40 km/hr (25 mph) by more than ±10%.

Overall Variation in Coverage. The total mass of salt collected for the nearly empty-load run should not differ from the mass collected for the full-load run (at the same speed) by more than ±10%.

Accuracy of Longitudinal Coverage. The total mass of salt collected on any one transverse strip after one run should not differ from the mean mass collected on the three strips A, B, and C shown in figure E-2 after that run by more than ±20%.

Accuracy of Coverage of Main Zone. The total mass of salt collected on any one sample rectangle on the main zone after one run is not to be less than 50% nor more than 200% of the mean mass collected on all the sets of sample rectangles on the main zone for the nearly empty-load and full-load runs at the same speed.

Accuracy of Coverage on Margins. The mean mass of salt collected on either margin after one run should not be less than 25% of the mean mass collected on all the sets of sample rectangles on the main zone for the nearly empty-load and full-load runs at the same speed.

Waste. The total mass of salt collected on either verge for the nearly empty-load and full-load runs at the same speed is not to exceed 0.5% of the total mass collected on both those runs.

Spread Pattern Performance Test

General. The test consists of two runs: the first run is conducted with the hopper nearly empty (1/10 full) while the second is run with a full hopper. Both runs are conducted at 20 and 40 km/hr speeds (12 and 25 mph), making four runs altogether. On each run, samples are taken by collecting the material from three transverse strips marked in rectangles, which are spaced 50 m (164 ft) apart. The mass of salt collected on each sampling rectangle is recorded, and the records are then analyzed to show the characteristics of the distribution overall — longitudinally and transversely. A balance accurate to 0.1 g (0.004 oz) is used in order to eliminate an avoidable error, this being about 0.5% of the smallest nominal amount deposited on a margin. The effect of even a slight wind on the fine particles is considerable, and the test should therefore be carried out on a still day.

Test Site. The test should be carried out on a straight length of roadway. This should be as flat as possible with a cross slope not exceeding 1 in 40 to avoid distortion and large particles rolling. The roadway should be long enough for the spreader to accelerate to and maintain test spreads of 20 and 40 km/hr (12 and 25 mph) before entering the first test strip and to stop after leaving the third test strip; the roadway's minimum length should be 320 m (1,050 ft), of which 175 m (574 ft) should be before the first test strip.

The width of the strips is 8 m (26 ft) for the main zone, 1.5 m (5 ft) for each margin, and 2 m (7 ft) for each verge, for a total width of 15 m (49 ft). The breadth of the strips is 1 m (3 ft).

Test Material. Rock salt, complying with BS 3247, should have a moisture content of 4% ± 1%.

Procedure.

1. Mark out the test site as indicated in figure E-2. Ensure that the surfaces of the test strips are dry.

2. Sweep the transverse strips and 2 m (7 ft) on both sides of each strip until a negligible amount of salt is left on the surface.

3. Set the spreader for a nominal coverage of 10 g/m^2 (130 lb/lane-mile) and for a spread width of 11 m (36 ft). Fill the hopper to 1/10th of its capacity with test salt or with a sufficient amount for the test length plus 100 m (33 ft), whichever is greater.

4. Drive the spreader straight along the test length at the speed of 20 km/hr (12 mph) in the appropriate position in relation to the axis (or edge) of the main zone for symmetrical or asymmetrical spreading.

5. Carefully collect the salt on each verge, margin, and sampling rectangle, and weigh it on a balance accurate to 0.1 g (0.004 oz). Record the masses (in grams) on a form similar to that shown in table E-4.

6. Fill the hopper or vehicle to capacity, sweep the test site as in step 2, and repeat steps 4 and 5.

7. Repeat steps 2 through 6 at the second test speed of 40 km/hr (25 mph) without changing the coverage setting.

Requirements for Discharge Performance

When tested by either static discharge performance or road discharge performance, the calculated rate of discharge should be within ±2 g/m^2 (26 lb/lane-mile) of the nominal rate of discharge set.

Static Discharge Performance Test

1. Fill the hopper or vehicle with sufficient test salt. Jack the driving axle of the test vehicle off the ground and disconnect the spreader from the feed. Check the nondrive wheels.

2. Set the spreader for a discharge rate of 10 g/m^2 (130 lb/lane-mile) and a speed of 48 km/hr (30 mph). Then measure the mass of salt discharged into a receptacle in 2 min.

3. Carry out the test in step 2 for a spread width of 5 m (16 ft), increasing by 1 m (3 ft) to the maximum width of the spreader.

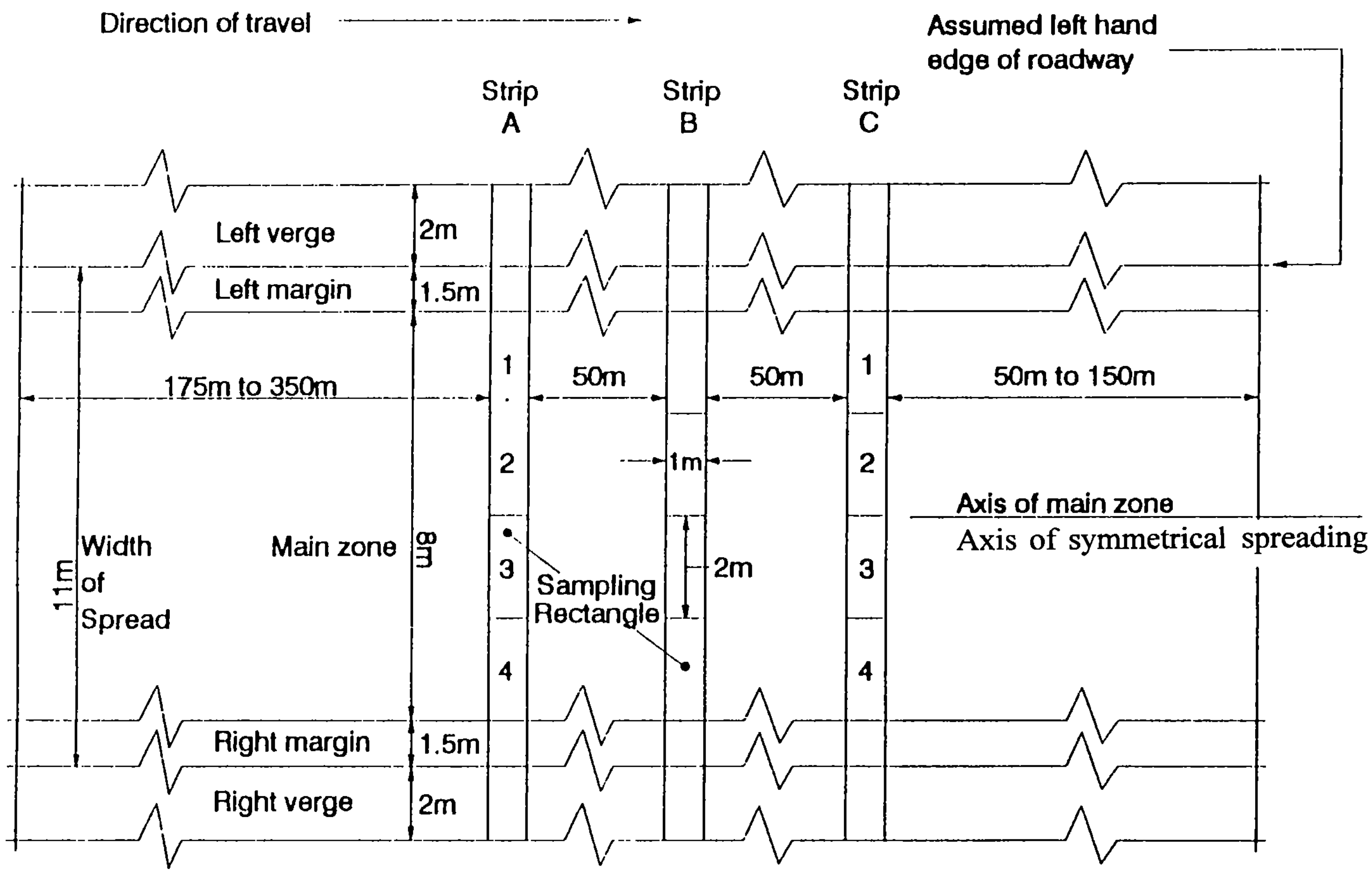


Figure E-2 Layout of test site.

Table E-4 Typical record form of test for spreader (mass of salt actually collected, in grams, to one decimal place).

Run and strip		Collected on verges			Collected on margins			Collected on main zone sampling rectangles					Total collected
		Left	Right	Total x	Left	Right	Total y	1	2	3	4	Total z	$x + y + z$
First (1/10 full)	A												
	B												
	C												
Total first run													(*A*)
Second (full)	A												
	B												
	C												
Total second run													(*B*)
Total both runs		(*E*)	(*D*)										(*C*)
Means		–	–	–	(*F*)	(*H*)	–	–	–	–	–	(*G*)	–

Maker .... Type .... Class ....

Tested at .... km/h Width of spread .... m Symmetrical* Asymmetrical*

Coverage .... g/m² Wind speed .... km/h at 2 m above the ground

Place of test ....

Date of test .... Signature ....

Testing authority responsible for test ....

NOTE. Letters in parentheses indicate the totals and means used in the formulae in table 4.

*Delete as appropriate.

4. Calculate the rate of discharge.

Road Discharge Performance Test

1. Set the spreader for a discharge rate of 10 g/m^2 (130 lb/lane-mile) and for a width spread of 6 m (20 ft). Fill the vehicle or hopper with sufficient test salt.
2. Weigh the loaded vehicle on a permanent or portable scale.
3. Carry out a normal spreading run with a width of 6 m (20 ft).
4. Spread a known route length, then reweigh the vehicle and the remaining load, making allowance for the fuel used.
5. Calculate the rate of discharge.

Danish Spreader Testing

General

The state's Agricultural Test Centre at Bygholm has developed and tested a new collection method for wetted salt. Earlier spread pattern test procedures consisted of collecting spread dry salt in trays with grates. This collection method was unsuitable for wetted salt. As a result, a wet vacuuming procedure was used to collect the spread salt. This process also enables the test to be carried out on an asphalt surface, which was deemed desirable. The collection method was developed for a Danish spreader manufacturer. It is not known if the procedure has been accepted as a standard protocol.

Tests consisted of stationary dosage tests to examine the accuracy of the dosage with different control settings of the spreader as well as spreading tests at different speeds and spreading settings. The developed testing procedure was conducted to acquire a working knowledge of the fundamental spreading pattern, which could be expected when planning to salt.

Purpose of the Tests

The purpose of the tests was to look at the importance of the following elements in connection with salt spreading:

- spreader equipment,
- type of salt,
- dosage,
- spreading width,
- wetting,
- speed.

Other factors, such as wind velocity and direction, influence of traffic, and condition of the road (roughness, moisture, etc.), which also are important for the spreading pattern, were not included in the tests.

Extent of the Tests

Spreader. The spreader model tested, which was chosen in consultation with the operators, was expected to become standard equipment for Denmark.

Salt Types. For the spreading tests, two types of salt were used, namely, vacuum salt and rock salt. The vacuum salt has a median size of 1.3 mm (0.05 in), with a moisture content of 2.9%. The rock salt has a median size of 1.3 mm (0.05 in) and a maximum size of less than 4 mm (0.15 in). The rock salt's moisture content is 0.5%. When testing with moistened salt, the dry salt amount is automatically reduced to 70% and brine is added at the rate of 30% by weight.

Spreader Testing. The salt spreader tests included a stationary test of the dosage accuracy for the spreaders at different spreading adjustments (dosage) and tests of spreading patterns at different speeds and spreading adjustments (spreading widths).

Dosage Test. The dosage test was carried out under stationary conditions. For equipment with a fifth-wheel drive, an electric motor was used to turn the spreader's driving wheel at an equivalent speed of 50 km/hr (31 mph).

For the dosage test, two collections were made lasting 15 seconds each (equivalent to a road length of 208 m at 50 km/hr [682 ft at 31 mph]) for each adjustment. The dosage tests are conducted with rock salt and vacuum salt, respectively, with and without wetting, and with 6 and 10 m (20 and 33 ft) spreading widths, respectively. The tests involved a total of eight salt combinations. For each type of salt combination, moistening and spreading widths were conducted with salt dosages of 5, 10, 15, 20, and 30 g/m^2 (65, 130, 195, 260, and 390 lb/lane-mile). A total of 40 tests was conducted for each piece of equipment.

Spreader Pattern Tests. The tests for the spreading patterns were conducted at a test site with an asphalt surface and an area of approximately 600 m (1,969 ft) long and over 10 m (33 ft) wide. Within the test area, a range of measurement was established by laying out a grid pattern, which was 5 m (16 ft) long and had 10 sections 1 m (3 ft) wide. In addition, a marginal zone on each side of the grid pattern was established in which the amount of salt that fell outside the range of measurement was collected.

During the test, the spreader vehicle drove with its right front wheel 1 m (3 ft) from the edge of the lane. This is equivalent to placing the center of the spreading disc 2.2 m (7 ft) from the right edge of the range of measurements. All the spreading tests were carried out with an asymmetric spreading equivalent to the adjustments of step 1 (on the previous page) on the control units. At each test, the wind velocity and direction were measured. The tests were conducted with wind velocities below 3 m/sec (10 ft/sec) across the range of measurement.

The spreading pattern tests were conducted with rock salt and vacuum salt, respectively, with and without moistening, for a total of four combinations. The basic control settings for each of these combinations were a spreading width of 6 m (20 ft), a dosage of 10 g/m^2 (130 lb/lane-mile), and a speed of 50 km/hr (31 mph). Additional spreading tests were conducted with control settings of a 10-m (33-ft) spreading width and a 20 g/m^2 (260 lb/lane-mile) dosage. Furthermore, tests were conducted where the speeds were changed to 30 km/hr (19 mph) for dry salt and to 70 km/hr (43 mph) for moistened salt.

Method Used to Determine the Spread Amount of Salt. A carpet sweeper was used to collect the salt and brine. The carpet sweeper simultaneously sprays clean water while it vacuums the saline solution. For salt and brine collection, a wash/draghead 0.3 m (0.98 ft) wide was used. This machine features a clear-water reservoir and a tank for the captured liquid, both with a capacity of 32 L (34 qt).

After vacuuming the saline solution from the test area, the operators determined salt content by the following process:

1. Diluting the collected liquid to a predetermined solid volume.

2. Removing of a 25-mL sample.

3. Adding of 7 drops of calcium chromate.

4. Titrating with of silver nitrate.

The amount of silver nitrate necessary to produce a color change in the liquid is directly related to the salt content.

A number of preliminary tests were conducted to determine the accuracy of the analysis. These tests indicated an average deviation of 2.5% from the true amount of salt.

Test Results

Dosage Tests. The dosage test results for each salt type appear as the deviation of the salt amount in percentages compared with the theoretical salt amount in grams per square meter (see figure E-3).

Spreading Pattern Test. For each test, the average amount of salt was reported in grams per square meter for each section within the range of measurements and in the marginal zones (see figure E-4).

German Standards for Spreaders

General

The Federal Republic of Germany has developed technical specifications and standards for winter spreader equipment[27]. These standards address such factors as technical data for equipment position, equipment height, draw gear, safety protection, and spread-material output. Within the spread-material output standard, requirements and procedures for dosage rate and spread pattern are detailed.

The dosage rate addresses the variables of spread density, spread width, and speed. The spread pattern addresses the distribution of the spread material on the roadway surface.

The German government is currently developing standards for spreading prewetted salt. Therefore, only draft standards are currently available.

