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Winter Maintenance, Roadside Management, and Rating Routine Maintenance Activities

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Transportation Research Record 1246

Contents

Foreword

This Record contains five papers on the effectiveness of various deicing chemicals, one paper on roadside vegetation enhancement via species and cultivar selection, and one paper on priority ratings for routine highway maintenance activities. The information presented in these papers should be of interest to maintenance professionals involved in winter maintenance, roadside maintenance, and management of routine maintenance activities.

The reports on deicing chemicals present the results of laboratory and field studies designed to evaluate the technical, operational, and economic aspects of using various deicing agents. The first two papers present the results of laboratory experiments. In the first paper, Ashworth et al. describe the results of experiments to test the effectiveness of deicing materials to reduce the bond strength of ice to portland cement concrete. Using interfacial shear strength tests, the researchers evaluated salt, calcium chlorides, South Dakota Deicer No. 2, and calcium magnesium acetate (CMA). In the second paper, Goyal et al. report the results of experiments to determine the rate of melting of ice caused by various deicing agents. Using several different conditions of relative humidity, temperature, treatment time, and deicer application rates, the researchers determined ice melting rates by weighing the aqueous saline solution absorbed into blotter paper.

The next three papers describe the results of field studies designed to evaluate deicing chemicals. The paper by Manning and Crowder describes a study conducted in Ontario to evaluate the performance characteristics of CMA and rock salt. The report describes the test site conditions, the application procedures, storage and handling characteristics, and the effectiveness of the chemicals used. The paper by Hamilton et al. reports the results of a technical evaluation of the effectiveness of CMA, sodium formate, and salt. The study was conducted in Ottawa using vehicle braking performance to evaluate deicer effectiveness. In the next paper, Smith describes the results of a study conducted in Madison, Wisconsin to evaluate CMA, CMA-coated sand, and sodium chloride. The deicer performance measures were provided by subjective truck driver ratings and by objective field observations.

The last two reports in this Record address the subjects of roadside vegetation and routine maintenance activities. Duell provides a perspective on vegetation enhancements via species and cultivar selection. The author notes that cultivar selection may be as important to the maintenance of roadside as the selection of species in a mixture. The rewards of a low-maintenance superior turf are obtained by selecting the appropriate combinations of superior cultivars for roadside mixtures. In the paper by Fwa et al., the researchers describe a procedure used in Indiana to determine priority ratings for routine maintenance activities by highway class and distress condition. The report presents the procedure and computations involved in determining the priority scores for individual maintenance activities.

Evaluation of South Dakota Deicer No. 2 and Calcium Magnesium Acetate by Shear Testing

T. Ashworth, J. A. Weyland, L. L. Lu, A. P. Ewing, and R. D. Wheeler

A laboratory study was performed in which the relative effectiveness of deicing materials as agents for the reduction of bond strength of ice to portland cement concrete (PCC) was determined. The materials of primary interest were South Dakota Deicer No. 2 (SD2) and calcium magnesium acetate (CMA). The materials were evaluated using interfacial shear strength tests of ice on PCC treated with aqueous solutions of the salts. Sodium and calcium chlorides were also included in the study for comparison. Results indicate that SD2 and CMA are significantly more effective in reducing the ice–pavement bond strength than these traditional salts. Also, the weakening of the adhesional strength by SD2 and CMA cannot be explained in terms of the effectiveness of component materials.

A staggering economic and environmental burden is being imposed upon the United States by the continued widespread use of sodium chloride on the nation's highways—now over 10 million tons per year (*1*). The extent and seriousness of the damage to highways, bridges, automobiles, water resources, and the ecology has now begun to be realized (*2*, *3*). In recent years the search for effective, inexpensive, and environmentally benign deicers has begun in earnest. A number of deicing materials [alcohols, calcium magnesium acetates (CMA), sodium chloride with corrosion inhibitors, etc.] have been developed and tested; although none of the materials studied to date are effective in solving all the economic and environmental problems, some significant advances have been made.

The South Dakota School of Mines and Technology (SDSM&T), funded by and working with the South Dakota Department of Transportation (SDDOT), has developed South Dakota Deicer No. 2 (SD2). Preliminary testing of the material showed it to have significant potential as a deicer and to be noncorrosive for steel embedded in concrete. Although SD2 is composed of sodium salts and therefore, at first, does not appear to have a significant advantage over sodium chloride (NaCl) in regard to salination, the greater effectiveness of SD2 in reducing the bond strength of ice to concrete could result in the necessity for much lower application rates.

Relevant properties of a deicing material include solubility in water, heat of solution, phase diagram for aqueous solution (freezing point depression), structure of frozen solution, and the ability of the molecules to bond to various substrates. In practical terms, these properties translate into how well the material can penetrate into ice and then undercut the interface, how much it reduces the bond between ice and the pavement, how much of the material is retained on the pavement, and so on. All of these attributes are important in a practical deicer. Properties related to potential for environmental damage (salination of water supplies, algae blooms, soil contamination, etc.) and corrosion to vehicles, structures, concrete reinforcement steel, and so forth, are also important.

The mechanism by which the bond strength of ice to a material is reduced is not well understood. It may be through the presentation to the ice of a coating layer to which the ice has difficulty bonding, or it may be due to the incorporation of small amounts of material into a thin layer of ice, thereby disorganizing the crystallographic structure of the ice and producing a layer with greatly reduced strength. It is this aspect of the mitigation of ice adhesion upon which the authors focused and designed their test procedure to investigate. In practical terms, this test approximates the conditions found when deicer is applied as a pretreatment or remains on the pavement as a residual after post-icing application.

BACKGROUND

The authors of this paper are currently conducting studies of SD2 (funded by SDDOT) and of CMA. These studies show that these materials have unusual properties. Briefly, the background on CMA and SD2 is as follows.

Calcium Magnesium Acetate

In March 1980, Bjorksten Research Laboratories, Inc., of Madison, Wisconsin, published research that was directed toward the development of a noncorrosive alternative to NaCl (*3*). Their report indicated two chemicals of choice, namely, methanol and CMA. The evidence presented indicated that CMA has several desirable qualities that are not completely applicable to other deicing options. In particular, Bjorksten Research Laboratories reported that CMA

- Shows no significant corrosion of steel, zinc, or aluminum;
- Exhibits corrosion inhibition toward A-36 steel and A-3560 cast aluminum;
- Does not present any more toxicity hazard through either the calcium or magnesium ions than the sodium ion;

Physics Department, South Dakota School of Mines and Technology, Rapid City, S.D. 57701-3995.

- Contains no nitrogen or phosphorus and therefore does not increase lake eutrophication; and
- Is essentially nontoxic and nonflammable.

Since the Bjorksten report, quantities of CMA adequate for field trials have been produced. Several reports are now available on these tests. As yet, there is no complete agreement on the effectiveness of the material, nor on its claimed noncorrosive or corrosion-inhibiting properties; some test results were clearly favorable, whereas others were somewhat ambivalent (*4–6*).

The material used in the tests reported in this paper was provided by Brian Chollar of the Federal Highway Administration. The material is in a spherical pelletized form; it is designated as C-8996, pure CMA, tested in Ontario, during the winter, 1986–1987; it is part of a batch produced by the Chevron Corp.

"South Dakota" Deicers

Interest in noncorrosive deicers by SDDOT led to an investigation by the Chemical Engineering Department at SDSM&T of the feasibility of producing CMA from locally available sources of dolomitic lime and cellulosic waste. Atmospheric fusion did not result in conversion to acetic acid. However, it was discovered that cellulose degradation under basic conditions at high temperatures and pressures could be used to produce a calcium lactate-acetate-glycolate compound; this was designated as South Dakota Deicer No. 1, or SD1. Further work on similar sodium-based compounds led to the development of SD2, and in May 1987 a patent (U.S. Patent 4,664,832) was granted to the state of South Dakota for this material. In the patent, the material is described as having a composition of

- Sodium glycolate, 33.1 percent;
- Sodium formate, 31.8 percent;
- Sodium acetate, 26.3 percent;
- Sodium maleate, 6.4 percent;
- Sodium fumarate, 1.4 percent;
- Small quantities of sodium lactate, sodium malate, sodium malonate, and sodium tartrate.