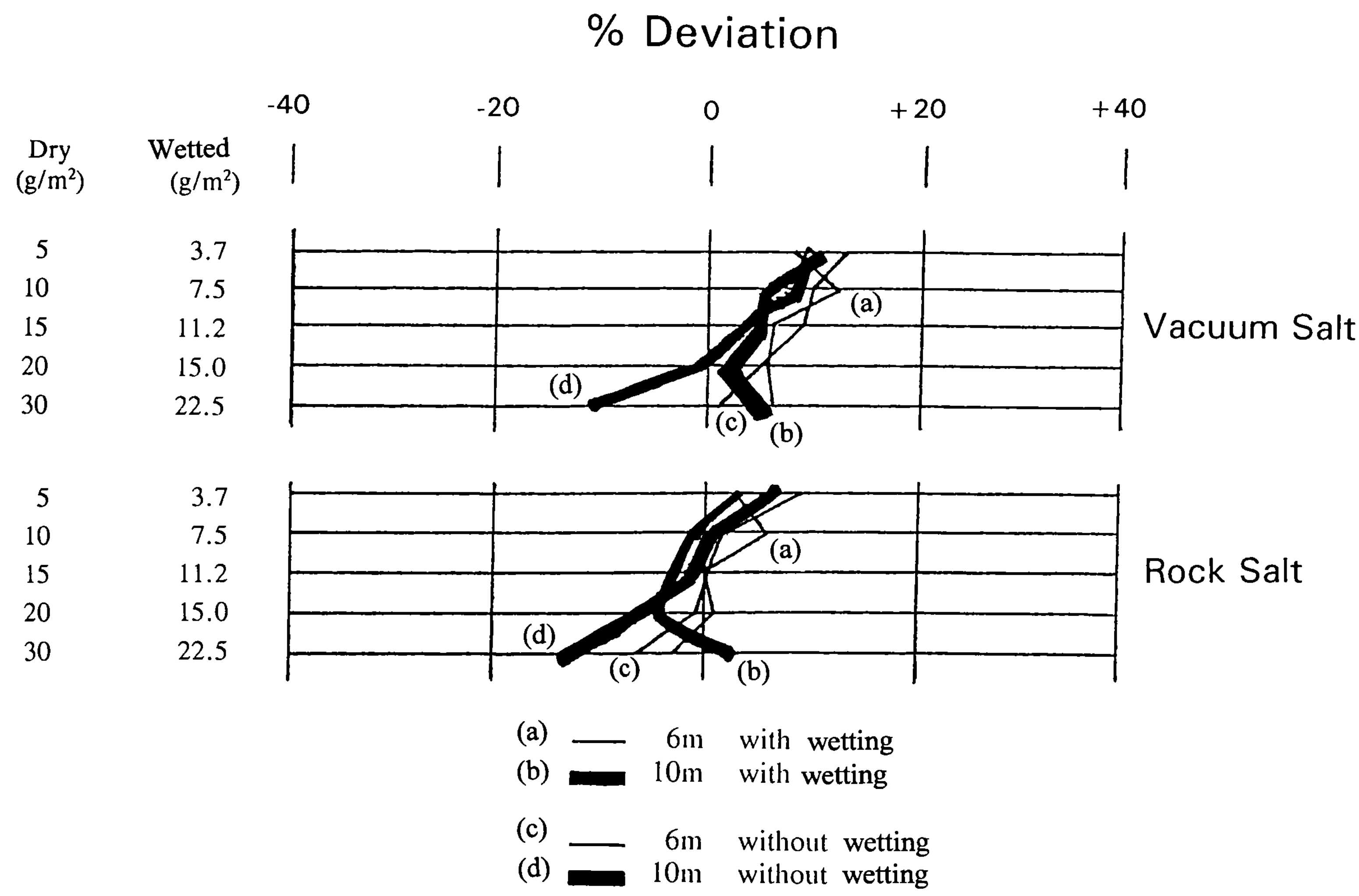
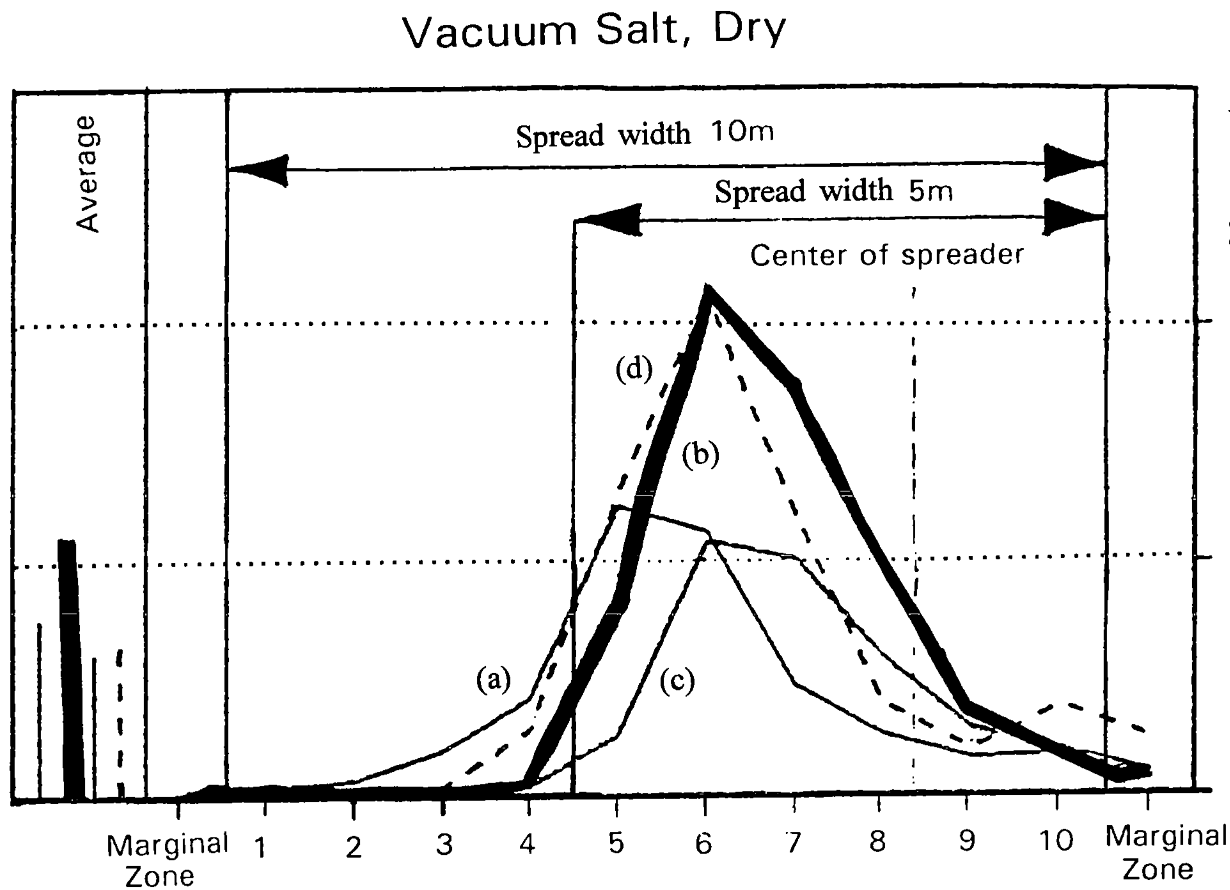


Figure E-3 Dosage test results.



Spread width 5m: (a) 10g/m^2, 50 km/hr; (b) 20 g/m^2, 50 km/hr; (c) 10 g/m^2, 30km/hr

Spread width 10m: (d) 10 g/m^2, 50 km/hr

Figure E-4 Spreading pattern test results.

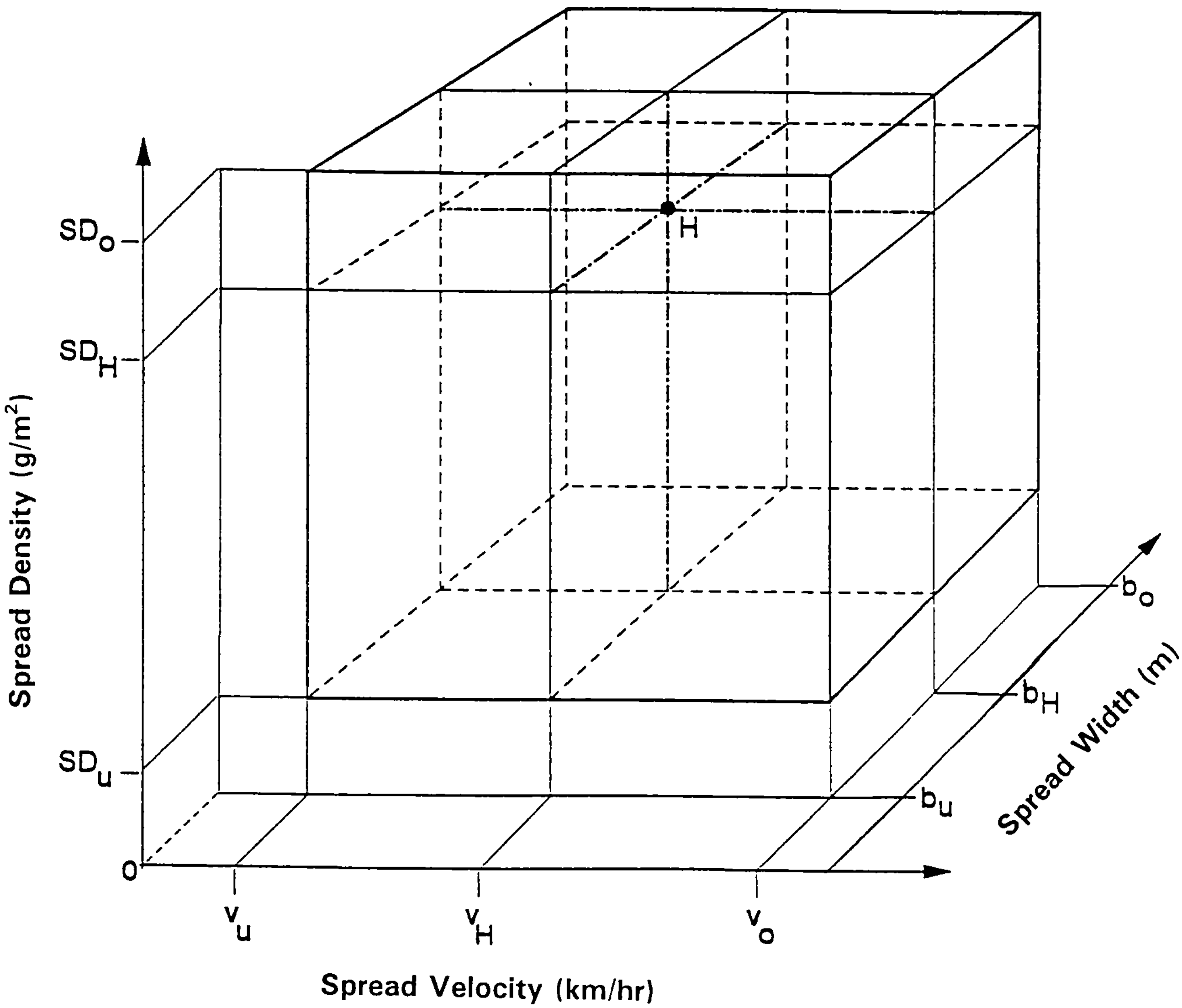


Figure E-5 Three-dimensional "operational space."

Dosage Rate Determination for Spreaders

General. The amount of material released from the spreader in a unit of time depends on the spread density (SD [g/m^{2}]), spread width (b [in meters]) over which the material is to be dispersed, and on the speed (v) of the spreader vehicle (km/hr).

Using the lower and the upper limits of these variables, a three-dimensional operational space is described within which all possible operating points lie (figure E-5).

The position of the principal operating level *H* (H = most frequent) is determined within the operational space by the values of the operating parameters (spread density, spread width, and speed) at which the spreader will most frequently be operated.

Control settings for spreading chemicals must be continuous or in steps of at most 5 g/m^2 (65 lb/lane-mile). Selections of spread width spread width must be in maximum increments of no more than 1 m (3 ft).

Requirements for Dosage. The requirements for dosage exactness are related to the percent deviation ΔSD between the measured and control settings of spread density SD:

- Dosage rate of the material is to be regulated so that the selected spread density remains constant over the vehicle's operational speed range.
- The spread density cannot change with changes in the spread width.
- When the dosage rates are measured and calculated in accordance with the Dosage Rate Test section below, the deviation (ΔSD) of the effective spread density from the control setting value must be less than ±6%.
- The operating ranges for spread width, spread density, and speed must correspond to the appropriate application range, spread material, and spread process. The principal values are presented on the following page for the determination of the test points to be used in the Dosage Rate Test section below.
- For use with prewetted salt, the solvent portion may not deviate more than ±20% from the nominal value.

Spread width (b)

	Salt spread width for b highest		Abrasive spread width
	≤ 8 m	> 8 m	
b lowest (m)	2 (3*)	3 (4*)	2
b most frequent (m)	4 (6*)	10	3
b highest (m)	8	12	4

* Test limit-value deviating from the operation limit-value during application tests.

Spread velocity (v)

	Dry salt	Prewetted salt	Abrasives
v lowest (km/hr)	3 (10*)	3 (10*)	3 (10*)
v most frequent (km/hr)	30	50	20
v highest (km/hr)	40	60	30

Spread density (SD)

	Dry salt	Prewetted salt	Abrasives
SD lowest (g/m^2)**	5	5 (10*)	80
SD most frequent (g/m^2)**	20	10	150
SD highest (g/m^2)**	40	40 (20*)	300

* Test limit-value deviation from the operation at limit-value during application tests.
** 1 g/m^2 = 13 lb/lane-mile.

Dosage Rate Test

General. The amount of material released from the spreader is tested for accuracy to determine conformity with the Requirements for Dosage described above. The testing is conducted by using the following combinations of control setting values (see previous page):

Test Condition	Spread Width	Spread Velocity	Spread Density
I	b most frequent	v most frequent	SD most frequent (principal operating point)
II	b lowest	v lowest	SD lowest
IIIa	b highest	v highest	SD most often
IIIb	b highest	v most frequent	SD highest

In addition, the following individual control functions are to be measured for the test:

Test parameter being evaluated	Spread Width	Spread Velocity	Spread Density
b lowest	b lowest	v most frequent	SD most frequent
b lowest	b highest	v most frequent	SD most frequent
v lowest	b most frequent	v lowest	SD most frequent
v highest	b most frequent	v highest	SD most frequent
SD lowest	b most frequent	v most frequent	SD lowest
SD highest	b most frequent	v most frequent	SD highest

Test.

1. Fill the spreader halfway with the type of spread material for which the dosage rate is being measured.

2. Operate the spreader over the test course.

3. Determine the control setting values from those combinations given above.

4. Establish distance for the spreader vehicle to travel during the measurement. The minimum amount of spread material collected for a test should be 10 kg (22 lb), and the travel distance must be greater than 100 m (328 ft). The recommended values for various spread materials are given in attachments on page 297.

5. For each combination of control setting values, take at least two separate measurements which meet the following condition:

$$\frac{\text{SD maximum} - \text{SD minimum}}{0.5\ (\text{SD maximum} + \text{SD minimum})} \leq 0.2$$

6. Evaluate the measured results with the Requirements for Dosage section.

Spread Pattern Performance

General. The spread pattern test is conducted at a speed of 20 km/hr (12 mph) with control settings of spread width of 4 m (13 ft) and spread density of 20 g/m^2 (260 lb/lane-mile).

With its hopper loaded to approximately half capacity, the spreader is driven over a marked grid system spreading dry salt. The salt samples are vacuumed into paper filters from the surface of the grid system. The mass of the salt vacuumed from each sampling rectangle is weighed to an accuracy of 0.1 g (0.04 oz) and then recorded. The data are analyzed to show the characteristics of the distribution overall, both longitudinally and transversely.

Test Site. The test should be carried out on a straight length of roadway. The roadway should be as flat as possible with a cross slope not exceeding 1 in 20. The roadway should be long enough for the spreader to accelerate to and maintain the test speed of 20 km/hr (12 mph) before entering the first test strip and to stop after leaving the third test strip.

The test area surface should be asphalt concrete, exhibiting a macro roughness as experienced in the middle of the roadways. The mean roughness has a depth of 0.5 ± 0.3 mm (0.02 ± 0.01 in) as calculated by the sand patch method, according to "Protocol for Combined Anti-Skid and Roughness Measurements with Pendulum-Device and Flow Meter."

A grid system, consisting of strips, is marked out on the test area in accordance with figure E-6. The width of the strips for salt spreading is 6 m (20 ft) for the nominal spread width and 1 m (3 ft) for the overspreading rectangles, for a total width of 8 m (26 ft). This test width can be extended to 12 m (20 ft) for wider spread width applications. Capture walls (dimensions of 2.5 m [8.2 ft] long and 300 mm [12 in] high) are placed along the outer edge of the overspreading rectangles. The length of the strips (in the direction of travel) is 2 m (7 ft).

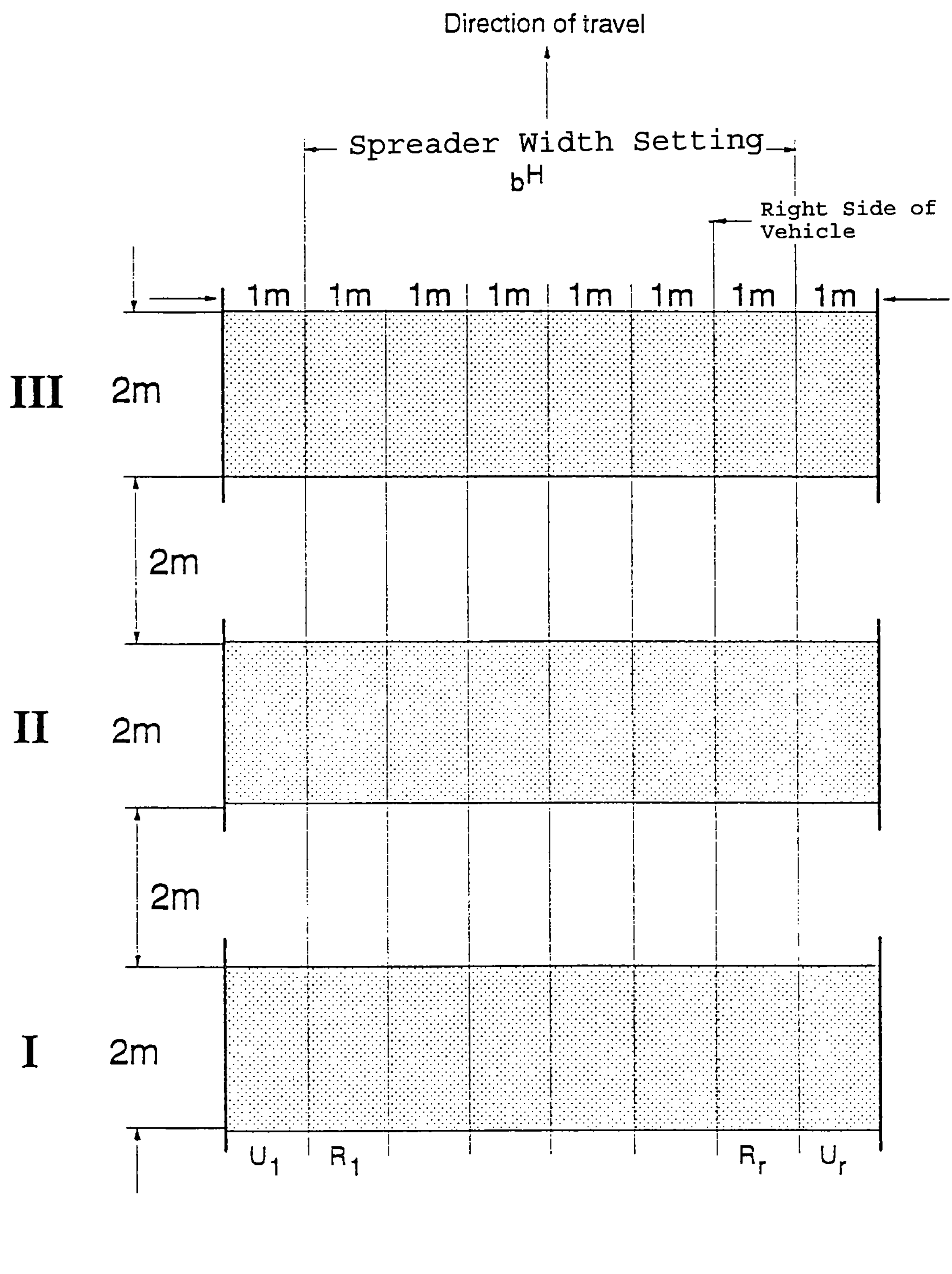


Figure E-6 Grid layout.

Table E-5 Computation form.

	Collected spread-material amount (g)								Summation of columns 1 - 8	Deviation from average value (%)
	U_l	R_l	1	2	3	4	R_r	U_r		
Column	1	2	3	4	5	6	7	8	9	10
Strip width (m)	1	1					1	1	–	–
Lateral strip I										(2)
Lateral strip II										(2)
Lateral strip III										(2)
Σ_{Total}										(1)
(3) Percent of the total amount.			–	–	–	–				
(4) Spread density$_{,x}$ [g/m^2)	–	–					–	–		
(5) A_{Qx} (%)	–	–					–	–		

(1)The average value in this box is determined by dividing the number in Σ_{Total} Column 9 by the factor 3.

(2)The numerical value in this box is determined by the expression: $\frac{\text{Column 9 entry} - \text{average value in (1)}}{\text{average value in (1)}} \cdot 100 = [\%]$

(3)Percent of the total amount is given by the expression: $\frac{\Sigma_{Total}\text{ (Col. 1, 2, 7, or 8)}}{\Sigma_{Total}\text{ Column 9}} \cdot 100 = [\%]$

(4) Spread thickness in the test rectangular area x

(x = 1, 2, 3, 4 Number of the test rectangular area)

$$SD_x = \frac{\Sigma_{Total}\text{ (Col. 3, 4, 5, or 6)}}{6\ \dagger} = [g/m^2]$$

(5) Deviation of spread thickness in the test rectangular area x

$$A_Q = \frac{(SD_x - SD_m)}{SD_m} \cdot 100 = [\%]$$

SD_m is the mean spread density in the nominal spread track including overspread amount

$$SD_m = \frac{\Sigma_{Total}\text{ (Col. 9)}}{6 \cdot b^H\ \dagger} = [g/m^2]$$

b^H = spreader width setting

† Factor 6 is a collection area composed of three rectangular areas in the direction of travel.