Initial testing was performed by personnel in the Chemical Engineering Department and SDDOT. The results were promising: in aqueous solution, SD2 has a low eutectic point (below −30°C), it has high solubility in water, and it is noncorrosive and nontoxic (D. Johnson, unpublished data).

Preliminary tests of the adhesive strength of ice to concrete treated with SD2 were performed in the Physics Department during the period December 1986 through May 1987. The results were very encouraging and led to funding by SDDOT of a more detailed evaluation of the material. This work is described below. A corresponding evaluation of CMA was added to the research program. Although this work is aimed primarily at determining the properties of the materials, it also begins to address questions about how they work. For example, what is the active element in SD2? Is it one or more of the major components acting individually? Rough measurements of the freezing point curves together with other indirect evidence suggest not (D. Johnson, unpublished data), but this needs to be shown systematically.

DEFINITION OF THE TEST PROCEDURE

Evaluation of the materials was performed by determining the interfacial shear strength of ice formed on portland cement concrete (PCC) substrates that have been treated with aqueous solutions of the various salts. A carefully defined test procedure was developed; details are given in the next section. Briefly, the test involves treating the substrate with an aqueous solution of the test material and then, after it has dried, forming ice on it in a Teflon retaining ring. This ice is then broken from the substrate with a shearing force, thus giving a measure of the ultimate yield strength. The measurement sequences performed include one series at a fixed application rate of 0.22 g/cm^2 [equivalent to 200 lb per lane–mile (lb/lm)] as a function of test temperature and another series at fixed test temperatures (−5°C and −15°C) as a function of application rate.

This test procedure was chosen for a number of reasons. As stated previously, the authors wished to investigate the strength of adhesion of ice to a substrate that represented a highway pavement and to determine how the presence of various materials affected this bonding. They also wanted to perform tests in which the conditions could be controlled as carefully as possible. Application of the treatment material on the substrate as an aqueous solution allowed it to be applied uniformly and at an accurately known rate. PCC was chosen as the substrate because it could be produced simply in an appropriate form and because it could be used repeatedly without breaking. Some tests were performed on various forms of asphalt. Open graded asphalts were not useful because the ice interlocked into them and the substrates were destroyed or badly damaged each time a test was performed. Tests on asphalt in which the binder sealed the surface were sucessful at the higher temperatures used, but below −10°C the binder was brittle and the surface was usually damaged when the ice was broken from it.

Some may argue that these tests do not mirror the realities of roads during winter storms and therefore are of little value. However, shear strength testing in the laboratory environment does allow one to make comparisons between various deicing materials, and although reporting a shear strength of 10 kg/cm^2 is not a number that a highway engineer can use to immediate advantage, comparing shear strength values at various temperatures and treatment rates does allow him to evaluate deicers in a comparative manner.

Another practical problem with this type of testing is that of units. It has become evident that the authors cannot satisfy everyone simultaneously on this issue. In a consistent set of SI units, the rate of application of material clearly should be given in kilograms per square meter and the shear strengths in newtons per square meter (N/m^2), or pascals (Pa). On the other hand, practical units of application are pounds per lane–mile (lb/lm) and in most of the work previously reported, shear strengths are given in the mixed units of kilograms per square centimeter. The authors chose to express their data in these most-used units, with values in appropriate alternative units added parenthetically. Temperatures are given in degrees Celsius, because this gives the most direct relation to the freezing point. For cases in which other units are preferred, the following conversion factors may be used:

$$100 \text{ lb/lm} = 0.111 \text{ g/cm}^2 = 1.11 \text{ kg/m}^2$$

$$1 \text{ kg/cm}^2 = 9.8 \times 10^4 \text{ N/m}^2 = 9.8 \times 10^4 \text{ Pa} = 14.2 \text{ lb/in.}^2$$

INTERFACIAL SHEAR STRENGTH TEST PROCEDURE

General Description

The basic system for interfacial shear testing was developed as part of a previous research project sponsored by FHWA (*7*, *8*). It consists of a Cal-Tester Model TH-5 5000–lb tester mounted outside a freezer with the loading members passing through the side of the freezer into an insulated, temperature controlled box, as shown in Figure 1. Plastic bushings through the freezer wall allow for smooth operation of the tester without significant moisture infiltration. The sample holder is mounted on the frame of the testing machine. Temperature control is achieved with a thermistor temperature sensor, an on–off regulator controlling the supply of power to an electric light bulb, and an air circulation fan. When the box remains closed, the temperature can be regulated to within 0.1°C. Further details of the system can be found in the project report (*7*, *8*) and the M.S. theses of Lu (*9*) and Ewing (*10*).

Substrate Specification

The concrete substrates were prepared in one batch according to ASTM C-192-76. Data for the concrete are as follows: air content, 6 percent; slump, 2.25 in.; W/C ratio, 0.49; 36 percent fine aggregate consisting of natural river sand; 64 percent coarse aggregate consisting of Minnekahta crushed limestone of maximum size 1 in.; a 28-day strength of 3.627×10^7 Pa (5,260 lb/in.^{2}); unit weight 2403 kg/m^3; and date of mix, March 16, 1979.

Specimen Preparation

Test specimens were produced by freezing water in Teflon rings placed on the substrate being studied, as shown in Figure 2. To ensure that the substrates were prepared in a standard manner, a procedure was developed as shown in Figure 3 and defined as follows:

1. Soak the substrate in tap water for 15 to 18 hr (usually overnight following the test of the previous day).
2. Use brush and running tap water to clean substrate.
3. Rinse and brush substrate in distilled water.
4. If changing to a different test series (change in deicer chemical), then let soak in distilled water for 30 min. Test electrical conductivity of soak water and if less than 3×10^{-6} mhos, go to next step; otherwise, repeat cleaning. If not changing chemicals, then also go to next step.

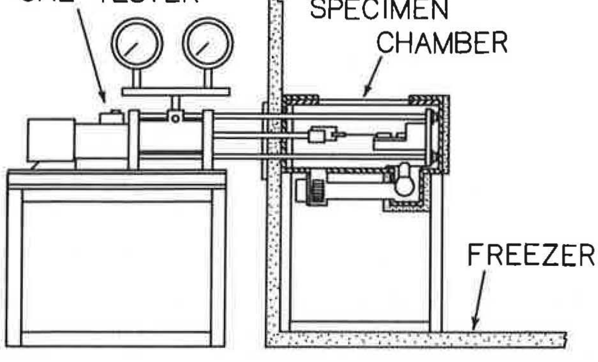

FIGURE 1 Shear testing systems.

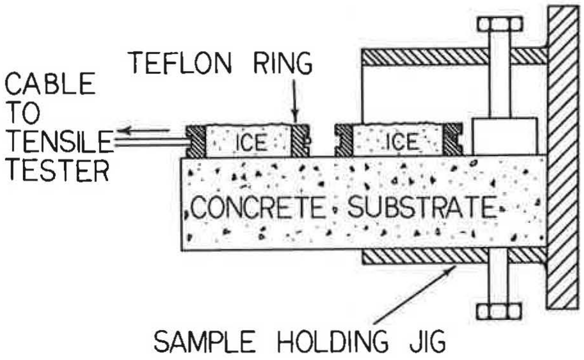

FIGURE 2 Test specimen arrangement.