Test Material. The testing material is rock salt which has a maximum size of 2 mm (0.08 in).

Procedure.

1. Mark out the test site as indicated in figure E-6. Erect capture walls along the outer edges of the overspreading rectangles (u). Ensure that the surfaces of test strips are dry.

2. Sweep the lateral strips I, II, and III and adjacent areas until a negligible amount of salt is left on the surface, then vacuum the lateral strips.

3. Set the spreader controls for the most frequent coverage of 20 g/m^2 (260 lb/lane-mile) and for a spread width of 4 m (13 ft). Fill the hopper to approximately half capacity.

4. The spinner displacement setting (asymmetric) should be set so that when the vehicle's right side is driven along the left edge of the rectangle designated as (R_r), the spread material is covering the right edge strip, R_r.

5. Drive the spreader straight along the test area with the vehicle's right side along the left edge of the right edge strip (R_r) of the grid layout at the speed of 20 km/hr (12 mph).

6. The amount of spread material deposited in the individual rectangles is vacuumed into paper filters and weighed to the nearest 0.1 g (0.04 oz). Record the weights on a form similar to that shown in table E-5.

7. Perform the various computations as required to evaluate spreader performance.

8. Compare the results against the requirements listed below.

Spread Pattern Performance Requirements.

Accuracy of Longitudinal Coverage. The total mass of material collected on any one transverse strip should not differ from the mean mass collected on the three strips by more than ±30%.

Waste. The total mass of material collected on either overspread strip (U_l, U_r) should not exceed 5% of the total mass collected.

Accuracy of Coverage on Side Strips. The mass of material collected on either side strip (R_l, R_r) should not be less than 5% of the total mass collected.

Accuracy of Coverage on Inner Test Strips. The allowed deviation of the computed spread density for the inner lengthwise strips between the side strips in comparison to the average spread density of all the rectangles in the grid system should be less than 90% and no greater than 50%.

Equipment Manufacturers

Salon in Finland

Salon Terästyö Oy, located at Salo, Finland, is a highway equipment manufacturing company which manufactures spreaders and snow plows. Their equipment spreads liquid solution, prewetted salt, and dry salt and sand.

The liquid solution spreader unit, which is mounted on the rear of a truck using a quick mounting system, is a standard for the Finnish National Road Administration. The unit has two liquid spinners which can be adjusted manually to control the symmetry of the spread pattern. The spread width is 2 to 8 m (7 to 26 ft). The liquid is pumped from the supply tank with two hydraulically operated solution pumps. The pumps are controlled with electric clutches and can deliver 520 L/min (550 qt/min).

The supply tank is typically a skid-mounted, slide-in tank. Salon employs a unique design for the supply tanks, consisting of a two-wall construction of fiberglass, separated by approximately 5 mm (0.2 in) of polyurethane. This design provides for a very strong tank.

The Salon company uses electric remote controls, which are manufactured by Bucher Hydraulik of Klettgau, Germany. These controls, which are custom-designed for the client, provide for ground-speed orientation.

The company also manufactures a combination unit, which can spread either liquid brine or prewetted salt. This unit features a spreading width from 2 to 8 m (7 to 26 ft) and has only one spinner. The liquid pumps discharge up to 260 L/min (68 gal/min) and discharge salt at a rate of 5 to 40 g/m^2 (65 to 520 lb/lane-mile). The unit has a tank capacity of 5 m^3 (6.5 yd^3). The entire system is a slide-in model that can be loaded and operational within 15 minutes. Hydraulic power for the unit is supplied by the truck. The company also manufactures dry chemical spreaders, which are tailgate-mounted on a dump box.

Salon works closely with the Finnish National Road Administration in providing and developing equipment for snow and ice operations. The company indicated that they can ship directly to the United States.

Epoke in Denmark

Epoke, located in Vejen, Denmark, has been manufacturing spreaders for 65 years and has distribution companies in Germany, Sweden, and the United States. This company utilizes a patented metering and delivery system in all their solid-material spreader equipment.

All Epoke's bulk spreaders feature hopper boxes where the hopper bottom is closed off with two rubber flaps. One of the bottom flaps is positioned against the delivery roller by adjusting springs. The delivery roller is equipped with replaceable cams, which allow material to pass between the delivery roller and the rubber flap. The cam size can be adapted for all material types and dosage rates. The tightness of the bottom flap is controlled by springs that are adjusted with a manual crank, which is located at the rear of the machine. A scale with sequential markings for continuous increments of spring base tension indicates the relative tension. The delivery roller pushes material out of the hopper and onto a rubber conveyor belt located underneath the hopper. An impeller axle with spring steel paddles located above the delivery roller is used to pulverize all lumps, distribute the spreading material in the hopper, and feed it to the delivery roller at a constant rate.

The rubber conveyor belt is equipped with internal and external scrapers to prevent material buildup on the conveyor belt. The entire conveyor belt can be removed from the spreader while the hopper is loaded.

The conveyor is geared to the speed of the delivery roller so the quantity of material on the conveyor remains the same regardless of the spreading quantity.

The material drops off the end of the conveyor belt into a closed stainless steel chute and onto a stainless steel spinner. The chute and chute frame are adjustable and feature a breakaway system to prevent damage to the spinner in case the sander accidentally is clogged by any foreign objects. The entire chute assembly is hinged, swinging upward when not in use or for ease of unloading material.

The impeller, the feed roller, the conveyor belt, and the spinner are all powered by the road wheel. The drive wheel features a piston-type hydraulic pump, which is mounted directly. The drive wheel is under a downward pressure in order to prevent sliding on icy surfaces. The amount of downward pressure exerted is controlled automatically by hydraulics according to the power demanded by the spreading function.

The entire system is controlled by the Epoke remote Servoset control, which enables the driver to control and operate the functions from the truck cab. This control box has a display and a built-in microprocessor used for calculation of spread quantity in kilograms, and other functions:

- Functions: Start/stop (spreading disconnected/connected)
  Adjustment of spreading width
  Adjustment of spreading quantity
  Adjustment of spreading symmetry
  Working lamp connected/disconnected
  Rotating warning lights
  Prewetting system—connected/disconnected

- Controls: Spreading width
  Spreading quantity
  Material quantity counter
  Time indicator
  Liquid indicator
  Spreading indicator
  Hopper empty indicator for spreading material

The electric remote control (the control box) is connected to the cab with a 12-V or 24-V multiple plug. In addition, the control is attached to the spreader by connecting the corrosion resistant, multipoled plug of the remote control cable to the plug box, which is placed on the rear hopper wall.

The electrical system is called Servoset 10 followed by a letter and a figure. The letter (K, H, or E) indicates which type of gear box fits to the Servoset, while the figure after the letter indicates the variant of the control box, refers to spread width and quantity, and denotes whether the control box should be width/quantity compensated.

On spreaders with three- and seven-step gear boxes, the spread width is stated in meters, and the spread quantity is adjusted by change of the stated gears. The spread quantity is also displayed on the control box in grams per square meter.

On spreaders with a synchron/nine-step gear box, the control box has functions that control both quantity and width. The dosage varies from 5 to 40 g/m^2 (65 to 520 lb/lane-mile) in 5 g/m^2 (65 lb/lane-mile) increments. The spread width can vary from 2 to 12 m (7 to 39 ft) in 1-m (3-ft) increments.

When the spreader is equipped for prewetting, it can apply liquids directly to the material being spread. The system automatically adjusts the flow rate of liquid so that the liquid-to-solid ratio remains constant regardless of change in truck speed, spread quantity, or pattern width. The prewetting system is also equipped with hydraulic controls that automatically reduce the material quantity exiting the conveyor belt by 30% when the liquid system is engaged.

The spread pattern can be shifted to the left or the right side behind the machine by shifting the spreading chute. This is accomplished according to where the material lands on the spinner disk. Assuming the spinner turns counterclockwise and the material lands near the center of the disk, the spread pattern is asymmetrical to the right of the machine. If the material lands nearer the front edge of the disk, the spread pattern is asymmetrical to the left of the machine.

The width of spread depends on the speed of the spinner, the diameter of the spinner, and its height above the roadway. Factors that govern spread width are droptime (T), spinner diameter (d), peripheral speed of the spinner (r):

$$\text{Spread width} = \frac{\pi r T d}{30}$$

where:

T	=	droptime = $\left[\frac{2m}{g}\right]^{1/2}$ (sec)
r	=	speed of spinner (rev/min)
m	=	height of spinner above road (m)
g	=	9.81 (m/s^2)
π	=	3.1416
d	=	diameter of spinner (m)

NOTE: Air resistance is not included in these calculations.

The spread width will generally increase 1 m (3 ft) for each 80 rpm increase in spinner speed. The company recommends that the spread width should be set 2 m (7 ft) less than the width of the roadway during spreading operations. When applying material to the roadway with a spinner, a banding effect of the material on the roadway occurs. The distance between the bands is dependent upon the number of vanes on the spinner disk and the speed of the spreader vehicle. As the number of vanes increases, the banding distance decreases; vehicle speed increases, the banding distances increase.

All spreader equipment sold in the European Community must meet certain requirements, such as those established in Germany. For the dosage test, the equipment is tested at three different speeds. The spread pattern test uses a grid system, which is laid out on a bituminous surface (see the German Standard Testing Protocols). In addition, the Epoke prewetting equipment was tested by the Danish Agricultural Test Centre in Bygholm. For the testing protocols, see Denmark Standards for Spreaders.

Epoke manufactures liquid spreaders incorporated nozzles on a spreading boom. The liquids are sprayed from a low height above the roadway, so that there is negligible influence from air currents or turbulence behind the vehicle that can cause the liquid to blow away.

Epoke's SW 2000 model is a tow-behind liquid spreader similar to their TK 12 series truck-mounted liquid spreader. The SW 2000 is designed to be towed by a truck with an existing liquid tank. As the spreader is powered by its own traction-driven wheel, it is road-speed controlled. It can be operated at speeds up to 60 km/hr (37 mph).

Liquid flows by gravity through a clear 75-mm (3-in) plastic hose from the tank to the spreader, where two liquid pumps provide an adequate supply of liquid chemical to each nozzle. These two pumps, which are a diaphragm type featuring six diaphragms each, share a common inlet filter. The main spraybar, which is 2,264 mm (89 in) long, is equipped with six nozzles—three large and three small. The spraybar's main nozzles are capable of achieving 3.5 m (11.5 ft) of spraying coverage. At low speeds, the smaller nozzles are engaged. As the truck's speed increases and the need for liquid increases, the smaller nozzles disengage automatically and the larger nozzles are engaged without a break in spray pattern. As the truck slows down, the reverse process occurs and the smaller nozzles engage again.

Three additional stainless steel nozzles mounted on the left end of the main spray bar are adjustable so that a perfect spray pattern in the left lane can be maintained. With the side nozzles engaged, a spraying width of 7 m (23 ft) can be obtained. Each side nozzle is pressure regulated to ensure a smooth and even flow, even at slow speeds.

The spreader features a remote control box, which is located next to the driver in the truck cab. This remote box is connected with the spreader by applying the multipoled plug of the remote control box to the plug box, which is placed on the front of the spreader housing. The following functions are controlled from inside the cab:

- stop/start of spraying;
- start/stop of side nozzles (3.5 or 7 m [11.5 or 23 ft]);
- light indicating which nozzles are in use;
- spreading quantity adjustments (2.5, 5, 7.5, 10, 12.5, 15 g/m^2 [33, 65, 98, 130, 163, 195 lb/lane-mile]);
- pump revolution counter;
- zero position for pump revolution counter; and
- spray indicator.

The spreader has manual start capabilities should the truck lose electrical power.

Epoke provides a table of the amount of liquid chemical required to cover two spread widths with a range of concentrations (table E-6). This is for a 22.1% solution of NaCl which has a density of 1.172 kg/L.

Table E-6 Epoke's spreading table.

g/m^2*	L/km per spreading 3.5 m	L/km per spreading 7 m
2.5	33.7	67.4
5.0	67.3	134.6
7.5	101.0	202.0
10.0	134.7	269.6
12.5	168.3	336.6
15.0	202.0	404.0

* 1 g/m^2 = 13 lb/lane-mile.

The liquid spreader is connected to the towing vehicle with an adjustable hitch and stabilizing chains. The hitch is adjustable up and down, in and out, in order to meet all truck requirements. The two heavy 9.5-mm (3/8-in) galvanized stabilizing chains are provided to ensure a tight turning circle and effortless backing.

To provide the liquid spreader with a maintenance-free environment, the liquid pumps, valving, and electrical components are housed in a steel enclosure. The top covers, which open to provide for inspection and service, are rubber gasketed to prevent contaminants from entering. Also, the steel members of the spreader are sandblasted, zinc dust-primed, second-primed, and surface-coated with two-component polyurethane paint.

Also during the visit, Epoke personnel informed the team of data they had collected from various countries regarding the use of liquid chemicals and prewetted salt. They referred to information contained in the VTI Report No. 276 titled "Highway Snow and Ice Control—State of the Art," which was published in 1985, and a number of Norwegian research projects.

Liquid solutions have been used to prevent slippery roads in Europe for a number of years. The method is probably best known in Italy, where they have used liquids on their roadways for several years. The Italians primarily use a CaCl solution, which has a concentration of 27%. When the solution is used as a preventive treatment, 18 to 37 g/m^2 (234 to 481 lb/lane-mile) of brine is spread, which corresponds to 5 to 10 g/m^2 (65 to 130 lb/lane-mile) of dry CaCl. When liquid material is spread to melt a thin layer of ice or snow, 74 to 92 g/m^2 (962 to 1,196 lb/lane-mile) of brine is applied, which corresponds to 20 to 25 g/m^2 (260 to 325 lb/lane-mile) of dry material.[7]

The deicing practices in the Scandinavian countries differ substantially from those in Italy insofar as a 23% solution of NaCl is used rather than a 27% solution of CaCl. Also in Scandinavia, the use of a liquid salt solution as a preventive treatment against slippery roads has proven successful. However, when spreading salt brine on compacted snow the results vary.

A research project being conducted in Norway during the past two winters using liquid salt brine has produced conflicting results. From 470 snow events, 51% of the results were reported as good, 10% were not acceptable, and 14% were poor. The remaining 25% of the results were recorded as unknown. In this project, the determination or evaluation of the roadway condition was made by conducting friction measurements. No information was provided on how the friction measurements were made or the time interval allowed after the application of the salt brine.

The evaluations of surface condition were based on these friction values:

Good	=	friction above 40
Not acceptable	=	friction between 30 and 40
Poor	=	friction below 30

The Epoke personnel noted that it was unusual that 25% of the tests had unknown results. The unknown test results may be attributed to incorrect operation, dosage, etc. Personnel also may not know how much liquid salt brine should be spread, resulting in an underdosage application with poor results. This was demonstrated during the winter of 1991-92 in Tromsö where 1,400 m^3 (376,000 gal) of liquid was spread. Positive results of using salt brine on snow occurred only after the maintenance people had shortened their application routes in order to make the liquid suffice, which indicated that previously too little material was being spread.

It was reported that 23% sodium chloride solution shows good results down to −10°C (14°F). However, use of salt brine at temperatures below −6°C (21°F) was not recommended.

The application rate for preventive salting is 10 to 20 g (0.35 to 0.7 oz) liquid per square meter corresponding to 2.5 to 5 g (0.09 to 0.18 oz) dry material per square meter, which is used depending on pavement temperature and humidity. The same quantity is also used to remove a thin layer of ice or frost. Prior to snow or during snowfall, 40 to 60 g/m^2 (520 to 780 lb/lane-mile) is spread, which corresponds to 12.5 to 15 g (0.44 to 0.53 oz) of dry material per square meter. With a few exceptions, preventive salting on dry or wet roads in Sweden has shown good results. On frost or thin ice layers, the results were good, and "full friction" can be obtained in less than 1 minute. When it was snowing and the roads were covered with slush or loose snow, the results varied. Liquids worked well during short snowfall. During long or intense snowfall, several reapplications were necessary to obtain good results. Liquid gave poor results on hard, packed snow. Therefore, it was important to plow or sweep the snow before applying liquids.

Table E-7 gives the recommended liquid quantities for application.

Table E-7 Recommended liquid quantities 23% (NaCl solution).

Weather and road conditions	Liquid quantity (g/m^2)*
Preventive against ice:	
Dry road, humidity below 85%	10 to 15
Dry road, humidity above 85%	15 to 20
Wet road	15 to 20
Preventive against snow:	40
On frost	15 to 20
On snow and during snowfall	40 to 60

* 1 g/m^2 = 13 lb/lane-mile.

The above values were tested in four districts under many various conditions, of temperature, humidity, traffic concentration, spreading equipment, etc. Therefore, the results of the liquid spreading have also been variable. In one district, 67% of the results were reported as good while in another district, only 34% were reported as good. This large deviation may be due to the aforementioned variables. To demonstrate the effects of liquid spreading versus dry salt spreading on depressing the freezing point of material on the roadway, a number of examples were given. The data were obtained from reports gathered from Vägverket, Sweden, and Statens Vegvesen, Norway.

Example 1

In this example, there was 15 g/m^2 (195 lb/lane-mile) of water on the road surface, which made it appear moist but not wet. It was assumed that when the liquid salt was spread, all the salt would remain on the road. When 5 g/m^2 (65 lb/lane-mile) of dry salt was spread, the freezing point was lowered to −21°C (−6°F). When 5 g/m^2 (65 lb/lane-mile) of saturated liquid salt solution was spread, the freezing point was lowered only to −11°C (12°F).

Example 2

Example 2 had the same conditions as in Example 1, except that there were 60 g/m^2 (780 lb/ lane-mile) of water on the road surface, which made it appear wet. The freezing point was lowered to −6°C (21°F) using dry salt and was lowered to −5°C (23°F) using liquid salt.

Example 3

Example 3 included the same conditions as given in Examples 1 and 2, but because of the influence of traffic, the quantity of salt was reduced. After 500 vehicle axles passed, the quantity of dry salt was reduced to 0.5 g/m^2 (6.5 lb/lane-mile) and the quantity of liquid to 4 g/m^2 (52 lb/lane-mile). With this reduction, the freezing point was lowered to −3°C (27°F) using dry salt and using liquid salt, to −10°C (14°F).

Findings from various countries were cited as documenting the positive benefits of prewetting salt. Studies have been conducted that show the amount of dry salt versus prewetted salt that remains on the roadway after a given amount of traffic had passed. Studies conducted in Switzerland at the end of the 1960s[16] with vehicles passing the test section at 65 km/hr (40 mph) found the following:

	Percent material remaining on roadway	
Amount of traffic	Dry salt	Prewetted salt
After 5 vehicles	30%	93%
After 100 vehicles	15%	80%

Studies conducted in Germany with vehicles passing the test section at 90 km/hr (56 mph):

	Percent material remaining on roadway		
Amount of traffic	Dry salt	Salt prewetted with NaCl	Salt prewetted with $CaCl_2$
After 100 vehicles	20%	80%	80%
After 100 vehicles	10%	40%	60%

Studies conducted in Michigan in 1962[17] reported that 70% of dry salt landed on the 7-m (23-ft) roadway; and 95% of prewetted salt landed on the 7-m (23 ft) roadway. Neither the moisture content of the prewetted salt nor how the salt residual was determined was identified.