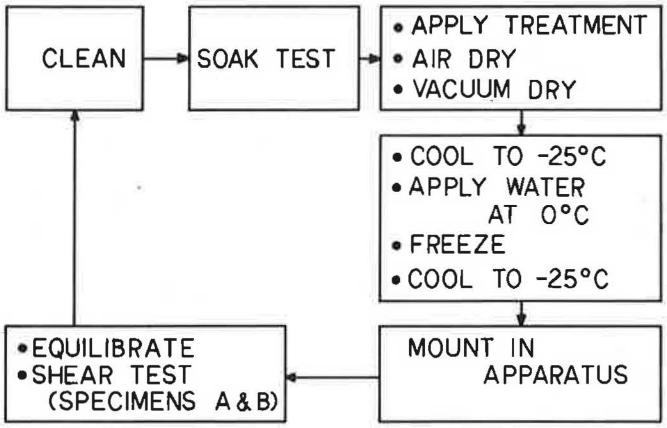

FIGURE 3 Flow diagram for shear strength tests.

[NOTE: At each change of deicer chemical, a reference test of interfacial shear strength on the untreated substrates must be made to ensure that the substrates are clean. If the reference test is below the original value of shear strength on the untreated substrates (within 0.5 kg/cm^2), cleaning and untreated shear tests are repeated until it is.]

5. Let substrates air dry.
6. Measure amount of chemical to be tested based on application rate (in previously defined units of lb/lm).
7. Add 6 ml of distilled water to the measured chemical (1.5 ml × 4 substrates = 6 ml).
8. Pour 1.5 ml (which allows complete wetting of surface) onto each substrate and use a small brush to distribute evenly.
9. Allow prepared substrates to air dry completely (minimum 4 to 5 hr).
10. Using rubber bands, attach two Teflon rings at the designated spots on each of the dried, prepared substrates.
11. Place prepared substrates in freezer overnight (−25°C).
12. Pour distilled water (at 0°C) into each of the eight Teflon rings.
13. After 1 hr, transfer substrates to temperature-controlled environment containing the shearing apparatus.

Details of Testing Sequence

The temperature in the testing chamber can be controlled to within 0.1°C. However, measurements indicate that the substrate-ice interfacial temperature changes as much as 0.5°C in the 2 min that it takes to change samples. In order to reduce the amount by which the freezer temperature rose while the substrate was being changed, a large sheet of aluminum-faced insulation was inserted near the top of the freezer, so that when the freezer was opened, only the sample chamber was subjected to room temperature. This tended to speed up the cool-down recovery time of the test chamber. The temperature control system typically takes about 2 hr to reach a given temperature within the range −5°C to −15°C inside the specimen test chamber. However, a much longer time is needed to reach a temperature of −20°C, requiring the test chamber to be left overnight.

One hour after the chamber temperature is set for testing, the four substrates used for a test (four substrates with two test specimens each provide eight replications for each test) are transfered from the specimen preparation freezer to the testing chamber. The first substrate is mounted in the test apparatus. Two cables are used, one for each Teflon ring. The length of the two cables is such that the first (front) specimen can be tested to failure without applying any significant load on the second specimen; the system is then reset and testing of the second specimen carried out. This makes it possible to test both samples on a substrate without having to open the sample chamber. The arrangement is shown in Figure 4.

Four nours are allowed for the substrates to come to thermal equilibrium at the test temperature. Measurements on a test specimen, with a thermocouple embedded at the interface, have shown this time to be more than adequate. Two tests are conducted on the first substrate; then the test chamber is opened to remove the first substrate and mount the second substrate. One hour is allowed for reestablishment of thermal equilibrium before the second substrate is tested. The same procedure is followed for testing the third and fourth substrates.

The shear rate used in all these tests is the fastest rate available from the Cal-Tester. A tensile loading rate of approximately 4,000 lb/min is achieved on the cables; this is equivalent to a shear loading rate of approximately 2 kg cm^{-2} sec^{-1} tat the specimen–substrate interface. Ice typically breaks off the substrate at loads of 10 to 300 lb, which corresponds approximately to a shear at the interface of 0.1 to 8.0 kg/cm^2. The force exerted at failure is recorded by the auxiliary pointer on the pressure gauge. In all cases in which the substrates had received treatment, the ice specimen broke cleanly at the interface. When the concrete surface was clean, breakage generally was at the interface but a small amount of ice sometimes remained attached (up to 1 mm thick over about 10 percent of the test area); this was most pronounced for tests at lower temperatures.

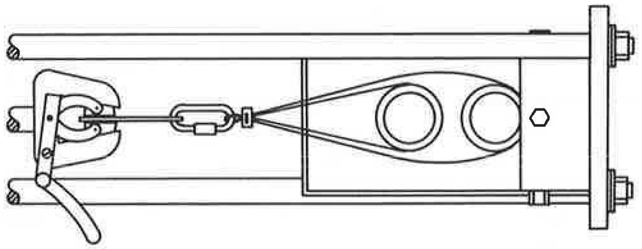

FIGURE 4 Specimen–cable arrangement.

INTERFACIAL SHEAR STRENGTH TEST RESULTS

It was found that there is a significant amount of variation in the adhesive strength of ice on concrete substrates. This was also true for different sites on a given substrate, presumably because of the random distribution of aggregate and mortar in a surface. As a result, the position of the Teflon rings on each substrate was kept the same for each test. Also, comparison of deicing materials was only made between tests conducted on the same set of substrates. Although there is an overall average standard deviation of 9 percent in the interfacial strength on untreated PCC, when values obtained from a particular site on a given substrate are compared, the standard deviation is significantly smaller, usually about 5 percent. Thus for all the data given, the actual standard deviation between results is approximately 10 percent, but the relative certainty between data points is somewhat better than this.

SD2 Compared with Sodium Chloride and Calcium Chloride

The test materials were compared in Measurement Series A1, A2, and B1, the results of which are shown in Figures 5, 6,

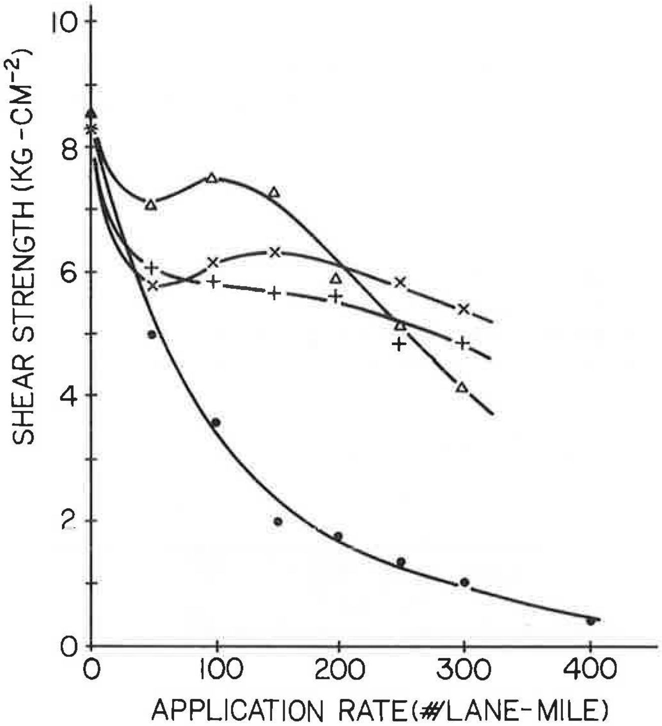

FIGURE 5 Interfacial shear strength versus application rate at −5°C: ● = SD2, △ = SD1, + = sodium chloride, × = calcium chloride (Measurement Series A1).

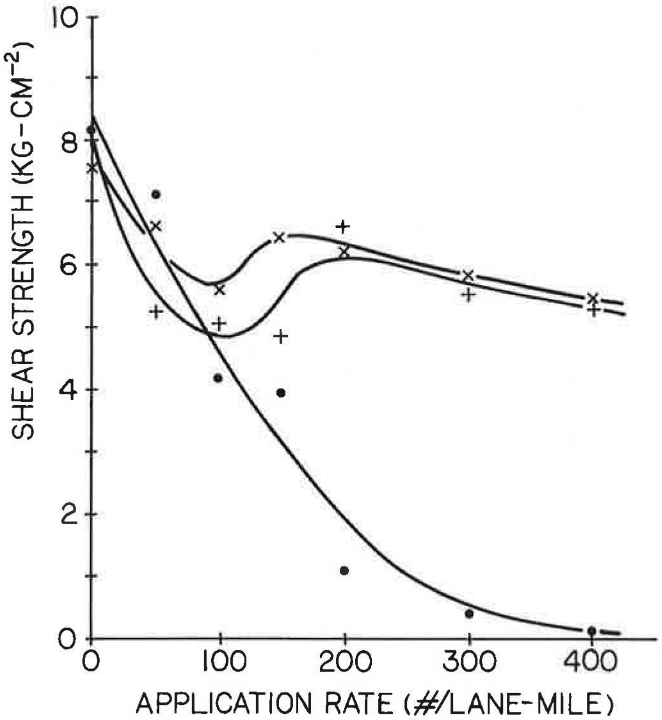

FIGURE 6 Interfacial shear strength versus application rate at −15°C: ● = SD2, △ = SD1, + = sodium chloride, × = calcium chloride (Measurement Series A2).

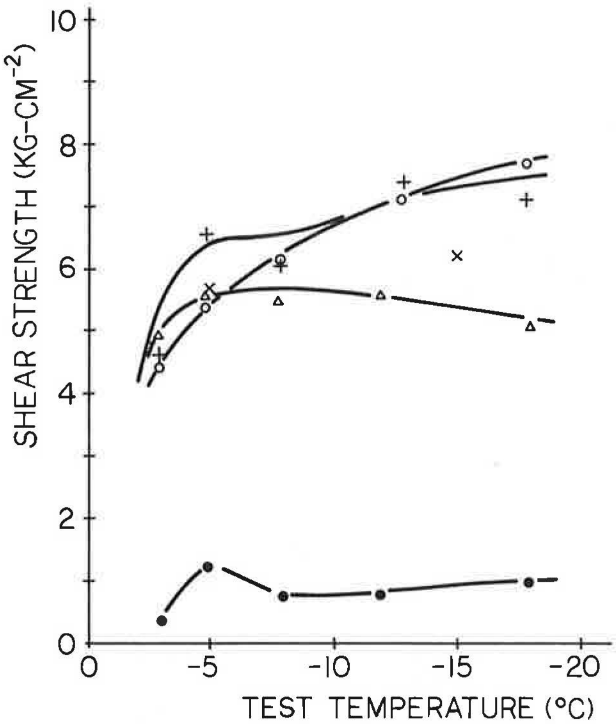

FIGURE 7 Interfacial shear strength versus test temperature at 200 lb/lm: ● = SD2, + = sodium chloride, × = calcium chloride, ○ = sodium formate, △ = sodium glycolate (Measurement Series B1).

and 7. Series A1 and A2 determined the shear strength of ice on treated PCC substrates as a function of deicer application rate at −5°C and −15°C, respectively, whereas Series B1 determined shear strength as a function of temperature for an application rate of 200 lb/lm. These data show that SD2 is significantly more effective than NaCl or $CaCl_2$ in all cases where the application rate is 100 lb/lm or greater. Also shown in Figure 5 are data for SD1. In Figure 7, data for sodium formate and sodium glycolate are given; measurements using sodium acetate treatment are in progress.

SD2 Compared with Its Component Materials

Figures 8, 9, and 10 show a comparison of SD2 with its component materials. Roughly speaking, SD2 is composed of equal parts of sodium glycolate, sodium formate, and sodium acetate. Because of this, for comparison of results shown in Figures 8, 9, and 10, an application rate of 300 lb/lm of SD2 is approximately comparable to 100 lb/lm of each of these three major individual constituents. The most abundant minor components, sodium maleate and sodium fumarate, constitute approximately 6 percent and 1 percent of SD2, respectively.

The most dramatic conclusion that can be made from Figure 8 is that SD2 has a significantly lower shear strength than any of its three major components. For example, at −5°C, the shear strength of SD2 is approximately 0.4 kg/cm^2, whereas at the equivalent application rate of its constituents at 100 lb/lm, the shear strength is over an order of magnitude higher.

The shear strength versus application rate of SD2 and its major components at −15°C is summarized in Figure 9. There are several changes in the shear strength behavior of the major components at this lower temperature from the comparable

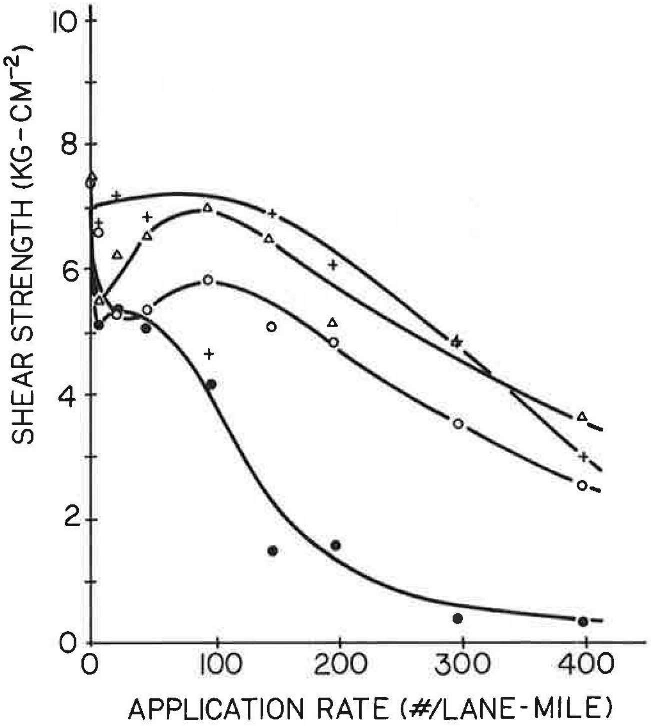

FIGURE 8 Interfacial shear strength versus application rate at −5°C: ● = SD2, ○ = sodium formate, △ = sodium glycolate, + = sodium acetate (Measurement Series C1).

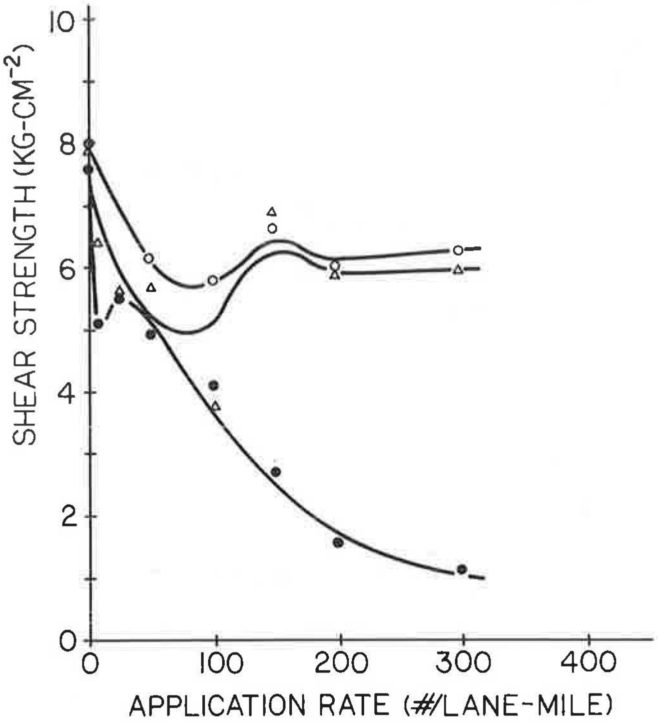

FIGURE 9 Interfacial shear strength versus application rate at −15°C: ● = SD2, ○ = sodium formate, △ = sodium glycolate, + = sodium acetate (Measurement Series C2).

results at −5°C. However, here again the most significant conclusion is that at the lower temperature it still is not possible to predict the shear strength behavior of SD2 from that of its major components.