A study was also described which showed the lowest effective temperatures for prewetted versus dry salt:

- Dry salt — deicing down to −6°C (21°F)
- Salt wetted with NaCl solution — deicing down to −10°C (14°F)
- Salt wetted with $CaCl_2$ solution — deicing down to −17°C (1°F)

There were no other particulars given regarding the above studies.

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Nido-Universal Machines

During the project team's trip to the Netherlands, the facilities of Nido-Universal Machines at Holten were visited to gather information about their spreader equipment. This company has specialized in development and manufacture of road winter maintenance equipment, such as spreaders and sprayers for deicing chemicals, for more than 40 years. Over the last 10 years, the company's focus has been on developing spreading equipment, which features very accurate dosage systems and additional devices, enabling road authorities to drastically reduce the amount of salt used.

Nido-Universal Machines' latest model spreader is the Nido 90, which is a demountable and suitable for handling all dry and moist spreading materials. The equipment is powered by a road wheel, which makes it fully road speed related. The controls are electronic with an integrated spread data registration.

The box for the spreader is a hopper type with a capacity ranging from 4 to 9 m^3 (5 to 12 yd^3). The prewetting fluid tanks hold up to 2,750 L (725 gal) and are positioned on either side of the hopper. The tanks are modular-constructed polyethylene liquid tanks, each with a capacity of 250 L (66 gal). This enables the capacity of the tanks to be easily matched to that of the hopper. The tanks are filled via the tank lid or via a connection at the rear of the spreader. The liquid, which is delivered accurately and constantly by a hydraulically driven pump, passes through a check valve, and then flows by gravity onto the spinner. No nozzles are used to prewet the material.

A rubber conveyor belt with raised herringbone cleats conveys the material from the hopper box to the spinner. A door, which is hydraulically controlled, and lump crushers (hanging steel chains), which help to eliminate material lumps from being fed onto the spinner, are located near the discharge end of the conveyor belt.

The material discharged from the belt falls through a stainless steel chute that can be easily adjusted for varying chassis heights. The spinner and spinner cover, both of which are made of plastic, are highly flexible and are virtually maintenance-free. The chute mechanism is fully adjustable, either by hand to give an asymmetric/symmetric spread pattern or by an electric actuator that provides control in the cab. The spinner assembly can be easily tipped up with the aid of a gas strut.

The power source for the spreader is a hydraulic pump driven by the road wheel. This wheel is kept in contact with the road surface by means of a hydraulic ram powered by a hand pump with an incline accumulator to maintain constant pressure on the road surface. The wheel position is adjustable horizontally as well as vertically to match different vehicle heights. The piston pump can operate in both directions, enabling the spreader to run while the vehicle is in reverse. The drive system provides immediate response of both the spinner and the belt when the vehicle starts. The wheel leg can be rotated into the near vertical position by the use of a hydraulic cylinder.

The Nido 90 uses a programmable microprocessor for its control system. There are three ways of programming the control system:

- Nido will program the control system.
- The users can do the programming themselves, using their own computer and a special program.
- The users can do the reprogramming themselves, using special instructions and the control box itself. This is currently in the development stage.

The control box is completely smooth with a watertight switch panel, and has no knobs that are prone to rust. The control box has a compact design with dimensions of 200 x 100 x 40 mm (8 x 4 x 1.6 in) with thin, flexible connector cables that enable the driver to place the control box at a convenient location according to specification. Within the cab, there is also a disconnect in the connector cable that can be disconnected easily, which permits the control box to be readily removed. The control keys are illuminated with digital indication of spreading width and dosage.

The control system operating functions are

- spreading—on/off,
- spread width with infinitely variable steps from 2 m to 11 m (7 to 36 ft),

- spread mixture with infinitely variable steps from 5 g/m^2 to 40 g/m^2 (65 to 520 lb/lane-mile) ice control chemical,
- spread mixture with infinitely variable steps from 25 to 300 g/m^2 (325 to 3,900 lb/lane-mile) abrasive material,
- maximum dosage,
- beacon lamp—on/off,
- work lamp—on/off,
- spread pattern position adjustment, and
- prewetting on/off.

The microprocessor in the control box contains specific check programs to simplify fault tracing. These fault programs include

- internal check program self-test,
- conveyor belt fault indication,
- spreading disk fault indication,
- control box battery fault indication,
- communication between control box and spreader failure indication,
- spreading indication, and
- low fluid level.

The control box provides for hopper unloading and a speed simulation of 30 km/hr (19 mph) to be used for calibration. It is also provided with closed loop feedback for the conveyor, pump, and spread spinner, for continuous monitoring of the required spread width and programmed spread quantity. If required, the spreader adjusts itself. In addition, the control system has an emergency control. If the feedback fails, the emergency program is switched on so that spreading is still possible.

The management functions of the system provide for programming the selection of limiting values and options that can be used during spreading. The following functions, which can be determined by management, are available to the operating personnel and/or to management:

- material (salt, sand, gravel),
- grain size,
- specific weight,
- spreading width (minimum/maximum size),and
- dosage rate (minimum/maximum amount).

During spreading operations, all operations are recorded. After spreading operations, the control box is removed from the truck and all data are downloaded into the computer and a complete report is generated on the spreading operation. The data provided include kilograms of solids used and cumulative amount used, daily amount of liquid used and, cumulative amount used and an hour counter.

The Nido 90 spreaders are designed for an extended life span, and all steel parts are shotblasted and finished with full anticorrosion treatment, protected by three layers of two-part epoxy paint. The electrical and hydraulic parts are protected as much as possible against the ingress of salt and salt solution. The various components, which are made of either plastic or stainless steel, are corrosion-free. This process ensures a minimum amount of maintenance.

Nido also manufactures a liquid spinner spreader, which is identified as R.S.P. sprayer. This unit attaches to the rear of a truck with modular, polyethylene liquid tanks, each with a capacity of 2,000 L (528 gal). The unit is powered either by the vehicle's hydraulic system or by a road wheel. The road wheel is similar to the one used on the Nido 90 demountable spreader.

In this unit, the liquid is pumped by two impeller pumps to a specially designed stainless steel spinner. The spinner is slightly convex with 10 curved vanes, and the spinner mechanism is manually adjustable to give asymmetric or symmetric spread patterns. The unit can apply liquid to the roadway surface at the rate of 10 to 40 g/m^2 (130 to 520 lb/lane-mile) over a spread width from 2 to 8 m (7 to 26 ft) in stepless increments while traveling between 10 and 60 km/hr (6 and 37 mph).

A remote control box, which is located in the truck cab, provides the following functions:

- spraying—on/off;
- spread width—digital readout in meters; and
- dosage rate—digital readout in g/m^2.

This unit is designed for an extended life span, with all steel parts being shotblasted and finished with full anticorrosion treatment, and is protected by three layers of two-component epoxy paint. The other essential parts are made of noncorrosive material.

One of the latest developments in Europe combines in a single unit the capability of spreading straight liquid, prewetted material, or dry material. Nido has developed such a unit, the Combi-Spreader. This unit has the same components as the Nido 90 spreader and the R.S.P. sprayer.

The Combi-Spreader has a 2,000-L (528 gal) liquid tank made of polyethylene mounted in front of the hopper. Prewetting liquid tanks are mounted on both sides of the hopper. The maximum size of the hopper is 5 m^3 (6.5 yd^3). These units are powered by a road wheel. The liquid is pumped by two impeller pumps to a specially designed spinner. This unit can apply material to the roadway surface at a dosage rate of 20 to 40 g/m^2 (260 to 520 lb/lane-mile) (in stepless increments) over a spread width of 2 to 6 m (7 to 20 ft) (in stepless increments). A remote control box is located in the truck cab with the same features as the control box for the Nido 90 spreaders. The spinner mechanism is manually adjustable for asymmetric or symmetric spread patterns.

Schmidt in Germany

The project team toured the Schmidt facility at St. Blasien in southern Germany to discuss testing protocols. Dr. Wolfgang Schmidt explained the testing procedure that is required by the Federal Republic of Germany and provided the specifications. The testing requirement set forth is for dry material and is paraphrased in this section.

In Germany, different procedures are followed when testing with wetted salt because it is difficult to vacuum. According to the Schmidt personnel, the testing used by the company involves placing the spreader in a stationary position and operating it at a simulated speed of 30 km/hr (19 mph). The spreading width is tested at 2, 3, 4, 5, and 6 m (7, 10, 13, 16, and 20 ft), and the application rate is set at 20 g/m^2 (260 lb/lane-mile). A test runs for approximately 2 minutes and leaves a fan-shaped spread pattern.

The wetted salt is then shoveled longitudinally into a row, transverse to the center line of the spreader. This row is subdivided into 1-m lengths, originating from the spinner location. Each subdivision of the wetted salt is collected and weighed, and the salt distribution is plotted.

Schmidt manufactures snowblowers, plows, and power brooms that are used at airports. In addition to spreaders, the company manufactures wing plows. Schmidt also manufactures the SST Series Automatic Bulk Gritters, which are truck-mounted spreaders of modular design. This unit features hopper box volumes of 1.2 to 6 m^3 (1.6 to 8 yd^3) with a variety of drive options and control systems. Abrasive and deicing material can be spread either dry or in combination with liquid proportioning (prewetting). A screw conveyor with a stainless steel crumbler ring at the outlet for uniform delivery conveys the material from the bottom of the hopper box to a stainless steel chute and spinner.

The spreading material is distributed by means of a stainless steel, rotary disk; the chute and spinner disk are made by Nido-Universal Machines. The material flow is metered and kept constant by automatic control of the conveyor and spinner. The different airborne behavior of salt and sand is automatically taken into account by the program selector switch for adjusting the speed of disk rotation. There are settings for fine, medium, or coarse particle size for salt and sand.

The conveyor screw and disk are driven hydraulically. The existing truck hydraulic system or a hydraulic pump driven by a power take-off shaft or separate diesel engine can be used. For prewetting, there are two impact-resistant polyethylene liquid tanks, one located on each side of the hopper box walls, and a liquid pump with V-belt hydraulic drive in the equipment compartment. Automatic control of liquid flow for application of 10,20, and 30 wt. % of dry material is provided.

The system application rates are:

- salt, either 5 to 20 g/m^2 (65 to 260 lb/lane-mile) with 2.5 g/m^2 (32.5 lb/lane-mile) increments or 5 to 40 g/m^2 (65 to 520 lb/lane-mile) with 5 g/m^2 (65 lb/lane-mile) increments; and

- sand, either 40 to 160 g/m^2 (520 to 2,080 lb/lane-mile) with 20 g/m^2 (260 lb/lane-mile) increments or 40 to 320 g/m^2 (520 to 4,160 lb/lane-mile) with 20 g/m^2 (260 lb/lane-mile) increments.

The spreading width settings are 2, 3, 4, 5, 6, and 8 m (7, 10, 13, 16, 20, and 26 ft). The control system continuously adjusts the asymmetrical/symmetrical spreading pattern. The entire operation is controlled from the driver's cab via the control console.

Kupper-Weisser in Germany

Kupper-Weisser, one of the three leading manufacturers of winter maintenance spreader equipment in Europe, is controlled by Kellner KG, a holding company. Kellner controls 18 manufacturing companies. According to the company, access to these various companies ensures that a better package of equipment can be provided to meet the needs of road administrations.

At the present time, neither Kellner nor Kupper-Weisser has a distributor in the United States. However, they can ship equipment directly.

All equipment that is produced by Kupper-Weisser meets the requirements of three German certification agencies:

- Technischer Überwachungsverein (TÜV) — The Technical Bureau for Testing and Supervision is an organization that checks all motor vehicles on a regular basis for compliance with traffic safety regulations.

- Bundesanstalt für das Strassenwesen (BAST) — This is the federal agency that specifies spreader equipment specifications and standards.

- Bundesverband der Unfallversicherungstr äger der Öffentlichen Hand (BAGUV) — This organization checks equipment for compliance with safety regulations. This organization is similar to the U.S. Occupational Safety and Health Administration.

National spreader standards such as the Deutsche Industrie Norm (DIN) in Germany, are established in Europe. The European standardization agency CEN, which consists of national standardization organizations, is currently working on a European standard. This standard will cover safety issues, as well as certain technical issues. In Germany, DIN is responsible for the technical aspect whereas BAGUV is responsible for safety aspects. The European standardization agency considers these two aspects individually. The only existing European standard covering highway vehicles and equipment is the European Standard, EN 500, which primarily applies to construction equipment.

Kupper-Weisser manufactures highway chemical spreader equipment (dry, prewetted, and liquid material), pumps and controls for mixing salt brine, and modular high-powered diesel engine with hydraulics.

The typical winter maintenance spreader sizes that are manufactured by Kupper-Weisser are salt hopper boxes (6 to 9 m^3 [8 to 12 $yd^{3]}$) and liquid salt tanks (2,500 L [660 gal]).

The size of the spinner is based on the desired spread width:

- 12 m (39 ft) spread needs a 800-mm (32-in) disk and
- 2 to 6 m (7 to 20 ft) spread needs a 600-mm (24-in) disk.

If chemical is to be applied to three lanes (16 m [53 ft]) at one time, dual spinners are required.

Material is metered by a large, open steel helical auger, the pitch of which has been chosen by design. Parallel to the auger is another shaft with fingers to break up lumps. The material is delivered to a chute at the rear where it is dropped onto a specially designed spinner disk.

The patented spinner has a series of three different radii which give the disk an almost triangular configuration. This shape provides different lengths of curved vanes or fins which control spread patterns on the roadway. The chute and spinner assembly is rotated to change the direction of the pattern.

The prewetting liquid is pumped through a check valve to an overflow chamber located just above the spinner. The liquid is discharged above the fluted hub of the spinner at a fixed location. The dry material and brine mix as they travel along the curved vanes. As the amount of prewetting liquid is increased, the amount of dry material is decreased in the same proportion so that the desired density remains constant. Kupper-Weisser uses sensors on the shafts of the auger and pumps to detect and measure the actual amount of material being delivered to the spinner. According to the company, no serious maintenance problems have been experienced with this system.

Arno Schworer, Technical Engineer of Electrics and Hydraulics, explained the operation of Kupper-Weisser's control system's by means of a simulator. The spreader operating system is controlled by a control panel, which is identical for all the company's models. The control panel, which measures 190 x 170 x 70 mm (7.5 x 7 x 3 in), can be tilted 45 degrees in all directions and is ergonomically designed for easy and clear operations. A backlighted keyboard and liquid crystal display show the operating state of the microprocessor. Error reports are rendered acoustically and optically.

The control panel is divided into three sections:

1. Operating field

   a. Spread width with
      - increments of 0.1 m (3 ft) from 2 to 8 m (7 to 26 ft) in standard version
      - increments of 0.1 m (3 ft) from 1 to 4 m (3 to 13 ft) on small vehicles
      - increments of 0.1 m (3 ft) from 3 to 12 m (10 to 39 ft) with special spinner disk
      - increments of 0.1 m (3 ft) from 2 to 16 m (7 to 52 ft) with automatic double spinner units

   b. Spread density
      - for salt, from 5 to 40 g/m^2 (65 to 520 lb/lane-mile) in increments of 1 g/m^2 (13 lb/lane-mile)
      - for grit, abrasives from 25 to 200 g/m^2 (325 to 2,600 lb/lane-mile) in increments of 1 g/m^2 (13 lb/lane-mile)

   c. Prewetting
      The amount of liquid application has a range of 5% to 30% in increments of 1%.

   The controls provide synchronous spreading width and spreading density. In addition, there are key controls for on/off spreading, emergency spreading, prewetting on/off, rotary light beacon, working lamps, and adjusting the pattern.

2. Control field

   The automatic spreading unit control system uses a light-emitting diode display to indicate:

- Fault — Automatic changeover from automatic to manual control
- Tank 1 — Spreading material tank empty via proximity switch
- Tank 2 — Spreading material tank empty via proximity switch with two-chamber automatic spreader unit
- Prewetted salt — Liquid salt tank empty via proximity switch, with final cut out of liquid salt pump
- System — Fault in the system
- Battery — Battery voltage of automatic spreader unit equipped with diesel engine
- Oil pressure — Oil pressure of automatic spreader unit equipped with diesel engine

In addition, the system contains a control switch which enables the spreader to be operated with a ground-speed orientation. The spreader can be calibrated under the ground speed orientation mode while stationary using a speed simulator for the speed range of 0 to 80 km/hr (0 to 50 mph).

3. Programmable and counter field

With the programmable keys, it is possible to individually enter the following variable names and their associated values on the liquid crystal display:

<u>Variable name</u> <u>Value</u>

- density 1 — Fluid density from tank 1, from 0.6 to 2.4 g/cm^3
- density 2 — Fluid density from tank 2, from 0.6 to 2.4 g/cm^3 or continuous dry material reduction with increase in amount of prewetting fluid from 5 to 30%
- reduce ml — Reduction of the dry material from 5 to 30% with prewetted salt
- reduce nt — Automatic adaptation of the spinner disk speed with different spreading material or prewetted salt
- simulation — Simulation of driving speed from 0 to 80 km/hr (0 to 50 mph)

The following values can be displayed:

- daily spreading distance traveled, in kilometers and meters,
- spreading distance traveled during the season, in kilometers,
- daily spreading quantity applied, in kilograms or tonnes,
- spreading quantity applied during the season, in kilograms or tonnes, and
- operating time, in hours.

The control box can also provide an accounting of all its snow and ice operations by means of a standard interface to a printer. The printout consists of two blocks of information. One block lists:

- application rate (g/m^2),
- percent of prewetting,
- spreader width,
- speed (km/hr),
- distance traveled while spreading at a given setting,
- distance traveled while plowing,
- total distance traveled,
- air temperature, and
- time of day.

The other provides a summary of the total amount of material spread and the distance traveled.

Because of environmental damage and groundwater contamination concerns, almost all European manufacturers have the capability to download data from their spreader controls. Kupper-Weisser listed the following reasons for downloading:

- Complete and correct documentation for use by road administrations and courts when necessary.

- Elimination of errors, which can occur due to inaccurate or missing reports from the driver.

- Elimination of paperwork done by drivers.

- Planning procurements, order placing, or calculation of spreading requirements (budget planning).

- Simplification of subsequent administration of winter service operations and immediacy of such information.

- Records for environmental protection authorities' questions or for similar groups' queries regarding quantities used.

- Immediate information for prompt reaction.

Air turbulence behind the spreader vehicle may cause drifts and swirls in the salt leaving the spinner disk. To address this problem, Kupper-Weisser has a patented wind deflector mounted just behind the hopper box and projecting above it. The slipstream is deflected onto the roadway behind the spreader vehicle.

In addition to spreaders that can prewet salt, the company offers a unit that can be switched from prewetting to spreading of liquid chemicals. This unit has a hopper box with a capacity of 6 m^3 (8 yd^3) and two polyester tanks mounted underneath the side walls of the hopper, with a total capacity of approximately 2,000 L (528 gal). The controls are the same as listed above. The spread density range for liquid application is 10 to 15 g/m^2 (130 to 195 lb/lane-mile), and the spread width is 2 to 7 m (7 to 23 ft).