Comparison of the shear strength of SD2 with that of its two most abundant minor components (Figure 10) indicates that they also are not individually responsible for the remarkably low shear strengths found. For example, at −5°C, 300 lb/lm of SD2 corresponds to 18 lb/lm of sodium maleate and 4 lb/lm of sodium fumarate. Again, an order of magnitude difference was found between the shear strength of SD2 and that of sodium maleate and sodium fumarate.

This raises several interesting possibilities—that the deicing properties of SD2 are due to a synergistic action, or, equally fascinating, that some unknown material, making up less than 1 percent of SD2, is responsible for the remarkably low shear strengths. In either case, the results are worthy of further investigation.

CMA Compared with Its Component Materials

The question then asked was: Is there a similar kind of synergistic effect that might be found for other deicers? Figures 11, 12, and 13 summarize shear strength measurements made on CMA. Here again, for an equal mixture of calcium acetate and magnesium acetate, a shear strength measured at 300 lb/lm must be compared with that of 150 lb/lm for its components.

Figure 11 summarizes shear strength data of CMA and its components at −5°C. One notices that, for application rates of 250 lb/lm or less, an increased shear strength of CMA compared with its components at a comparable application

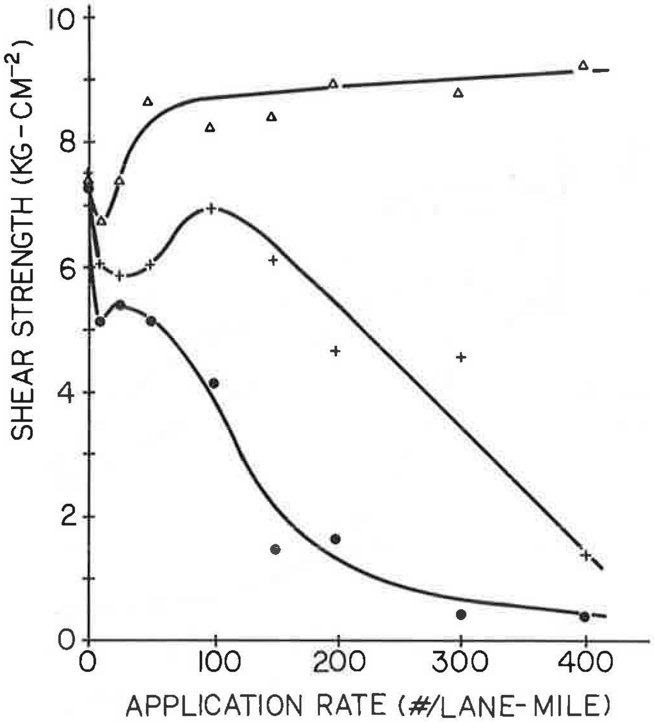

FIGURE 10 Interfacial shear strength versus application rate at −5°C: ● = SD2, + = sodium maleate, △ = sodium fumarate (Measurement Series C1).

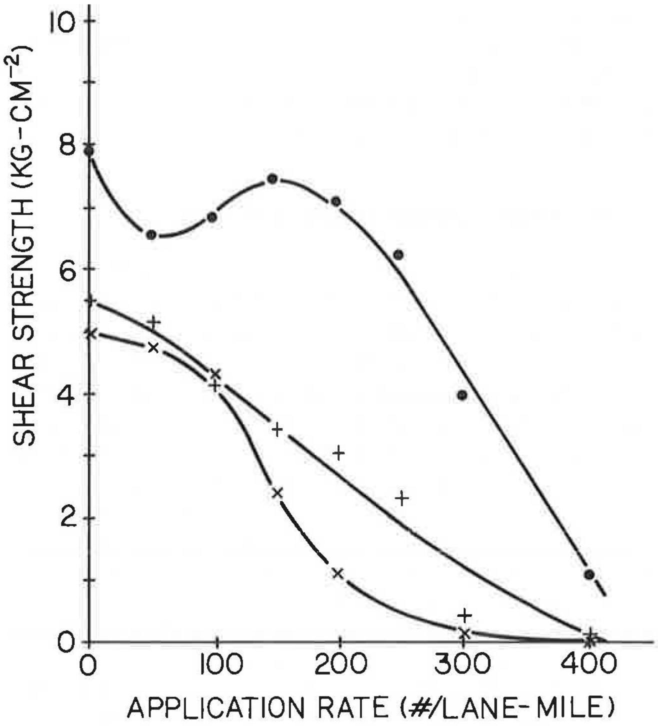

FIGURE 11 Interfacial shear strength versus application rate at −5°C: ● = CMA, + = magnesium acetate, × = calcium acetate (Measurement Series A1).

rate of either of its components. For application rates of 300 lb/lm and greater, the shear strength of CMA is about the same as would be expected from either of its components at a comparable application rate.

Figure 12 again plots shear strength versus application rate for these materials but this time at a colder temperature, −15°C. In addition to commercially prepared CMA, "synthetic" CMA was prepared by mixing equal portions of calcium acetate and magnesium acetate; the results for this mixture are plotted in Figure 12 as calcium/magnesium acetate. One can conclude the following from Figure 12:

1. At colder temperatures, calcium acetate appears to increase in shear strength with increasing application rates.
2. Both commercially prepared and "synthetic" CMA show similar characteristics, namely, a decrease in shear strength with increasing application rate.
3. There exists the possibility of a synergistic mechanism for CMA, since its shear strength characteristics do not appear to be due to either calcium acetate or magnesium acetate acting individually.

Figure 13 is a plot of shear strength versus temperature for a fixed application rate of 200 lb/lm. One interesting characteristic is the increase in shear strength as the temperature drops for both magnesium acetate and calcium acetate, but a decrease in shear strength for colder temperatures.

CONCLUSIONS

The following conclusions were reached:

1. The low shear strength of ice on concrete treated with SD2 is not due to individual properties of any one component of SD2, but rather to an interaction of components. A similar tendency was observed for CMA.
2. Several calcium compounds with "deicing" properties appear to have an affinity for concrete, as shown by an increasing shear bond strength with application rate. CMA is one of these materials with a "knee" in the curve of shear strength versus application rate.
3. There is a significant reduction in the strength of bonding of ice to a substrate that has been treated with very small amounts of material—10 lb/lm. This was true for all the materials tested.

These conclusions, once fully understood, may lead to new concepts of deicing. For example, it may be possible to develop a new generation of deicers that are noncorrosive, environmentally safe, and at the same time economically feasible because they cling to the highway over an entire winter. Thus, from this research program, the authors hope eventually to be able to recommend steps that will lead to improved materials and thereby help to alleviate the cost and environmental problems associated with the current winter highway maintenance practices.