Kupper-Weiser also manufactures a chemical spreader for use on airport runways, which also can be used on highways. This unit uses the same control system as other Kupper-Weisser spreaders. This unit can spread liquids with a quantity from 0 to 50 g/m^2 (0 to 650 lb/lane-mile) and a spread width from 2 to 7 m (7 to 23 ft). Tank capacity is 3,000 L (790 gal). The spinner disk is designed for spreading liquid chemicals. It is mounted on tilting brackets at the rear of the vehicle, which enables the spread pattern to be adjusted asymmetrically. The application rate is ground-speed oriented.

Kupper-Weisser is currently developing a method of measuring residual salt on the road from the moving spreader truck and using that information to regulate the chemical application rate.

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Appendix F

Summary of Material Applied to Test and Control Sections During 1991-92 Winter:

Maryland
Colorado
Nevada
Missouri
Ohio
Minnesota
New York

STATE OF MARYLAND

Storm #1 - January 14, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	14
Material used	100% rock salt and 70:30 sand/salt mix
Application rate per pass	77 - 564 lbs/ln-mi
Total material applied (all passes combined)	85,520 lbs
Total salt applied (all passes combined)	28,021 lbs
Total sand applied (all passes combined)	57,499 lbs

Test aborted at 1500.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	12
Material used	sand/salt mix*
Application rate per pass	43 - 235 lbs/ln-mi
Total material applied (all passes combined)	16,066 lbs
Total salt applied (all passes combined)	2,358 lbs
Total sand applied (all passes combined)	13,707 lbs

*Sand/salt mix used was 70:30, 90:10, and 50:50

STATE OF MARYLAND
Storm #2 - January 15, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	17
Material used	Sand/salt mix*
Application rate per pass	248 - 882 lbs/ln-mi
Total material applied (all passes combined)	127,610 lbs
Total salt applied (all passes combined)	24,027 lbs
Total sand applied (all passes combined)	103,582 lbs

Test aborted at 2359.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	38
Material used	sand/salt mix*
Application rate per pass	47 - 235 lbs/ln-mi
Total material applied (all passes combined	42,763 lbs
Total salt applied (all passes combined)	10,007 lbs
Total sand applied (all passes combined)	32,757 lbs

*Sand/salt mix used was 70:30 and 90:10.

STATE OF MARYLAND
Storm #3 - January 12, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	9
Material used	100% rock salt and 90:10 sand/salt mix
Application rate per pass	64 - 353 lbs/ln-mi
Total material applied (all passes combined)	47,747 lbs
Total salt applied (all passes combined)	7,309 lbs
Total sand applied (all passes combined)	40,438 lbs

Test aborted at 0500.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	32
Material used	sand/salt mix*
Application rate per pass	94 - 235 lbs/ln-mi
Total material applied (all passes combined)	41,438 lbs
Total salt applied (all passes combined)	4,595 lbs
Total sand applied (all passes combined)	36,843 lbs

*Sand/salt mix used was 90:10 and 70:30.

STATE OF MARYLAND
Storm #4 - January 23, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	14
Material used	Sand/salt mix*
Application rate per pass	248 - 259 lbs/ln-mi
Total material applied (all passes combined)	39,378 lbs
Total salt applied (all passes combined)	6,122 lbs
Total sand applied (all passes combined)	33,257 lbs

Test aborted at 2200.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	21
Material used	sand/salt mix*
Application rate per pass	86 - 235 lbs/ln-mi
Total material applied (all passes combined)	32,986 lbs
Total salt applied (all passes combined)	7,380 lbs
Total sand applied (all passes combined)	25,605 lbs

*Sand/salt mix used was 90:10 and 70:30 for test section, and 90:10, 70:30, and 50:50 for control section.

STATE OF MARYLAND
Storm #5 - January 31, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	14
Material used	100% rock salt and 70:30 sand/salt mix
Application rate per pass	64 - 496 lbs/ln-mi
Total material applied (all passes combined)	113,242 lbs
Total salt applied (all passes combined)	30,991 lbs
Total sand applied (all passes combined)	82,251 lbs

Test aborted at 2030.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	22
Material used	sand/salt mix*
Application rate per pass	43 - 235 lbs/ln-mi
Total material applied (all passes combined)	25,747 lbs
Total salt applied (all passes combined)	5,326 lbs
Total sand applied (all passes combined)	20,421 lbs

*Sand/salt mix used was 90:10 and 70:30 for test section, and 90:10, 70:30, and 50:50 for control section.

STATE OF MARYLAND
Storm #6 - February 4, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	3
Material used	100% rock salt
Application rate per pass	77 lbs/ln-mi
Total material applied (all passes combined)	5,069 lbs

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	5
Material used	70:30 sand/salt mix
Application rate per pass	188 lbs/ln-mi
Total material applied (all passes combined)	9,400 lbs
Total salt applied (all passes combined)	2,820 lbs
Total sand applied (all passes combined)	6,580 lbs

STATE OF MARYLAND
Storm #7 - February 13, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	5
Material used	70:30 sand/salt mix
Application rate per pass	248 lbs/ln-mi
Total material applied (all passes combined)	27,298 lbs
Total salt applied (all passes combined)	19,108 lbs
Total sand applied (all passes combined)	8,189 lbs

Test aborted at 0358.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	7
Material used	70:30 sand/salt mix
Application rate per pass	47 - 235 lbs/ln-mi
Total material applied (all passes combined)	10,627 lbs
Total salt applied (all passes combined)	1,063 lbs
Total sand applied (all passes combined)	9,564 lbs

STATE OF MARYLAND
Storm #8 - February 16, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	4
Material used	100% sand/salt mix
Application rate per pass	77 lbs/ln-mi
Total material applied (all passes combined)	6,758 lbs

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	10
Material used	sand/salt mix*
Application rate per pass	86 - 188 lbs/ln-mi
Total material applied (all passes combined)	14,736 lbs
Total salt applied (all passes combined)	5,112 lbs
Total sand applied (all passes combined)	9,624 lbs

*Sand/salt mix used was 70:30 and 50:50

STATE OF MARYLAND
Storm #9 - February 28, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	7
Material used	100% rock salt
Application rate per pass	154 - 192 lbs/ln-mi
Total material applied (all passes combined)	23,654 lbs

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	10
Material used	70:30 sand/salt mix
Application rate per pass	90 - 188 lbs/ln-mi
Total material applied (all passes combined)	12,117 lbs
Total salt applied (all passes combined)	3,635 lbs
Total sand applied (all passes combined)	8,482 lbs

STATE OF MARYLAND
Storm #10 - March 14, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	6
Material used	Sand/salt mix*
Application rate per pass	238 - 259 lbs/ln-mi
Total material applied (all passes combined)	32,757 lbs
Total salt applied (all passes combined)	9,827 lbs
Total sand applied (all passes combined)	22,930 lbs

Test aborted at 0400.

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	6
Material used	Sand/salt mix*
Application rate per pass	86 - 90 lbs/ln-mi
Total material applied (all passes combined)	5,261 lbs
Total salt applied (all passes combined)	2,269 lbs
Total sand applied (all passes combined)	2,991 lbs

*Sand/salt mix used was 50:50 and 90:10 for test section, and 70:30 and 50:50 for control section.

STATE OF MARYLAND
Storm #11 - March 15-16, 1992

Test Section - 11 miles (Two-lane, two-way highway)

Number of passes	4
Material used	100% rock salt
Application rate per pass	154 lbs/ln-mi
Total material applied (all passes combined)	13,517 lbs

Control Section - 10 miles (Two-lane, two-way highway)

Number of passes	4
Material used	70:30 sand/salt mix
Application rate per pass	266 lbs/ln-mi
Total material applied (all passes combined)	9,926 lbs
Total salt applied (all passes combined)	2,978 lbs
Total sand applied (all passes combined)	6,948 lbs

STATE OF COLORADO
Storm #1 - March 9, 1992

Test Section - 9.1 miles (Westbound direction, 2 lanes)

Number of passes	3
Material used	Sand/salt mix* prewetted with liquid $CaCl_2$
Application rate per pass	265 lbs/ln-mi
Total material applied (all passes combined)	14,332 lbs
Total sand applied (all passes combined)	11,692 lbs
Total salt applied (all passes combined)	2,395 lbs
Total $CaCl_2$ applied (all passes combined)	245 lbs

Control Section - 9.1 miles (Eastbound direction, 2 lanes)

Number of passes	3
Material used	sand/salt mix*
Application rate per pass	258 lbs/ln-mi
Total material applied (all passes combined)	14,087 lbs
Total sand applied (all passes combined)	11,551 lbs
Total salt applied (all passes combined)	2,536 lbs

*Sand/salt mix is 82% sand, 18% salt.

STATE OF NEVADA

Storm #1 - December 18, 1991

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	2
Material used	Sand/salt mix* prewetted with liquid $MgCl_2$
Application rate per pass	1,138 lbs/ln-mi
Total material applied (all passes combined)	15,207 lbs
Total sand applied (all passes combined)	12,530 lbs
Total salt applied (all passes combined)	2,566 lbs
Total $MgCl_2$ applied (all passes combines)	110 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	0

*Sand/salt mix is 83% sand, 17% salt

STATE OF NEVADA
Storm #2 - December 29, 1991

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	4
Material used	Liquid $MgCl_2$
Application rate per pass	102 lbs/ln-mi
Total material applied (all passes combined)	2,727 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	2
Material used	Sand/salt mix*
Application rate per pass	1,190 lbs/ln-mi
Total material applied (all passes combined)	15,898 lbs
Total salt applied (all passes combined)	2,703 lbs
Total sand applied (all passes combined)	13,196 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #3 - January 2-3, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	1
Material used	Sand/salt mix* prewetted with liquid $MgCl_2$
Application rate per pass	683 lbs/ln-mi
Total material applied (all passes combined)	9,124 lbs
Total sand applied (all passes combined)	7,518 lbs
Total NaCl applied (all passes combined)	1,540 lbs
Total $MgCl_2$ applied (all passes combined)	66 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	3
Material used	Sand/salt mix*
Application rate per pass	966 - 1,385 lbs/ln-mi
Total material applied (all passes combined)	24,959 lbs
Total sand applied (all passes combined)	20,716 lbs
Total salt applied (all passes combined)	4,243 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #4 - January 5, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	3
Material used	Liquid $MgCl_2$ and sand/salt mix* prewetted with $MgCl_2$
Application rate per pass	102 - 973 lbs/ln-mi
Total material applied (all passes combined)	7,864 lbs
Total sand applied (all passes combined)	5,257 lbs
Total NaCl applied (all passes combined)	1,097 lbs
Total $MgCl_2$ applied (all passes combined)	1,411 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	3
Material used	sand/salt mix*
Application rate per pass	966 - 1,620 lbs/ln-mi
Total material applied (all passes combined)	28,097 lbs
Total sand applied (all passes combined)	23,321 lbs
Total salt applied (all passes combined)	4,777 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #5 - January 6-7, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	2
Material used	Sand/salt mix prewetted with liquid $MgCl_2$* Sand/salt mix*
Application rate per pass	1,430 - 2,141 lbs/ln-mi
Total material applied (all passes combined)	23,854 lbs
Total sand applied (all passes combined)	19,713 lbs
Total salt applied (all passes combined)	4,038 lbs
Total $MgCl_2$ applied (all passes combined)	104 lbs

Control Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	3
Material used	sand/salt mix*
Application rate per pass	1,080 - 2,126 lbs/ln-mi
Total material applied (all passes combined)	30,965 lbs
Total sand applied (all passes combined)	25,701 lbs
Total salt applied (all passes combined)	5,264 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #6 - February 11, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	0

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	2
Material used	sand/salt mix*
Application rate per pass	728 - 923 lbs/ln-mi
Total material applied (all passes combined)	11,366 lbs
Total salt applied (all passes combined)	1,932 lbs
Total sand applied (all passes combined)	9,434 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #7 - February 15, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	2
Material used	Liquid $MgCl_2$
Application rate per pass	102 lbs/ln-mi
Total material applied (all passes combined)	1,364 lbs

Control Section - 6.68 miles (Southbound direction 2, lanes)

Number of passes	6
Material used	sand/salt mix*
Application rate per pass	778 - 2,592 lbs/ln-mi
Total material applied (all passes combined)	52,597 lbs
Total salt applied (all passes combined)	8,941 lbs
Total sand applied (all passes combined)	43,655 lbs

*Sand/salt mix 83% sand, 17% salt.

STATE OF NEVADA

Storm #8 - February 16, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	4
Material used	Liquid $MgCl_2$
Application rate per pass	102 lbs/ln-mi
Total material applied (all passes combined)	2,727 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	4
Material used	sand/salt mix*
Application rate per pass	1,385 - 2,126 lbs/ln-mi
Total material applied (all passes combined)	41,956 lbs
Total salt applied (all passes combined)	7,133 lbs
Total sand applied (all passes combined)	34,823 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF MISSOURI
Storm #1 - March 18-19, 1992

Test Section - 2.8 miles(Two-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	101 lbs/ln-mi
Total material applied (all passes combined)	566 lbs
Total NaCl applied (all passes combined)	560 lbs
Total $CaCl_2$ applied (all passes combined)	6 lbs

Control Section - 2.8 miles (Two-lane, divided highway)

Number of passes	1
Material used	NaCl
Application rate per pass	100 lbs/ln-mi
Total material applied (all passes combined)	280 lbs

STATE OF OHIO
Storm #1 - February 8, 1992

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	101 lbs/ln-mi
Total material applied (all passes combined)	2,421 lbs
Total NaCl applied (all passes combined)	2,400 lbs
Total $CaCl_2$ applied (all passes combined)	21 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl
Application rate per pass	100 lbs/ln-mi
Total material applied (all passes combined)	2,400 lbs

STATE OF OHIO

Storm #2 - February 13, 1992

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	101 lbs/ln-mi
Total material applied (all passes combined)	4,842 lbs
Total NaCl applied (all passes combined)	4,800 lbs
Total $CaCl_2$ applied (all passes combined)	42 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	4
Material used	NaCl
Application rate per pass	150 - 200 lbs/ln-mi
Total material applied (all passes combined)	8,400 lbs

STATE OF OHIO
Storm #3 - February 14, 1992

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	101 lbs/ln-mi
Total material applied (all passes combined)	2,421 lbs
Total NaCl applied (all passes combined)	2,400 lbs
Total $CaCl_2$ applied (all passes combined)	21 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl
Application rate per pass	100 - 150 lbs/ln-mi
Total material applied (all passes combined)	3,000 lbs

STATE OF MINNESOTA
Storm #1 - February 10, 1992
U.S. Interstate 35

Test Section - 1.5 miles (Four-lane, divided highway)

Number of passes	7
Material used	CMA/NaCl mix* prewetted with liquid 25% CMA
Application rate per pass	76 - 1,104 lbs/ln-mi
Total material applied (all passes combined)	7,134 lbs
Total NaCl applied (all passes combined)	5,414 lbs
Total CMA applied (all passes combined)	1,720 lbs

Control Section - 4.3 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application rate per pass	259 - 729 lbs/ln-mi
Total material applied (all passes combined)	7,383 lbs

*CMA/NaCl mix is 78% NaCl, 22% CMA.

STATE OF MINNESOTA
Storm #3 - February 17, 1992
U.S. Interstate 35

Test Section - 1.5 miles (Four-lane, divided highway)

Number of passes	1
Material used	CMA/NaCl mix* prewetted with liquid 25% CMA
Application rate per pass	875 lbs/ln-mi
Total material applied (all passes combined)	1,313 lbs
Total NaCl applied (all passes combined)	996 lbs
Total CMA applied (all passes combined)	316 lbs

Control Section - 4.3 miles (Four-lane, divided highway)

Number of passes	0

No applications made

*CMA/NaCl mix is 78% NaCl, 22% CMA.

STATE OF MINNESOTA
Storm #4 - February 20, 1992
U.S. Interstate 35

Test Section - 1.5 miles (Four-lane, divided highway)

Number of passes	3
Material used	CMA/NaCl mix* prewetted with liquid 25% CMA
Application rate per pass	725 - 1,167 lbs/ln-mi
Total material applied (all passes combined)	4,588 lbs
Total NaCl applied (all passes combined)	3,482 lbs
Total CMA applied (all passes combined)	1,106 lbs

Control Section - 4.3 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application rate per pass	130 - 259 lbs/ln-mi
Total material applied (all passes combined)	3,341 lbs

*CMA/NaCl mix is 78% NaCl, 22% CMA.

STATE OF MINNESOTA
Storm #4- February 20, 1992
U.S. Highway 53

Test Section - 17 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$ and sand/salt mix*
Application rate per pass	205 - 375 lbs/ln-mi
Total material applied (all passes combined)	19,713 lbs
Total sand applied (all passes combined)	10,200 lbs
Total NaCl applied (all passes combined)	9,350 lbs
Total $CaCl_2$ applied (all passes combined)	163 lbs

Control Section - 17 miles (Four-lane, divided highway)

Number of passes	0

No applications made

*Sand/NaCl mix is 80% sand, 20% NaCl.

STATE OF NEW YORK
Storm #1 - January 23, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	13
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	115 lbs/ln-mi
Total material applied (all passes combined)	22,925 lbs
Total NaCl applied (all passes combined)	22,533 lbs
Total $CaCl_2$ applied (all passes combined)	392 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	8
Material used	NaCl
Application rate per pass	220 - 226 lbs/ln-mi
Total material applied (all passes combined)	27,148 lbs

STATE OF NEW YORK
Storm #2 - February 1, 1992

Test Section - 7.7 miles (Four-lane, divided highway

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	124 lb/ln-mi
Total material applied (all passes combined)	3,809 lbs
Total NaCl applied (all passes combined)	3,744 lbs
Total $CaCl_2$ applied (all passes combined)	65 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application rate per pass	226 lbs/ln-mi
Total material applied (all passes combined)	3,480 lbs

STATE OF NEW YORK
Storm #3 - February 4, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	8
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	123 lbs/ln-mi
Total material applied (all passes combined)	15,105 lbs
Total NaCl applied (all passes combined)	14,975 lbs
Total $CaCl_2$ applied (all passes combined)	130 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl
Application rate per pass	226 lbs/ln-mi
Total material applied (all passes combined)	24,363 lbs

STATE OF NEW YORK
Storm #4 - February 8-9, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	13
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	114 - 123 lbs/ln-mi
Total material applied (all passes combined)	22,868 lbs
Total NaCl applied (all passes combined)	22,671 lbs
Total $CaCl_2$ applied (all passes combined)	167 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	14
Material used	NaCl
Application rate per pass	220 - 226 lbs/ln-mi
Total material applied (all passes combined)	47,732 lbs

STATE OF NEW YORK
Storm #5 - February 11, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	114 lbs/ln-mi
Total material applied (all passes combined)	8,742 lbs
Total NaCl applied (all passes combined)	8,666 lbs
Total $CaCl_2$ applied (all passes combined)	75 lbs

Test aborted at 1500.

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application rate per pass	220 lbs/ln-mi
Total material applied (all passes combined)	10,143 lbs

STATE OF NEW YORK
Storm #6 - February 12-14, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	6
Material used	NaCl prewetted with liquid 32% $CaCl_2$; NaCl
Application rate per pass	114 - 220 lbs/ln-mi
Total material applied (all passes combined)	13,895 lbs
Total NaCl applied (all passes combined)	13,834 lbs
Total $CaCl_2$ applied (all passes combined)	62 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl
Application rate per pass	220 - 226 lbs/ln-mi
Total material applied (all passes combined)	17,005 lbs

STATE OF NEW YORK

Storm #7 - February 16, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	123 lbs/ln-mi
Total material applied (all passes combined)	3,776 lbs
Total NaCl applied (all passes combined)	3,744 lbs
Total $CaCl_2$ applied (all passes combined)	33 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application rate per pass	122 lbs/ln-mi
Total material applied (all passes combined)	3,744 lbs

STATE OF NEW YORK
Storm #8 - February 16, 1992

No applications were made.

STATE OF NEW YORK
Storm #9 - February 22, 1992

Test Section - 7.7 miles (four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	123 lbs/ln-mi
Total material applied (all passes combined)	1,888 lbs
Total NaCl applied (all passes combined)	1,872 lbs
Total $CaCl_2$ applied (all passes combined)	16 lbs

Control Section - 7.7 miles (four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application rate per pass	122 lbs/ln-mi
Total material applied (all passes combined)	1,872 lbs

STATE OF NEW YORK
Storm #10 - February 24, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	123 lbs/ln-mi
Total material applied (all passes combined)	7,553 lbs
Total NaCl applied (all passes combined)	7,487 lbs
Total $CaCl_2$ applied (all passes combined)	65 lbs

Control Section - 7.7 miles (four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application rate per pass	226 lbs/ln-mi
Total material applied (all passes combined)	6,961 lbs

STATE OF NEW YORK
Storm #11 - February 26-27, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application rate per pass	119 - 123 lbs/ln-mi
Total material applied (all passes combined)	7,452 lbs
Total NaCl applied (all passes combined)	7,387 lbs
Total $CaCl_2$ applied (all passes combined)	64 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl
Application rate per pass	118 - 226 lbs/ln-mi
Total material applied (all passes combined)	10,604 lbs

STATE OF NEW YORK
Storm #12 - February 28-29, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl prewetted with liquid 32% $CaCl_2$; NaCl
Application rate per pass	123 - 226 lbs/ln-mi
Total material applied (all passes combined)	21,082 lbs
Total NaCl applied (all passes combined)	21,049 lbs
Total $CaCl_2$ applied (all passes combined)	33 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl
Application rate per pass	220 - 226 lbs/ln-mi
Total material applied (all passes combined)	24,267 lbs

STATE OF NEW YORK

Storm #31 - March 11-15, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	33
Material used	Sand/salt mix* with liquid 32% $CaCl_2$, NaCl prewetted with liquid 32% $CaCl_2$, and NaCl
Application rate per pass	122 - 260 lbs/ln-mi
Total material applied (all passes combined)	81,622 lbs
Total sand applied (all passes combined)	5,959 lbs
Total NaCl applied (all passes combined)	75,306 lbs
Total $CaCl_2$ applied (all passes combined)	356 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	33
Material used	NaCl and sand/salt mix*
Application rate per pass	132 - 226 lbs/ln-mi
Total material applied (all passes combined)	94,768 lbs
Total sand applied (all passes combined)	3,055 lbs
Total NaCl applied (all passes combined)	91,713 lbs

*Sand/salt mix is 75% sand, 25% NaCl.

STATE OF NEW YORK
Storm #14 - March 17, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$; NaCl
Application rate per pass	123 - 226 lbs/ln-mi
Total material applied (all passes combined)	5,369 lbs
Total NaCl applied (all passes combined)	5,352 lbs
Total $CaCl_2$ applied (all passes combined)	16 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	42
Material used	NaCl
Application rate per pass	226 lbs/ln-mi
Total material applied (all passes combined)	6,961 lbs

STATE OF NEW YORK
Storm #15 - March 22, 1992

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	11
Material used	NaCl prewetted with liquid 32% $CaCl_2$; NaCl
Application rate per pass	114 - 221 lbs/ln-mi
Total material applied (all passes combined)	29,223 lbs
Total NaCl applied (all passes combined)	29,104 lbs
Total $CaCl_2$ applied (all passes combined)	119 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	11
Material used	NaCl
Application rate per pass	122 - 220 lbs/ln-mi
Total material applied (all passes combined)	35,695 lbs

Appendix G

Summary of Material Applied to Test and Control Sections During 1992-93 Winter:

Maryland
Colorado
Nevada
Missouri
Ohio
Minnesota
New York
Washington

STATE OF MARYLAND
Storm #1 - January 8-11, 1993
MD Route 495

Test Section - 10.4 miles (Two-lane, undivided highway)

Number of passes	19
Material used	NaCl/sand*
Application per rate pass	173 - 324 lbs/ln-mi
Total material applied (all passes combined)	81,769 lbs
Total sand applied (all passes combined)	40,884 lbs
Total NaCl applied (all passes combined)	40,884 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	19
Material used	NaCl/sand*
Application per rate pass	54 -76 lbs/ln-mi
Total material applied (all passes combined)	24,381 lbs
Total sand applied (all passes combined)	12,191 lbs
Total NaCl applied (all passes combined)	12,191 lbs

*Mix is 50% NaCl, 50% sand.

STATE OF MARYLAND
Storm #2 - January 24-25, 1993
MD Route 495

Test Section - 10.4 miles (Two-lane, undivided highway)

Number of passes	8
Material used	NaCl/sand*
Application per rate pass	173 - 475 lbs/ln-mi
Total material applied (all passes combined)	31,450 lbs
Total sand applied (all passes combined)	15,725 lbs
Total NaCl applied (all passes combined)	15,725 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	6
Material used	NaCl/sand**
Application per rate pass	54 - 113 lbs/ln-mi
Total material applied (all passes combined)	6,905 lbs
Total sand applied (all passes combined)	3,926 lbs
Total NaCl applied (all passes combined)	2,979 lbs

*Mix is 50% NaCl, 50% sand.

**Mix is 50:50 NaCl/sand and 30:70 NaCl/sand.

STATE OF MARYLAND
Storm #2 - January 29, 1993
MD Route 495

Test Section - 10.4 miles (Two-lane, undivided highway)

Number of passes	7
Material used	NaCl/sand*
Application per rate pass	173 - 475 lbs/ln-mi
Total material applied (all passes combined)	31,899 lbs
Total sand applied (All passes combined)	15,949 lbs
Total NaCl applied (all passes combined)	15,949 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	2
Material used	NaCl/sand**
Application per rate pass	113 lbs/ln-mi
Total material applied (all passes combined)	2,369 lbs
Total sand applied (all passes combined)	1,658 lbs
Total NaCl applied (all passes combined)	711 lbs

*Mix is 50% NaCl, 50% sand.

**Mix is 30% NaCl, 70% sand.

STATE OF MARYLAND

Storm #4 - February 1, 1993
MD Route 495

Test Section - 10.4 miles (Two-lane, undivided highway)

Number of passes	4
Material used	NaCl/sand*
Application per rate pass	475 lbs/ln-mi
Total material applied (all passes combined)	19,768 lbs
Total sand applied (all passes combined)	9,884 lbs
Total NaCl applied (all passes combined)	9,884 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	2
Material used	NaCl/sand**
Application per rate pass	90 lbs/ln-mi
Total material applied (all passes combined)	1,895 lbs
Total sand applied (all passes combined)	1,327 lbs
Total NaCl applied (all passes combined)	569 lbs

*Mix is 50% Nacl, 50% sand.
**Mix is 30% NaCl, 70% sand.

STATE OF COLORADO
Storm #1 - November 20-21, 1992
U.S. Interstate 25

Test Section - 5.05 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	254 - 509 lbs/ln-mi
Total material applied (all passes combined)	17,983 lbs
Total sand applied (all passes combined)	16,261 lbs
Total NaCl applied (all passes combined)	1,414 lbs
Total $CaCl_2$ applied (all passes combined)	308 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	4
Material used	NaCl/sand*
Application per rate pass	250 - 500 lbs/ln-mi
Total material applied (all passes combined)	10,100 lbs
Total sand applied (all passes combined)	9,292 lbs
Total NaCl applied (all passes combined)	808 lbs

*NaCl/sand mix is 8% NaCl, 92% sand.

STATE OF COLORADO
Storm #2 - November 21-December 4, 1992
Colorado Route 470

Test Section - 9.1 miles (Four-lane, divided highway)

Number of passes	14
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	254 - 509 lbs/ln-mi
Total material applied (all passes combined)	64,809 lbs
Total sand applied (all passes combined)	52,234 lbs
Total NaCl applied (all passes combined)	11,466 lbs
Total $CaCl_2$ applied (all passes combined)	1,109 lbs

Control Section - 9.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	254 lbs/ln-mi
Total material applied (all passes combined)	9,258 lbs
Total sand applied (all passes combined)	7,462 lbs
Total NaCl applied (all passes combined)	1,638 lbs
Total $CaCl_2$ applied (all passes combined)	158 lbs

*NaCl/sand mix is 18% NaCl, 82% sand.

STATE OF COLORADO
Storm #3 - November 23, 1992
U.S. Interstate 25

Test Section - 5.05 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	254 - 509 lbs/ln-mi
Total material applied (all passes combined)	5,138 lbs
Total sand applied (all passes combined)	4,646 lbs
Total NaCl applied (all passes combined)	404 lbs
Total $CaCl_2$ applied (all passes combined)	88 lbs

Control Section - 5.05 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl/sand*
Application per rate pass	500 lbs/ln-mi
Total material applied (all passes combined)	2,525 lbs
Total sand applied (all passes combined)	2,323 lbs
Total NaCl applied (all passes combined)	202 lbs

*NaCl/sand mix is 8% Nacl, 92% sand.

STATE OF COLORADO
Storm #4 - December 3-5, 1992
U.S. Interstate 25

Test Section - 5.05 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	253 - 254 lbs/ln-mi
Total material applied (all passes combined)	7,680 lbs
Total sand applied (all passes combined)	6,969 lbs
Total NaCl applied (all passes combined)	606 lbs
Total $CaCl_2$ applied (all passes combined)	105 lbs

Control Section - 5.05 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl/sand*
Application per rate pass	500 lbs/ln-mi
Total material applied (all passes combined)	10,100 lbs
Total sand applied (all passes combined)	9,292 lbs
Total NaCl applied (all passes combined)	808 lbs

*NaCl/sand mix is 8% Nacl, 92% sand.

STATE OF COLORADO
Storm #5 - December 12-13, 1992
U.S. Interstate 25

<u>Test Section - 5.05 miles (Four-lane, divided highway)</u>

Number of passes <u>0</u>

No applications were made on test section except spot sanding.

<u>Control Section - 10.5 miles (Two-lane, undivided highway)</u>

Number of passes <u>0</u>

No applications were made on control section except spot sanding.

STATE OF COLORADO
Storm #6 - February 3, 1993
U.S. Interstate 25

Test Section - 5.05 miles (Four-lane, divided highway)

Number of passes	0

No applications were made on test section except spot sanding.

Control Section - 5.05 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl/sand*
Application per rate pass	500 lbs/ln-mi
Total material applied (all passes combined)	12,625 lbs
Total sand applied (all passes combined)	11,615 lbs
Total NaCl applied (all passes combined)	1,010 lbs

*NaCl/sand mix is 8% Nacl, 92% sand.

STATE OF COLORADO
Storm #7 - February 9-10, 1993
U.S. Interstate 25

Test Section - 5.05 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl/sand mix* prewetted with 32% $CaCl_2$
Application per rate pass	509 lbs/ln-mi
Total material applied (all passes combined)	10,276 lbs
Total sand applied (all passes combined)	9,292 lbs
Total NaCl applied (all passes combined)	808 lbs
Total $CaCl_2$ applied (all passes combined)	176 lbs

Control Section - 50.5 miles (Four-lane, divided highway)

Number of passes	6
Material used	NaCl/sand*
Application per rate pass	500 lbs/ln-mi
Total material applied (all passes combined)	15,150 lbs
Total sand applied (all passes combined)	13,938 lbs
Total NaCl applied (all passes combined)	1,212 lbs

*NaCl/sand mix is 8% Nacl, 92% sand.

STATE OF NEVADA
Storm #1 - November 19, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	0

No application were made on the test section.

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	1
Material used	Sand/salt mix*
Application per rate pass	1,310 lbs/ln-mi
Total material applied (all passes combined)	8,753 lbs
Total sand applied (all passes combined)	7,265 lbs
Total salt applied (all passes combined)	1,488 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #2 - December 6-7, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	19
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	8,571 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	2
Material used	Sand/salt mix*
Application per rate pass	1,411 lbs/ln-mi
Total material applied (all passes combined)	18,854 lbs
Total sand applied (all passes combined)	15,649 lbs
Total salt applied (all passes combined)	3,205 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #3 - december 11, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	4
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	3,117 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	3
Material used	Prewet mix and sand/salt mix*
Application per rate pass	677 - 1,065 lbs/ln-mi
Total material applied (all passes combined)	16,160 lbs
Total sand applied (all passes combined)	13,358 lbs
Total salt applied (all passes combined)	2,736 lbs
Total $MgCl_2$ applied (all passes combined)	65 lbs

*Prewet mix is 83:17 sand/salt mix prewet with 27% liquid $MgCl_2$ at a rate of 5 gal/ton.
Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #4 - December 16-18, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	14
Material used	Liquid $MgCl_2$ sand/salt mix*
Application per rate pass	44 - 1,780 lbs/ln-mi
Total material applied (all passes combined)	44,826 lbs
Total sand applied (all passes combined)	29,607 lbs
Total salt applied (all passes combined)	6,064 lbs
Total $MgCl_2$ applied (all passes combined)	9,155 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	8
Material used	Sand/salt mix*
Application per rate pass	675 - 1,168 lbs/ln-mi
Total material applied (all passes combined)	49,728 lbs
Total sand applied (all passes combined)	41,275 lbs
Total salt applied (all passes combined)	8,454 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #5 - December 28-30, 1992

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	6
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	7,553 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	0

No applications were made on the control section

STATE OF NEVADA
Storm #6 - January 1, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	1
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	779 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	0

No applications were made on the control section

STATE OF NEVADA
Storm #7 - January 5-9, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	2619
Material used	Liquid $MgCl_2$ and sand/salt mix*
Application per rate pass	1,171 - 1,138 lbs/ln-mi
Total material applied (all passes combined)	49,999 lbs
Total sand applied (all passes combined)	28,566 lbs
Total salt applied (all passes combined)	5,851 lbs
Total $MgCl_2$ applied (all passes combined)	15,583 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	10
Material used	Sand/salt mix*
Application per rate pass	405 - 1,068 lbs/ln-mi
Total material applied (all passes combined)	57,008 lbs
Total sand applied (all passes combined)	47,316 lbs
Total salt applied (all passes combined)	9,691 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA

Storm #8 - January 9-10, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	61
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	4,675 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	10
Material used	Sand/salt mix*
Application per rate pass	655 - 1,221 lbs/ln-mi
Total material applied (all passes combined)	69,070 lbs
Total sand applied (all passes combined)	57,328 lbs
Total salt applied (all passes combined)	11,742 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA

Storm #9 - January 12-14, 1993

Test Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	12
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	9,350 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	13
Material used	Sand/salt mix*
Application per rate pass	806 - 1,495 lbs/ln-mi
Total material applied (all passes combined)	95,855 lbs
Total sand applied (all passes combined)	79,560 lbs
Total NaCl applied (all passes combined)	16,295 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #10 - January 15-18, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	17
Material used	Liquid $MgCl_2$ and sand/salt mix*
Application per rate pass	117 - 1,246 lbs/ln-mi
Total material applied (all passes combined)	52,916 lbs
Total sand applied (all passes combined)	37,374 lbs
Total salt applied (all passes combined)	7,655 lbs
Total $MgCl_2$ applied (all passes combined)	7,887 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	25
Material used	Sand/salt mix*
Application per rate pass	405 - 1,495 lbs/ln-mi
Total material applied (all passes combined)	105,331 lbs
Total sand applied (all passes combined)	87,425 lbs
Total salt applied (all passes combined)	17,906 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #11 - January 26-27, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	10
Material used	Liquid $MgCl_2$
Application per rate pass	72 - 117 lbs/ln-mi
Total material applied (all passes combined)	4,398 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	7
Material used	Sand/salt mix*
Application per rate pass	569 - 890 lbs/ln-mi
Total material applied (all passes combined)	33,949 lbs
Total sand applied (all passes combined)	28,178 lbs
Total salt applied (all passes combined)	5,771 lbs

NOTE: This was a fog and ice event. On both test and control section, applications were made only to parts of the section, not to the entire section length.

*Mix is 50% Nacl, 50% sand.

STATE OF NEVADA
Storm #12 - February 11, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	4
Material used	Liquid $MgCl_2$
Application per rate pass	117 lbs/ln-mi
Total material applied (all passes combined)	3,117 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	0

No applications were made on the control section.

Precautionary applications, not a storm event.

STATE OF NEVADA
Storm #13 - February 15-20, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	29
Material used	Liquid $MgCl_2$ and sand/salt mix*
Application per rate pass	94 - 1,116 lbs/ln-mi
Total material applied (all passes combined)	68,022 lbs
Total sand applied (all passes combined)	40,984 lbs
Total salt applied (all passes combined)	8,394 lbs
Total $MgCL_2$ applied (all passes combined)	18,644 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	19
Material used	Sand/salt mix*
Application per rate pass	718 - 1,246 lbs/ln-mi
Total material applied (all passes combined)	121,417 lbs
Total sand applied (all passes combined)	100,776 lbs
Total salt applied (all passes combined)	20,641 lbs

*Sand/salt mix is 83% sand, 17% salt.

STATE OF NEVADA
Storm #14 - February 22-27, 1993

Test Section - 6.68 miles (Northbound direction, 2 lanes)

Number of passes	23
Material used	Liquid $MgCl_2$
Application per rate pass	94 - 379 lbs/ln-mi
Total material applied (all passes combined)	24,028 lbs

Control Section - 6.68 miles (Southbound direction, 2 lanes)

Number of passes	7
Material used	Sand/salt mix*
Application per rate pass	882 - 1,068 lbs/ln-mi
Total material applied (all passes combined)	45,795 lbs
Total sand applied (all passes combined)	38,010 lbs
Total salt applied (all passes combined)	7,785 lbs

NOTE: On test section, applications were not always made to entire length of the section.

*Sand/salt mix is 83% sand, 17% salt.

STATE OF MISSOURI

Storm #1 - November 6-7, 1992
U.S. Interstate 29

Test Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	100 lbs/ln-mi
Total material applied (all passes combined)	280 lbs

Control Section - 2.8 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	400 lbs/ln-mi
Total material applied (all passes combined)	2,240 lbs

STATE OF MISSOURI
Storm #2 - November 22, 1992
U.S. Interstate 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl Mix* prewetted with 28% $MgCl_2$
Application per rate pass	222 lbs/ln-mi
Total material applied (all passes combined)	2,269 lbs
Total cinders applied (all passes combined)	1,260 lbs
Total NaCl applied (all passes combined)	994 lbs
Total $MgCl_2$ applied (all passes combined)	15 lbs

Control Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	4,202 lbs
Total cinders applied (all passes combined)	2,349 lbs
Total NaCl applied (all passes combined)	1,853 lbs

*Cinders/NaCl mix is 50% cinders, 50% NaCl.