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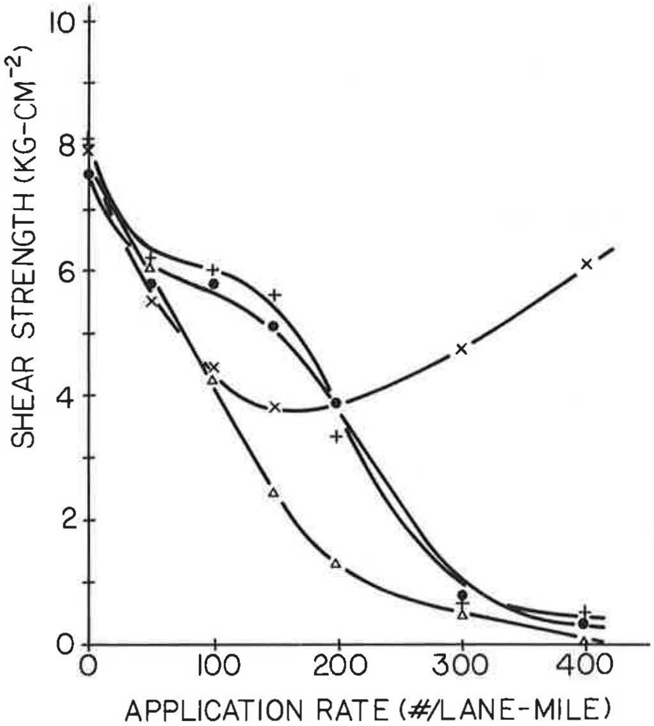

FIGURE 12 Interfacial shear strength versus application rate at −15°C: ● = CMA, + = magnesium acetate, △ = calcium/magnesium acetate, × = calcium acetate (Measurement Series A2).

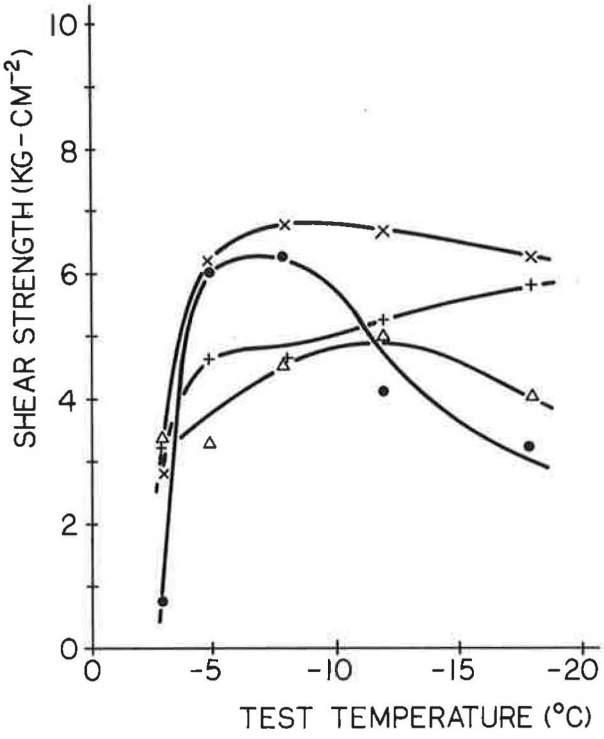

FIGURE 13 Interfacial shear strength versus test temperature at 200 lb/lm: ● = CMA, △ = calcium/magnesium acetate, × = calcium acetate, + = magnesium acetate (Measurement Series B1).

work on SD2 and their authorization for its publication; in particular, they would like to thank the contract monitor, David Huft; the technical advisor, Dan Johnston; and Wallace Larson, the Deputy Secretary of Transportation, for their help and cooperation.

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Time, Temperature, and Relative Humidity in Deicing of Highways Using Sodium Chloride or Magnesium Chloride with a Metal Corrosion Inhibitor

GOPAL GOYAL, JADE LIN, AND JOSEPH L. MCCARTHY

The ice-melting effectiveness of sodium chloride (SC), "Qwiksalt® + PCI® Granular Reduced Corrosion Road Deicer" (Qwiksalt or QS) and "Freezgard® + PCI® Liquid Reduced Corrosion Road Deicer" (Freezgard or FG) with respect to the removal of ice from highways was studied by laboratory experimentation. QS is a solid consisting of a mixture of SC, magnesium chloride, water, and a lignin-based biodegradable corrosion inhibitor called PCI corrosion control polymer. FG is a concentrated aqueous solution of magnesium chloride and PCI. The rate of melting of ice by salts was investigated by two variants of a "blotter" method in which the aqueous saline solution generated by the melting of ice and dissolving of salt is absorbed onto a tared blotter paper and weighed. The effects of several different conditions of relative humidity, temperature, treatment time, and extent of application of the deicers were studied. Results are reported as grams of saline solution generated per square meter of ice surface and also as estimated net pounds of water generated per lane-mile (63,360 ft^2). Some preliminary experiments were conducted to estimate the effectiveness of the preparations with respect to penetration of ice and debonding of the ice-concrete interface. Relative to SC, Qwiksalt generates brine more rapidly during treatment times up to 30 min. Differences are observed especially under conditions of low temperature and low relative humidity, for example, at −18°C and about 5 to 20 percent relative humidity. Freezgard forms brine very rapidly, although less extensively than QS or SC. These new deicers should find many important applications.

For the effective functioning of modern society, reliable and rapid transportation is an essential need. During winter, the highways in some parts of the United States are heavily covered with snow and ice, which may substantially impede travel. Sodium chloride (SC) is often applied to melt ice on highways and thereby to facilitate movement of automobiles and other vehicles. However, this salt is limited in effectiveness at low temperatures and corrodes metal parts of automobiles and bridges, including reinforcing steel members embedded in concrete.

Published literature reporting controlled experimentation designed to determine the effects of variables on the rate and extent of melting of compacted snow and ice by use of salts is small. Detailed methodology has been nearly nonexistent. Keyser has presented reviews of ice melting by salts (*1, 2*). Earlier experiments by Kersten et al. (*3*) and by Brohm and Edwards (*4*) were conducted at levels of deicer application that were considerably higher than present field practice. Additional investigations were reported by Grant in 1974 (*5*).

In a 1986 study (*6*), Schenk evaluated the rates of ice melting by calcium magnesium acetate (CMA) preparations, calcium chloride, and SC by measuring the rates at which pellets penetrate into ice at various temperatures. This might be called the penetration method. In most cases, calcium chloride penetrated more rapidly than did the SC, and both acted more rapidly than any of the several CMA preparations tested.

In 1988, McElroy and Blackburn of the Midwest Research Institute and Hagymassy and Kirchner of the Dow Chemical Company reported the results of three investigations relating to deicers (*7–9*). One described comparative studies of CMA and rock salt (*7*). To evaluate extent of melting, a deicer salt was placed on the surface of ice and, at the end a selected treatment time, the sample container was tilted. The solution that formed was collected in a syringe, its volume was determined, and the solution was reintroduced into the melt holes. This might be called the pour-off method.

In a study of effects of wetting rocksalt (*8*), experimentation was conducted at −4°, −10°, and −15°C (25°, 14°, and 5°F) with rocksalt and with samples of the same rocksalt after wetting with solutions of calcium chloride. The preparations were apparently applied at a rate of 3 oz of rocksalt per square yard of ice surface (about 102 g/m^2 of ice surface), or about 1,378 lb of deicer per lane-mile (lb/lm) of 63,360 ft^2. The amounts of solution generated increased progressively with time. The amounts formed were substantially less at lower temperatures. Wetting with calcium chloride solutions caused the sodium chloride to act 10 to 20 percent more rapidly.

In another important paper (*9*), the authors commented that there were no standard methods available for testing deicer penetration and ice melting capacity when their study was initiated. Using the pour-off method, they found that

- At all temperatures studied, calcium chloride penetrates ice at about twice the rate of the other deicers studied (SC, potassium chloride, and urea);
- SC does not work well at −15°C (5°F), penetrates more slowly than does calcium chloride up to about 45 min, and penetrates at about the same rate thereafter;

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TABLE 1 CHEMICAL COMPOSITION OF DEICERS STUDIED[a]

Component	SC	QS	FG
NaCl	99.70	80.	0.
$MgCl_2$	0.	2.3	25.
PCI	0.	15.	5.
H_2O	0.08	2.7	68.1
Other	(b).	(c).	(d).