STATE OF MISSOURI
Storm #3 - November 25, 1992
U.S. Interstate

Test Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	400 lbs/ln-mi
Total material applied (all passes combined)	1,120 lbs

Control Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	400 lbs/ln-mi
Total material applied (all passes combined)	1,120 lbs

STATE OF MISSOURI
Storm #4 - December 5-6, 1992
U.S.Interstate 29

Test Section - 2.8 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	100 - 101 lbs/ln-mi
Total material applied (all passes combined)	1,126 lbs
Total NaCl applied (all passes combined)	1,120 lbs
Total $CaCl_2$ applied (all passes combined)	6 lbs

Control Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	400 - 404 lbs/ln-mi
Total material applied (all passes combined)	4,502 lbs
Total NaCl applied (all passes combined)	4,480 lbs
Total $CaCl_2$ applied (all passes combined)	22 lbs

STATE OF MISSOURI
Storm #4 - December 5-6, 1992
U.S. Highway 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	7
Material used	Cinders/NaCl mix* prewetted with 28% $MgCl_2$
Application per rate pass	222 lbs/ln-mi
Total material applied (all passes combined)	7,941 lbs
Total cinders applied (all passes combined)	4,410 lbs
Total NaCl applied (all passes combined)	3,479 lbs
Total $MgCl_2$ applied (all passes combined)	51 lbs

Control Section - 5.1 miles (Four-lane, divided highway)

Number of passes	6
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	12,607 lbs
Total cinders applied (all passes combined)	7,047 lbs
Total NaCl applied (all passes combined)	5,560 lbs

*Cinders/NaCl mix is 50% cinders, 50% NaCl.

STATE OF MISSOURI
Storm #5 - December 30, 1992
U.S. Interstate 29

Test Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	283 lbs
Total NaCl applied (all passes combined)	280 lbs
Total $CaCl_2$ applied (all passes combined)	3 lbs

Control Section - 2.8 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	400 lbs/ln-mi
Total material applied (all passes combined)	1,120 lbs

STATE OF MISSOURI
Storm #7 - January 7-8, 1993
U.S. Interstate 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl mix* prewetted with 28% $MgCl_2$
Application per rate pass	222 lbs/ln-mi
Total material applied (all passes combined)	2,269 lbs
Total cinders applied (all passes combined)	1,260 lbs
Total NaCl applied (all passes combined)	994 lbs
Total $MgCl_2$ applied (all passes combined)	15 lbs

Control Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	4,202 lbs
Total cinders applied (all passes combined)	2,349 lbs
Total NaCl applied (all passes combined)	1,853 lbs

*Cinders/NaCl mix is 50% cinders, 50% NaCl.

STATE OF MISSOURI
Storm #8 - January 18, 1993
U.S. Highway 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	3
Material used	Cinders/NaCl mix* prewetted with 28% $MgCl_2$
Application per rate pass	222 lbs/ln-mi
Total material applied (all passes combined)	3,403 lbs
Total NaCl applied (all passes combined)	1,890 lbs
Total NaCl applied (all passes combined)	1,491 lbs
Total $MgCl_2$ applied (all passes combined)	22 lbs

Control Section - 10.5 miles (Two-lane, undivided highway)

Number of passes	3
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	6,304 lbs
Total cinders applied (all passes combined)	3,524 lbs
Total NaCl applied (all passes combined)	2,780 lbs

*Cinders/NaCl mix is 50% cinders, 50% NaCl.

STATE OF MISSOURI
Storm #9 - January 20, 1993
U.S. Highway 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	6
Material used	Cinders/NaCl mix* prewetted with 28% $MgCl_2$
Application per rate pass	222 lbs/ln-mi
Total material applied (all passes combined)	4,538 lbs
Total cinders applied (all passes combined)	2,518 lbs
Total NaCl applied (all passes combined)	1,986 lbs
Total $MgCl_2$ applied (all passes combined)	34 lbs

Control Section - 5.1 miles (Four-lane, divided highway)

Number of passes	5
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	10,506 lbs
Total cinders applied (all passes combined)	5,873 lbs
Total NaCl applied (all passes combined)	4,633 lbs

*Cinders/Nacl mix is 50% cinders, 50% NaCl.

STATE OF MISSOURI
Storm #10 - February 15, 1993
U.S. Highway 71

Test Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	4,202 lbs
Total cinders applied (all passes combined)	2,349 lbs
Total NaCl applied (all passes combined)	1,853 lbs

Control Section - 5.1 miles (Four-lane, divided highway)

Number of passes	2
Material used	Cinders/NaCl mix*
Application per rate pass	412 lbs/ln-mi
Total material applied (all passes combined)	4,202 lbs
Total cinders applied (all passes combined)	2,349 lbs
Total NaCl applied (all passes combined)	1,853 lbs

*Cinders/NaCl mix is 50% cinders, 50% NaCl.

STATE OF OHIO
Storm #1 - November 28, 1992
U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	2,421 lbs
Total NaCl applied (all passes combined)	2,400 lbs
Total $CaCl_2$ applied (all passes combined)	21 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	100 - 150 lbs/ln-mi
Total material applied (all passes combined)	3,000 lbs

STATE OF OHIO
Storm #2 - December 2, 1992
U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	1,210 lbs
Total NaCl applied (all passes combined)	1,200 lbs
Total $CaCl_2$ applied (all passes combined)	10 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	100 lbs/ln-mi
Total material applied (all passes combined)	1,200 lbs

This is not a real storm event. Chemical application was made as a precautionary measure against a storm which did not develop.

STATE OF OHIO
Storm #3 - December 10, 1992
U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	4,842 lbs
Total NaCl applied (all passes combined)	4,800 lbs
Total $CaCl_2$ applied (all passes combined)	42 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	4
Material used	NaCl
Application per rate pass	150 lbs/ln-mi
Total material applied (all passes combined)	7,200 lbs

STATE OF OHIO
Storm #4 - January 8, 1993
U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application per rate pass	102 lbs/ln-mi
Total material applied (all passes combined)	2,442 lbs
Total NaCl applied (all passes combined)	2,400 lbs
Total $CaCl_2$ applied (all passes combined)	42 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	100 lbs/ln-mi
Total material applied (all passes combined)	2,400 lbs

STATE OF OHIO

Storm #5 - January 10, 1993

U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl prewetted with liquid 32% $CaCl_2$
Application per rate pass	102 lbs/ln-mi
Total material applied (all passes combined)	7,325 lbs
Total NaCl applied (all passes combined)	7,200 lbs
Total $CaCl_2$ applied (all passes combined)	125 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	150 - 200 lbs/ln-mi
Total material applied (all passes combined)	10,800 lbs

STATE OF OHIO
Storm #6 - February 13-14, 1993
U.S. Interstate 71

Test Section - 6.5 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl/grit mix prewetted with liquid 32% $CaCl_2$*
Application per rate pass	216 lbs/ln-mi
Total material applied (all passes combined)	8,412 lbs
Total NaCl applied (all passes combined)	4,134 lbs
Total grit applied (all passes combined)	4,134 lbs
Total $CaCl_2$ applied (all passes combined)	144 lbs

Control Section - 6.5 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl/grit mix*
Application per rate pass	212 lbs/ln-mi
Total material applied (all passes combined)	8,268 lbs
Total NaCl applied (all passes combined)	4,134 lbs
Total grit applied (all passes combined)	4,134 lbs

*NaCl/grit mix is 50% Nacl, 50% grit.

STATE OF OHIO
Storm #7 - February 16, 1993
U.S. Interstate 71

Test Section - 6.5 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl/grit mix prewetted with liquid 32% $CaCl_2$*
Application per rate pass	216 lbs/ln-mi
Total material applied (all passes combined)	8,412 lbs
Total NaCl applied (all passes combined)	4,134 lbs
Total grit applied (all passes combined)	4,134 lbs
Total $CaCl_2$ applied (all passes combined)	144 lbs

Control Section - 6.5 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl/grit mix*
Application per rate pass	212 lbs/ln-mi
Total material applied (all passes combined)	8,268 lbs
Total NaCl applied (all passes combined)	4,134 lbs
Total grit applied (all passes combined)	4,134 lbs

*NaCl/grit mix is 50% Nacl, 50% grit.

STATE OF OHIO

Storm #8 - February 21, 1993
U.S. Interstate 70

Test Section - 6 miles (Six-lane, divided highway)

Number of passes	5
Material used	NaCl prewetted with liquid 32% $CaCl_2$*
Application per rate pass	102 - 203 lbs/ln-mi
Total material applied (all passes combined)	6,104 lbs
Total NaCl applied (all passes combined)	6,000 lbs
Total $CaCl_2$ applied (all passes combined)	104 lbs

Control Section - 6 miles (Six-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	150 - 300 lbs/ln-mi
Total material applied (all passes combined)	9,000 lbs

STATE OF OHIO

Storm #9 - February 21, 1993

U.S. Interstate 71

Test Section - 6.4 miles (Six-lane, divided Highway)

Number of passes	6
Material used	NaCl
Application per rate pass	240 lbs/ln-mi
Total material applied (all passes combined)	9,360 lbs

Control Section - 6.5 miles (Six-lane, divided highway)

Number of passes	6
Material used	NaCl
Application per rate pass	240 lbs/ln-mi
Total material applied (all passes combined)	9,360 lbs

STATE OF OHIO
Storm #10 - February 25-26, 1993
U.S. Interstate 71

Test Section - 6.5 miles (Six-lane, divided highway)

Number of passes	12
Material used	NaCl/grit mix prewetted with liquid 32% $CaCl_2$*
Application per rate pass	216 - 302 lbs/ln-mi
Total material applied (all passes combined)	20,197 lbs
Total NaCl applied (all passes combined)	9,926 lbs
Total grit applied (all passes combined)	9,926 lbs
Total $CaCl_2$ applied (all passes combined)	346 lbs

Control Section - 6.5 miles (Six-lane, divided highway)

Number of passes	12
Material used	NaCl/grit mix*
Application per rate pass	212 - 297 lbs/ln-mi
Total material applied (all passes combined)	19,851 lbs
Total NaCl applied (all passes combined)	9,926 lbs
Total grit applied (all passes combined)	9,926 lbs

*NaCl/grit mix is 50% Nacl, 50% grit.

STATE OF MINNESOTA
Storm #1 - November 2-4, 1992
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	100 - 400 lbs/ln-mi
Total material applied (all passes combined)	29,764 lbs
Total NaCl applied (all passes combined)	28,783 lbs
Total $CaCl_2$ applied (all passes combined)	981 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl
Application per rate pass	100 - 400 lbs/ln-mi
Total material applied (all passes combined)	29,599 lbs

STATE OF MINNESOTA
Storm #2 - November 8-9, 1992
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	400 lbs/ln-mi
Total material applied (all passes combined)	6,456 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	200 lbs/ln-mi
Total material applied (all passes combined)	6,456 lbs

STATE OF MINNESOTA
Storm #2 - November 8-9, 1992
U.S. Interstate 35

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	3
Material used	CMA/NaCl mix*
Application per rate pass	225 - 516 lbs/ln-mi
Total material applied (all passes combined)	10,552 lbs
Total NaCl applied (all passes combined)	8,441 lbs
Total CMA applied (all passes combined)	2,110 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	144 lbs/ln-mi
Total material applied (all passes combined)	1,983 lbs

*CMA/NaCl mix is 20% CMA, 80% NaCl.

STATE OF MINNESOTA

Storm #3 - November 16-17, 1992

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	200 - 400 lbs/ln-mi
Total material applied (all passes combined)	45,852 lbs
Total sand applied (all passes combined)	44,613 lbs
Total $CaCl_2$ applied (all passes combined)	1,240 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	6
Material used	NaCl
Application per rate pass	150 lbs/ln-mi
Total material applied (all passes combined)	37,122 lbs

STATE OF MINNESOTA
Storm #3 - November 15-17, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	4
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	235 - 989 lbs/ln-mi
Total material applied (all passes combined)	18,838 lbs
Total NaCL applied (all passes combined)	14,954 lbs
Total CMA applied (all passes combined)	3,884 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application per rate pass	153 - 163 lbs/ln-mi
Total material applied (all passes combined)	4,360 lbs

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #4 - November 19-20, 1992
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	106 - 313 lbs/ln-mi
Total material applied (all passes combined)	13,532 lbs
Total NaCl applied (all passes combined)	12,705 lbs
Total $CaCl_2$ applied (all passes combined)	826 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	300 lbs/ln-mi
Total material applied (all passes combined)	9,684 lbs

STATE OF MINNESOTA
Storm #4 - November 19-20, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	1
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	149 lbs/ln-mi
Total material applied (all passes combined)	2,122 lbs
Total NaCL applied (all passes combined)	1,676 lbs
Total CMA applied (all passes combined)	445 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	215 lbs/ln-mi
Total material applied (all passes combined)	2,964 lbs

*CMA/NaCl Mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #5 - December 1, 1992
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	300 lbs/ln-mi
Total material applied (all passes combined)	4,842 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	300 lbs/ln-mi
Total material applied (all passes combined)	4,842381 lbs

STATE OF MINNESOTA

Storm #5 - December 1, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	1
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	205 lbs/ln-mi
Total material applied (all passes combined)	2,920 lbs
Total NaCl applied (all passes combined)	2,307 lbs
Total CMA applied (all passes combined)	613 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application per rate pass	210 lbs/ln-mi
Total material applied (all passes combined)	8,707 lbs

*CMA/NaCl Mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #6 - December 3, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	1
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	410 lbs/ln-mi
Total material applied (all passes combined)	2,920 lbs
Total NaCl applied (all passes combined)	2,307 lbs
Total CM applied (all passes combined)	613 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	144 lbs/ln-mi
Total material applied (all passes combined)	1,983 lbs

*CMA/NaCl mix is 80% Nacl, 20% NaCl.

STATE OF MINNESOTA
Storm #8 - December 13, 1992
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	100 - 200 lbs/ln-mi
Total material applied (all passes combined)	7,323 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	100 - 200 lbs/ln-mi
Total material applied (all passes combined)	9,684 lbs

STATE OF MINNESOTA
Storm #10 - December 22, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)	
Number of passes	0
No applications were made on the test section	
Control Section - 6.91 miles (Four-lane, divided highway	
Number of passes	1
Material used	NaCl
Application per rate pass	65 lbs/ln-mi
Total material applied (all passes combined)	2,082 lbs

STATE OF MINNESOTA
Storm #11 - December 25, 1992
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	2
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	225 - 405 lbs/ln-mi
Total material applied (all passes combined)	8,971 lbs
Total NaCl applied (all passes combined)	7,177 lbs
Total CMA applied (all passes combined)	1,794 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	0

No applications were made on the control section.

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #13 - January 2-3, 1993
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	3
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	407 lbs/ln-mi
Total material applied (all passes combined)	8,699 lbs
Total NaCl applied (all passes combined)	6,873 lbs
Total CMA applied (all passes combined)	1,826 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	462 lbs/ln-mi
Total material applied (all passes combined)	6,385 lbs
Total sand applied (all passes combined)	12,191 lbs
Total NaCl applied (all passes combined)	12,191 lbs

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #14 - January 12, 1993
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	204 - 306 lbs/ln-mi
Total material applied (all passes combined)	24,752 lbs
Total NaCl applied (all passes combined)	24,210 lbs
Total $CaCl_2$ applied (all passes combined)	542 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl/sand*
Application per rate pass	1000 lbs/ln-mi
Total material applied (all passes combined)	48,420 lbs
Total sand applied (all passes combined)	24,210 lbs
Total NaCl applied (all passes combined)	24,210 lbs

*NaCl/sand mix is 50% Nacl, 50% sand.

STATE OF MINNESOTA
Storm #1 - January 12-15, 1993
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	9
Material used	CMA/NaCl mix*; CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	326 - 810 lbs/ln-mi
Total material applied (all passes combined)	44,274 lbs
Total NaCl applied (all passes combined)	35,347 lbs
Total CMA applied (all passes combined)	8,927 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	6
Material used	NaCl
Application per rate pass	462 - 577 lbs/ln-mi
Total material applied (all passes combined)	43,077 lbs

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #15 - January 23, 1993
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	399 lbs/ln-mi
Total material applied (all passes combined)	12,880 lbs
Total NaCl applied (all passes combined)	12,510 lbs
Total $CaCl_2$ applied (all passes combined)	370 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	375 lbs/ln-mi
Total material applied (all passes combined)	12,105 lbs

STATE OF MINNESOTA
Storm #15 - January 20-23, 1993
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	5
Material used	CMA/NaCl mix* prewetted with 25% CMA
Application per rate pass	205 - 488 lbs/ln-mi
Total material applied (all passes combined)	16,807 lbs
Total NaCl applied (all passes combined)	12,101 lbs
Total CMA applied (all passes combined)	4,706 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl
Application per rate pass	144 - 462 lbs/ln-mi
Total material applied (all passes combined)	32,470 lbs

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF MINNESOTA
Storm #16 - January 26, 1993
U.S. Highway 53

Test Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	266 lbs/ln-mi
Total material applied (all passes combined)	8,246 lbs
Total NaCl applied (all passes combined)	8,070 lbs
Total $CaCl_2$ applied (all passes combined)	176 lbs

Control Section - 16.14 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	250 lbs/ln-mi
Total material applied (all passes combined)	8,070 lbs

STATE OF MINNESOTA
Storm #16 - January 26, 1993
U.S. Interstate 35

Test Section - 7.12 miles (Four-lane, divided highway)

Number of passes	3
Material used	CMA/NaCl mix* prewetted with 20% CMA
Application per rate pass	244 - 488 lbs/ln-mi
Total material applied (all passes combined)	10,416 lbs
Total NaCl applied (all passes combined)	6,678 lbs
Total CMA applied (all passes combined)	3,738 lbs

Control Section - 6.91 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	210 lbs/ln-mi
Total material applied (all passes combined)	2,902 lbs

*CMA/NaCl mix is 80% Nacl, 20% CMA.

STATE OF NEW YORK

Storm #1 - December 2, 1992

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	225 lbs/ln-mi
Total material applied (all passes combined)	3,461 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	225 lbs/ln-mi
Total material applied (all passes combined)	3,461 lbs

STATE OF NEW YORK
Storm #2 - December 4-5, 1992
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)	
Number of passes	7
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	106 - 212 lbs/ln-mi
Total material applied (all passes combined)	6,524 lbs
Total NaCl applied (all passes combined)	6,461 lbs
Total $CaCl_2$ applied (all passes combined)	63 lbs

Control Section - 7.7 miles (Four-lane, divided highway)	
Number of passes	7
Material used	NaCl
Application per rate pass	223 - 446 lbs/ln-mi
Total material applied (all passes combined)	24,012 lbs

STATE OF NEW YORK
Storm #3 - December 7-9, 1992
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	16
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	80 - 361 lbs/ln-mi
Total material applied (all passes combined)	26,523 lbs
Total NaCl applied (all passes combined)	26,390 lbs
Total $CaCl_2$ applied (all passes combined)	133 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	12
Material used	NaCl
Application per rate pass	184 - 368 lbs/ln-mi
Total material applied (all passes combined)	33,689 lbs

STATE OF NEW YORK
Storm #4 - December 10-12, 1992
Ny Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	25
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	43 - 450 lbs/ln-mi
Total material applied (all passes combined)	52,710 lbs
Total NaCl applied (all passes combined)	52,348 lbs
Total $CaCl_2$ applied (all passes combined)	362 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	25
Material used	NaCl
Application per rate pass	84 - 450 lbs/ln-mi
Total material applied (all passes combined)	68,464 lbs

STATE OF NEW YORK

Storm #4 - December 23-24, 1992

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	8
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	80 - 160 lbs/ln-mi
Total material applied (all passes combined)	9,883 lbs
Total NaCl applied (all passes combined)	9,787 lbs
Total $CaCl_2$ applied (all passes combined)	96 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	9
Material used	NaCl
Application per rate pass	184 - 453 lbs/ln-mi
Total material applied (all passes combined)	24,196 lbs

STATE OF NEW YORK

Storm #6 - December 25, 1992

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	86 lbs/ln-mi
Total material applied (all passes combined)	1,320 lbs
Total NaCl applied (all passes combined)	1,309 lbs
Total $CaCl_2$ applied (all passes combined)	11 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	0

No applications were made on the control section.

STATE OF NEW YORK
Storm #7 - December 26-27, 1992
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	8
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	82 - 452 lbs/ln-mi
Total material applied (all passes combined)	14,835 lbs
Total NaCl applied (all passes combined)	14,737 lbs
Total $CaCl_2$ applied (all passes combined)	99 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	11
Material used	NaCl
Application per rate pass	180 - 452 lbs/ln-mi
Total material applied (all passes combined)	33,449 lbs

STATE OF NEW YORK
Storm #8 - January 1-2, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	9
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	101 - 540 lbs/ln-mi
Total material applied (all passes combined)	27,580 lbs
Total NaCl applied (all passes combined)	27,523 lbs
Total $CaCl_2$ applied (all passes combined)	58 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	7
Material used	NaCl
Application per rate pass	121 - 450 lbs/ln-mi
Total material applied (all passes combined)	23,213 lbs

STATE OF NEW YORK
Storm #9 - January 3, 1993
NY Route 104

Test Section - 7.7 miles (FOUR-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	227 lbs/ln-mi
Total material applied (all passes combined)	6,994 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl
Application per rate pass	227 lbs/ln-mi
Total material applied (all passes combined)	8,743 lbs

STATE OF NEW YORK
Storm #10 - January 8, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	4
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	126 - 273 lbs/ln-mi
Total material applied (all passes combined)	10,023 lbs
Total NaCl applied (all passes combined)	9,936 lbs
Total $CaCl_2$ applied (all passes combined)	87 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	219 lbs/ln-mi
Total material applied (all passes combined)	16,842 lbs

STATE OF NEW YORK
Storm #11 - January 10-11, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	14
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	101 - 557 lbs/ln-mi
Total material applied (all passes combined)	43,654 lbs
Total NaCl applied (all passes combined)	43,349 lbs
Total $CaCl_2$ applied (all passes combined)	305 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	14
Material used	NaCl
Application per rate pass	227 - 557 lbs/ln-mi
Total material applied (all passes combined)	51,740 lbs

STATE OF NEW YORK
Storm #12 - January 12-14, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	14
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 242 lbs/ln-mi
Total material applied (all passes combined)	30,412 lbs
Total NaCl applied (all passes combined)	30,147 lbs
Total $CaCl_2$ applied (all passes combined)	265 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	22
Material used	NaCl
Application per rate pass	219 - 541 lbs/ln-mi
Total material applied (all passes combined)	70,452 lbs

STATE OF NEW YORK
Storm #13 - January 15, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	54 lbs/ln-mi
Total material applied (all passes combined)	831 lbs
Total Nacl applied (all passes combined)	824 lbs
Total $CaCl_2$ applied (all passes combined)	7 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	219 lbs/ln-mi
Total material applied (all passes combined)	3,368 lbs

STATE OF NEW YORK
Storm #14- January 17-18, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	9
Material used	NaCl prewetted with 32% $CaCl_2$; NaCl
Application per rate pass	54 - 221 lbs/ln-mi
Total material applied (all passes combined)	41,751 lbs
Total NaCl applied (all passes combined)	14,658 lbs
Total $CaCl_2$ applied (all passes combined)	92 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	10
Material used	NaCl
Application per rate pass	116 - 454 lbs/ln-mi
Total material applied (all passes combined)	25,846 lbs

STATE OF NEW YORK
Storm #15- January 19, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	108 - 117 lbs/ln-mi
Total material applied (all passes combined)	5,121 lbs
Total NaCl applied (all passes combined)	5,077 lbs
Total $CaCl_2$ applied (all passes combined)	45 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	231 - 437 lbs/ln-mi
Total material applied (all passes combined)	13,859 lbs

STATE OF NEW YORK

Storm #16 - January 22-23, 1993

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl

Spot salting only.

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl

Spot salting only.

STATE OF NEW YORK
Storm #17 - January 24-26, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)	
Number of passes	13
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	98 - 221 lbs/ln-mi
Total material applied (all passes combined)	22,747 lbs
Total NaCl applied (all passes combined)	22,549 lbs
Total $CaCl_2$ applied (all passes combined)	198 lbs

Control Section - 7.7 miles (Four-lane, divided highway)	
Number of passes	13
Material used	NaCl
Application per rate pass	218 - 437 lbs/ln-mi
Total material applied (all passes combined)	37,499 lbs

STATE OF NEW YORK
Storm #18 - January 27-31, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	32
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	98 - 233 lbs/ln-mi
Total material applied (all passes combined)	45,769 lbs
Total NaCl applied (all passes combined)	45,370 lbs
Total $CaCl_2$ applied (all passes combined)	398 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	31
Material used	NaCl
Application per rate pass	107 - 231 lbs/ln-mi
Total material applied (all passes combined)	66,630 lbs

STATE OF NEW YORK
Storm #19 - February 1-2, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	19
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	108 - 441 lbs/ln-mi
Total material applied (all passes combined)	40,966 lbs
Total NaCl applied (all passes combined)	40,653 lbs
Total $CaCl_2$ applied (all passes combined)	313 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	23
Material used	NaCl
Application per rate pass	107 - 437 lbs/ln-mi
Total material applied (all passes combined)	64,566 lbs

STATE OF NEW YORK
Storm #20 - February 4, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	202 - 462 lbs/ln-mi
Total material applied (all passes combined)	5,109 lbs
Total NaCl applied (all passes combined)	5,082 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	230 lbs/ln-mi
Total material applied (all passes combined)	3,542 lbs

STATE OF NEW YORK
Storm #21 - February 5-6, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	22
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 202 lbs/ln-mi
Total material applied (all passes combined)	38,233 lbs
Total NaCl applied (all passes combined)	37,900 lbs
Total $CaCl_2$ applied (all passes combined)	333 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	20
Material used	NaCl
Application per rate pass	230 - 557 lbs/ln-mi
Total material applied (all passes combined)	77,735 lbs

STATE OF NEW YORK
Storm #22 - February 8, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 202 lbs/ln-mi
Total material applied (all passes combined)	3,107 lbs
Total NaCl applied (all passes combined)	3,080 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	230 - 460 lbs/ln-mi
Total material applied (all passes combined)	7,084 lbs

STATE OF NEW YORK
Storm #23 - February 10, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	1,553 lbs
Total NaCl applied (all passes combined)	1,540 lbs
Total $CaCl_2$ applied (all passes combined)	14 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	0

No applications were made on the control section.

STATE OF NEW YORK

Storm #24 - February 11-14, 1993

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	36
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 545 lbs/ln-mi
Total material applied (all passes combined)	75,483 lbs
Total NaCl applied (all passes combined)	74,826 lbs
Total $CaCl_2$ applied (all passes combined)	657 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	38
Material used	NaCl
Application per rate pass	230 - 541 lbs/ln-mi
Total material applied (all passes combined)	134,546 lbs

STATE OF NEW YORK
Storm #25 - February 16-18, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	25
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 102 lbs/ln-mi
Total material applied (all passes combined)	38,853 lbs
Total NaCl applied (all passes combined)	38,515 lbs
Total $CaCl_2$ applied (all passes combined)	338 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	24
Material used	NaCl
Application per rate pass	100 - 230 lbs/ln-mi
Total material applied (all passes combined)	82,832 lbs

STATE OF NEW YORK
Storm #26 - February 19-20, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 102 lbs/ln-mi
Total material applied (all passes combined)	3,125 lbs
Total NaCl applied (all passes combined)	3,098 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	270 lbs/ln-mi
Total material applied (all passes combined)	4,162 lbs

STATE OF NEW YORK
Storm #27 - February 21-24, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	35
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 464 lbs/ln-mi
Total material applied (all passes combined)	77,805 lbs
Total NaCl applied (all passes combined)	77,128 lbs
Total $CaCl_2$ applied (all passes combined)	677 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	40
Material used	NaCl
Application per rate pass	219 - 460 lbs/ln-mi
Total material applied (all passes combined)	139,596 lbs

STATE OF NEW YORK
Storm #28 - March 3, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	102 lbs/ln-mi
Total material applied (all passes combined)	3,143 lbs
Total NaCl applied (all passes combined)	3,116 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	219 lbs/ln-mi
Total material applied (all passes combined)	6,737 lbs

STATE OF NEW YORK
Storm #29 - March 4-6, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	17
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 442 lbs/ln-mi
Total material applied (all passes combined)	33,938 lbs
Total NaCl applied (all passes combined)	33,642 lbs
Total $CaCl_2$ applied (all passes combined)	295 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	19
Material used	NaCl
Application per rate pass	219 - 540 lbs/ln-mi
Total material applied (all passes combined)	68,622 lbs

STATE OF NEW YORK
Storm #30 - March 8, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	1,553 lbs
Total NaCl applied (all passes combined)	1,540 lbs
Total $CaCl_2$ applied (all passes combined)	14 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	230 lbs/ln-mi
Total material applied (all passes combined)	3,542 lbs

STATE OF NEW YORK

Storm #31 - March 10-11, 1993

NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	15
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 441 lbs/ln-mi
Total material applied (all passes combined)	29,275 lbs
Total NaCl applied (all passes combined)	29,020 lbs
Total $CaCl_2$ applied (all passes combined)	255 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	17
Material used	NaCl
Application per rate pass	202 - 460 lbs/ln-mi
Total material applied (all passes combined)	53,575 lbs

STATE OF NEW YORK
Storm #32 - March 13-15, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	6
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 464 lbs/ln-mi
Total material applied (all passes combined)	15,379 lbs
Total NaCl applied (all passes combined)	15,245 lbs
Total $CaCl_2$ applied (all passes combined)	134 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	230 - 460 lbs/ln-mi
Total material applied (all passes combined)	15,708 lbs

STATE OF NEW YORK
Storm #33 - March 17-18, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	3
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 102 lbs/ln-mi
Total material applied (all passes combined)	4,678 lbs
Total NaCl applied (all passes combined)	4,638 lbs
Total $CaCl_2$ applied (all passes combined)	41 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	5
Material used	NaCl
Application per rate pass	219 - 230 lbs/ln-mi
Total material applied (all passes combined)	17,536 lbs

STATE OF NEW YORK
Storm #34 - March 20, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	3,107 lbs
Total NaCl applied (all passes combined)	3,080 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	230 lbs/ln-mi
Total material applied (all passes combined)	7,084 lbs

STATE OF NEW YORK
Storm #35 - March 21-22, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	101 - 102 lbs/ln-mi
Total material applied (all passes combined)	3,125 lbs
Total NaCl applied (all passes combined)	3,098 lbs
Total $CaCl_2$ applied (all passes combined)	27 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	2
Material used	NaCl
Application per rate pass	230 - 270 lbs/ln-mi
Total material applied (all passes combined)	7,704 lbs

STATE OF NEW YORK
Storm #36 - March 26, 1993
NY Route 104

Test Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl prewetted with 32% $CaCl_2$
Application per rate pass	102 lbs/ln-mi
Total material applied (all passes combined)	1,571 lbs
Total NaCl applied (all passes combined)	1,558 lbs
Total $CaCl_2$ applied (all passes combined)	14 lbs

Control Section - 7.7 miles (Four-lane, divided highway)

Number of passes	1
Material used	NaCl
Application per rate pass	219 lbs/ln-mi
Total material applied (all passes combined)	3,368 lbs

STATE OF WASHINGTON
Storm #1 - December 10, 1992
U.S. Interstate 90

Test Section - 11 miles (Six-lane, divided highway)

Number of passes	2
Material used	CMA/NaCl mix* prewetted with 23% liquid NaCl
Application per rate pass	101 lbs/ln-mi
Total material applied (all passes combined)	3,319 lbs
Total CMA applied (all passes combined)	660 lbs
Total NaCl applied (all passes combined)	2,659 lbs

Control Section - 11 miles (Six-lane, divided highway)

Number of passes	4
Material used	NaCl/sand mix**
Application per rate pass	545 - 818 lbs/ln-mi
Total material applied (all passes combined)	30,000 lbs
Total sand applied (all passes combined)	27,000 lbs
Total NaCl applied (all passes combined)	3,000 lbs

*CMA/NaCl mix is 20% CMA, 80% NaCl.
**NaCl/sand mix is 10% NaCl, 90% sand.

STATE OF WASHINGTON
Storm #2 - December 17, 1992
U.S. Interstate 90

Test Section - 11 miles (Six-lane, divided highway)

Number of passes	3
Material used	CMA/NaCl mix*
Application per rate pass	100 lbs/ln-mi
Total material applied (all passes combined)	4,700 lbs
Total CMA applied (all passes combined)	940 lbs
Total NaCl applied (all passes combined)	3,760 lbs

Control Section - 11 miles (Six-lane, divided highway)

Number of passes	7
Material used	NaCl/sand mix**
Application per rate pass	212 - 500 lbs/ln-mi
Total material applied (all passes combined)	26,628 lbs
Total sand applied (all passes combined)	23,965 lbs
Total NaCl applied (all passes combined)	2,663 lbs

*CMA/NaCl mix is 20% CMA, 80% NaCl.
**NaCl/sand mix is 10% NaCl, 90% sand.

Appendix H

Responses Received from Equipment Vendors Contacted

The responses received from equipment vendors are summarized in the following table according to type of spreaders or spreader components produced.

	Spreader Components				Spreaders						
	Controls	Hydraulics	Prewetting equipment	Spinners/ disks	Frame-mounted	Dump body	Tail-gate	Slide-in	Solid material	Prewetted material	Liquid chemical
Apitech PO Box 501 Milwaukee, WI 53201	✓	✓									
Basic Hydraulics Compu-Spread 110 Division 1450 Park Court Chanhassen, MN 55317	✓	✓									
Bryant Steel Works, Inc. RFD 2, Box 1470 Thorndike, ME 04986							✓		✓		
Component Technology, Inc. Minnesota Group 2500 East 25th Street, Suite 105 Minneapolis, MN 55406	✓	✓	✓								
Custom Urethane Elastomers, Inc. 11 Leonberg Road Mars, PA 16046				✓							
Dana Corporation Mobile Fluid Products Division PO Box 1313 Minneapolis, MN 55440	✓										
Dickey-John Corporation Box 10 Auburn, IL 62615	✓										

	Spreader Components				Spreaders						
	Controls	Hydraulics	Prewetting equipment	Spinners/ disks	Frame-mounted	Dump body	Tail-gate	Slide-in	Solid material	Prewetted material	Liquid chemical
École Polytechnique École affiliée à l'Université de Montreal 2900, boul. Édouard-Montpetit Montréal, Quebec Case postale 6079, succursale A Montréal, Quebec Canada H3C 3A7	✓	✓	✓	✓				✓	✓	✓	
Fluid Controls 1201 Peizer Highway Easley, SC 29640	✓										
Fontaine PO Box 1719 Collins, MS 39428							✓	✓	✓		
Heil Company Dump Body Group PO Box 49 Tischomingo, MA 38873						✓			✓		
Kupper-Weisser Gmbh Postfach 1162 D-7715 Brauunger Germany	✓	✓	✓	✓	✓			✓	✓	✓	✓
Little Falls Machine, Inc. 305 Third Street, SW Little Falls, MN 56345							✓		✓		
Meyer Products 18513 Euclid Avenue Cleveland, OH 44112							✓		✓		

	Spreader Components				Spreaders						
	Controls	Hydraulics	Prewetting equipment	Spinners/ disks	Frame-mounted	Dump body	Tail-gate	Slide-in	Solid material	Prewetted material	Liquid chemical
Mid-America Power Drives 1350 Lare Industrial Boulevard Burnsville, MN 55337	✓	✓									
Minnesota Wanner Company 5145 Eden Avenue South Minneapolis, MN 55436											✓
Muncie Power Products, Inc. PO Box 548 Muncie, IN 47308	✓	✓									
Pengwyn 2550 West 5th Avenue Columbus, OH 43204	✓	✓	✓								
Phil Larochelle Equipment, Inc. 250 2e Avenue Quebec, Quebec Canada GIL 3AL					✓	✓		✓	✓		
Schmidt 1175 Meyerside Drive, Unit 5 Mississauga, Ontario Canada L5T 1H3	✓	✓	✓	✓	✓				✓	✓	
Schmidt Engineering & Equipment Co., Ltd. 4703 West Electric Avenue Milwaukee, WI 53219	✓	✓	✓	✓	✓				✓	✓	

	Spreader Components				Spreaders						
	Controls	Hydraulics	Prewetting equipment	Spinners/ disks	Frame-mounted	Dump body	Tail-gate	Slide-in	Solid material	Prewetted material	Liquid chemical
Schmidt France Neige Bureau Ateliers et Magasin 109, Rue Louis Neel Z. I. Du Levatel BP15 38140 Rives-Sur-Fure France	✓	✓	✓	✓	✓				✓	✓	
Snow Equipment Sales 1287 Air City Avenue PO Box 251 Dayton, OH 45404			✓		✓					✓	
Swenson Spreader PO Box 127 Lindenwood, IL 61049					✓		✓	✓	✓	✓	
Tenco PO Box CP 60 St. Valerien, Quebec Canada J0H 2B0					✓	✓		✓	✓	✓	✓
The Gledhill Road Machine Company PO Box 567 Galion, OH 44833							✓		✓		
Thomsen/Epoke Products, Inc. 604 Hayden Station Road Windsor, CT 06095	✓	✓	✓	✓	✓			✓	✓	✓	✓
Tyler PO Box 249 East Highway 12 Benson, MN 56215					✓				✓	✓	

	Spreader Components				Spreaders						
	Controls	Hydraulics	Prewetting equipment	Spinners/ disks	Frame-mounted	Dump body	Tail-gate	Slide-in	Solid material	Prewetted material	Liquid chemical
US Highway Products, Inc. PO Box 2418 Westport, CT 06880				✓							
Western Products 7777 North 73rd Street PO Box 23045 Milwaukee, WI 53223								✓[b]	✓		

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