(a) Analyses were provided by scientists of the the Great Salt Lake Minerals and Chemicals Corp, Ogden, Utah. (b)" Other" consisted of insolubles = 0.03; $SO_4^{=}$ = 0.10; K^+ = 0.04; Na^+ = 0.02 and Ca^{++} = 0.03; (c) "Other" consisted of the several components of SC which wereused to prepare the QS. (d) "Other" consisted of $SO_4^{=}$ = 1.4, K^+ = 0.2, Na^+ = 0.2 and Ca^{++} = 0.01.

- Urea and potassium chloride are substantially less active than sodium and calcium chloride;
- For ice debonding, the order of preference is calcium chloride, SC, potassium chloride, and urea; and
- Sharp-edged deicers, such as crystals of SC, behave differently than spherical deicers.

The paper included the results of extensive penetration experiments.

In this context, and before the studies of McElroy et al. (*7–9*) were published, the present investigation was undertaken to compare the behavior of SC with two commercially available deicing preparations. One is a solid called Qwiksalt (QS) that consists of a mixture of SC, magnesium chloride, and water. The other is a liquid called Freezgard (FG) that is a nearly saturated aqueous solution of magnesium chloride. Both preparations contain a lignin sulfonate-type biodegradable metal corrosion inhibitor called PCI corrosion control polymer; the methods used for its preparation and evidence of its effectiveness have been described elsewhere (*10*). Table 1 gives the composition of each deicer studied.

In view of the difficulty of securing reproducible results in laboratory experimentation with compacted snow, the authors studied the melting of ice only. Experimentation using two variants of the blotter method was conducted to estimate the rates at which the deicers generated aqueous saline solutions under a number of experimental conditions.

EXPERIMENTAL

Materials

The preparations studies were provided by the Great Salt Lake Minerals and Chemicals Corporation of Ogden, Utah. As soon as they were received in the laboratory, they were stored in closed containers at room temperature. The SC sample originated from the Great Salt Lake and was separated by a process of solar evaporation. The magnesium chloride sample was obtained from the same source by further evaporation and crystallization from the brine. PCI is a product of the Georgia Pacific Corporation and is produced from lignin sulfonates by a process described by Neal (*10*). QS is made by pressing its components into the form of approximately spherical pellets. The densities of SC and QS were determined experimentally and found to be about 2.17 and 1.97 g/cm^3, respectively. The density of FG is 1.28 g/cm^3.

In terms of cumulative weight percentages, the distribution in size of particles for the SC sample studied was found to be 1, 84, and 97 for retention on 8, 14, and 20 mesh screens, respectively. For the industrial QS sample, the retentions were 4, 72, and 85. Thus the through-20-mesh fractions amounted to 3 and 15 percent for the SC and QS samples, respectively. A separate QS-2 sample was screened in the laboratory to provide uniform particles within the range of 12 to 14 mesh.

The ice studied was prepared using Seattle city tap water.

Blotter-S and Blotter-Z Procedures

Generally, ice was made by placing water in cylindrical plastic containers, usually 11.5 cm in diameter, which could be covered if desired, and then allowing the open containers to stand overnight in a −10°C cold room. Cold room temperature varied about ±2°C. If an ice surface was not substantially smooth, the preparation was rejected.

To carry out the blotter-S or blotter-Z method for estimating the rate and extent of melting of ice, already formed ice samples within their containers, along with previously weighed masses of the deicers to be studied, were equilibrated, usually overnight, at the temperature and relative humidity (RH) of interest. A test was begun by scattering the deicer uniformly over the surface.

In the "high" RH experiments, the plastic containers were tightly covered immediately after adding the deicer to the surface of the ice and the cover was removed only at the end of the treatment time. By this procedure, the equilibrium vapor pressure of the ice at the experimental temperature (i.e., RH = 100 percent) should have been attained or closely approached soon after starting the experiment.

The "low" RH experiments were carried out in a 61- × 42- × 46-cm "dry box" constructed from sheets of a transparent plastic material about 0.64 cm thick. The front (42 × 46 cm) of the box was penetrated by two circular holes and the ends of the sleeves of two rubber gloves were attached to the periphery of these holes. "Drierite" pellets (anhydrous calcium sulfate containing a blue-pink dye to signify its extent of conversion to the useless dihydrate from Hammond Chemical Company) were spread over the bottom of the dry box and served to create and maintain a low RH level within the box. Humidity was measured by a dial-indicating Cole-Parmer Model 3310-20 hygrometer calibrated by the supplier. Levels of about 10 percent RH (5 to 20 percent) were indicated during the subject experiments. The supplier of the hygrometer was uncertain of the reliability of the instrument at −20°C. However, freshly dried Drierite pellets (3 days' drying at 160°C) were used in the dry box and should have created and maintained the desired low RH levels.

In conducting experiments at low RH, an uncovered sample container, upside down with its exposed surface of ice located close to but not touching the Drierite, was equilibrated, usually overnight, inside the dry box. The weighed deicer, in an uncovered container, and tared blotters stored inside a moisture-impermeable plastic bag (Ziploc; Dow Chemical Company) were also equilibrated overnight inside the dry box at the desired temperature.

An experiment was begun, without opening the dry box, when the experimenter placed his hands within the gloves and scattered the deicer upon the surface of the ice. The experiment was terminated, always inside the dry box, by removing the blotter from the plastic bag, placing it on the surface of the treated ice, letting it absorb the available brine, and then replacing the wet blotter inside the plastic bag. The dry box was then opened for the minimum possible time (20 to 30 sec), the plastic bag and wet blotters were removed, and the box was reclosed. The wet blotters were weighed and the mass of brine collected was calculated in terms of grams of solution generated per square meter of ice surface.

Two variants of the blotter method were used. The blotter-S (for surface) procedure was completed by placing the blotter in contact with the horizontal and upward-facing surface of the ice and maintaining contact for about 10 sec while the brine solution was absorbed on the paper. In a few cases, two or three blotters were used in sequence. The wet blotter was then weighed to evaluate the mass of solution collected.

In the blotter-Z method, the blotter was placed in contact with the ice surface and the container was turned upside down. Then the system was shaken 5 to 10 times with vigorous motion in the vertical plane in an attempt to expel all of the brine through the created pores and onto the surface of the blotter.

Nonvolatile solids present in the solutions studied were determined by drying a weighed sample overnight at 105°C and then reweighing it.

RESULTS AND DISCUSSION

The objective of the present experiment was to evaluate the effects of variables upon the performance of SC and two commercially available deicers, Qwiksalt (QS) and Freezgard (FG). A laboratory-prepared sample identified as QS-2 was also studied. The chemical compositions of these materials are shown in Table 1. The main criteria of performance were taken to be the rate and extent of melting of ice per unit mass of deicer applied.

Variables of interest have been the particular deicer studied, its particle size distribution, the mass of deicer applied, the temperature and relative humidity of the gas phase over the deicer and surface of the ice, and the time of treatment. The effects of heat on melting and dissolving of ice and of heat transfer rates were not taken into special account. Some preliminary experiments were carried out relative to the penetration of ice by the deicer and to the debonding of ice-concrete interfaces.

Estimation of the Extent of Melting of Ice by Salts

At the time this investigation was undertaken, no standardized procedure for measuring the amounts of melting of ice by deicer salts could be found in the literature.

Initially, attempts were made to measure the brine that formed by simply tilting the ice sample container, pouring off the contents, and then weighing the mass of brine generated. When the authors read the papers of McElroy et al. (*7–9*), they learned that this pour-off method had been used in their experimentation. In the text below, some of their results are compared with those obtained in present work using the blotter methods.

In these experiments, after as much brine as possible had been poured off, it was observed that significant amounts of liquid were still associated with the ice surface. In an attempt to recover this brine, and thus to estimate the extent of the melting accompanied by the deicer, two variants of the blotting paper procedure were devised, blotter-S and blotter-Z. These schemes are discussed below and details are given in the experiment section.

Experiments usually were replicated three or more times. The standard deviation varied with the experimental conditions used. It is estimated that one standard deviation usually was equivalent to about ±5 percent of the mean value reported.

In the following tabulations, the level of deicer application is stated in terms of grams of deicer per square meter of ice surface and as pouds of deicer applied per lane-mile. Results of ice-melting experiments are reported in terms of the arithmetic mean of the number of grams of saline solution collected per square meter of ice surface. Estimates of the net water generated also are reported in parentheses in terms of pounds of water formed per lane-mile.

Experiments with FG

Because FG is a liquid, its behavior may be discussed advantageously before considering the solid deicers. The blotter-S method was tested as a means for characterizing FG and was found to give results that were reproducible within the range of about 10 percent. The net mass of ice melted was estimated by subtracting the mass of deicer added from the mass of the brine collected.

The effect of time of treatment was considered first (Table 2, Figure 1). Experiments were conducted using a deicer application level of 63 g/m^2 of ice surface or 818 lb/lm. At −5°C (23°F), the masses of formed solution and water were measured after treatment times of 4, 8, 15, and 30 min. Melting took place rapidly and was mostly completed within about 4 min.

When the temperature was lowered to −10°C (14°F) and then to −18°C (0°F), experimentation showed that the mass

TABLE 2 MELTING OF ICE IN THE PRESENCE OF FG[a]

Temp.	Applic.	GSSM/(PWLM) at Time (min)			
C	GDSM(PDLM)	4.	8.	15.	30.
R. H. = High					
- 5	63.2 (818)	187. (1598)	200.(1774)	218. (2009)	(b).
- 10 (c)	"	133. (908)	133. (907)	142. (1018)	148.(1096)
- 18 "		96.0 (425)	104. (528)	104. (528)	107. (568)
- 18	126. (1637)	194. (875)	196. (901)	200. (947)	198. (925)
- 18	253. (3273)	391.(1783)	378. (1621)	(b).	(b).
R. H. = Low					
- 10 (d)	63.2(818)	126.(813)	143.(1033)	(b).	(b).

(a) Abbreviations are defined as follows: GDSM = grams of deicer applied square meter of ice surface; PDLM = pounds of deicer applied per lane mile; GSSM = grams of brine solution collected per square meter; PWLM = net pounds of water collected per lane mile; RH = relative humidity; (b) means not determined; (c) For 0.5, 1, 2 and 3 minutes treatment time, GSSM = 98.0, 103.0, 123.0 and 122.0, resp.; (d) For 1, 2 and 3 minutes treatment time, GSSM = 98.0, 123.5 and 124.0, resp..

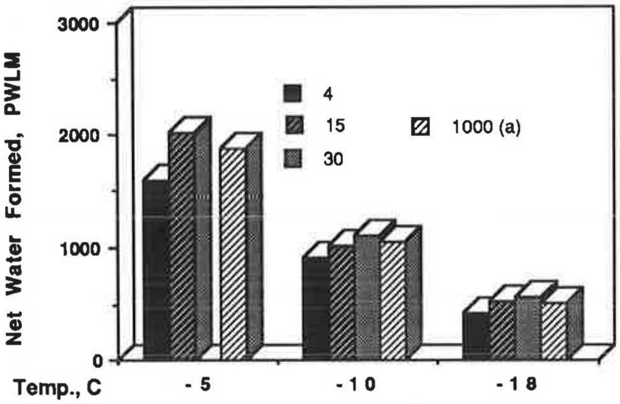

FIGURE 1 Ice melted by FG at 818 lg/lm and high RH versus time and temperature. (a) = estimated maximum PWLM (lb water/lane-mile).

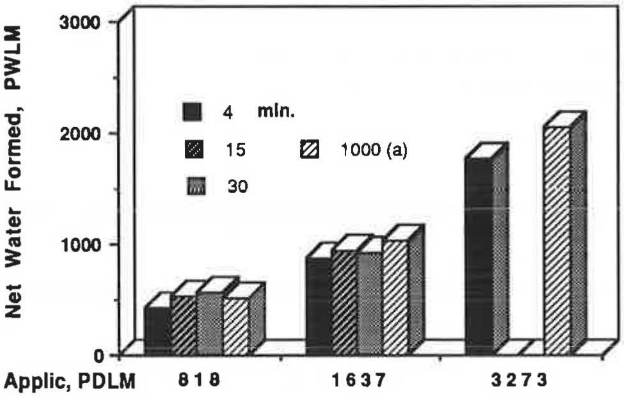

FIGURE 2 Ice melted by FG at −18°C and high RH versus time and application rate. (a) = estimated maximum PWLM. (PDLM = lb deicer/lane-mile.)

of water formed became progressively smaller, about one-half and then one-fourth of that formed at −5°C. At −10°C, about two-thirds of the total melting was completed in 1 or 2 min. Even at −18°C, most melting took place within the first 4 min after the treatment had been started.

When the mass of deicer applied at −18°C was doubled to about 1,637 lb/lm and then doubled again to 3,273 lb/lm (Table 2 and Figure 2), the masses of water produced increased in a similar manner, roughly doubling and then redoubling.

The effect of the RH prevailing in the gas phase above the ice was studied at two levels, "high" (about 90 to 100 percent RH) and "low" (about 5 to 20 percent RH), as described above (Table 2). At an application level of about 818 lb/lm and −10°C, the mass of melted ice was found to be about the same at the low and high RH levels.

Based on the assumption that, during the melting of ice by salts, equilibrium or near-equilibrium conditions exist with respect to the ice and the brine phases, estimates were made of the maximum brine yields attainable. In FG, magnesium chloride, PCI, and water are present to the extent of about 25, 5, and 70 percent by weight, respectively. From the phase diagram (*11*), it is known that aqueous solutions will contain about 7.8, 13, and 18 percent by weight of magnesium chloride when in equilibrium with ice at −5°, −10°, and −18°C. Assuming that the presence of PCI does not substantially change the solubility relations in the magnesium chloride–water system, the concentrations of nonvolatile solids present in FG solutions have been estimated to be 9.2, 15, and 21 mg per 100 mg of solution, respectively. These values yield multiplying factors of 0.908, 0.85, and 0.79 to provide for calculation of the mass of water present in the brines collected.

From these concentrations, the "theoretical" or maximum yields of brine were calculated. The results are shown in Figures 1 and 2 under the arbitrary designation of treatment time as 1,000 min. It is evident that each calculated result is in approximate agreement with the corresponding experimental finding. Since the latter were evaluated simply by subtracting the mass of deicer added from the mass of the brine collected, the agreement supports the proposition that phase equilibrium prevails, at least approximately, during the melting process and also that the blotter-S method is useful to evaluate the effects of variables with FG.

The authors conclude that FG acts rapidly to complete its full potential, as might be expected to occur with a liquid that comes into immediate and intimate contact with the ice surface. However, the ultimate extent of melting of ice by FG (compared, for example, with that of solid magnesium chloride or sodium chloride) will be considerably lower because FG and similar liquid preparations already contain water as their major component and thus have a correspondingly decreased capability to generate additional water.

Finally, it is important to note that the main concern here is with the magnesium chloride–water chemical system, for which the eutectic temperature is about −31°C. Assuming addition of 818 lb/lm of FG, the above-described calculation procedure was used to estimate the maximum amounts of net water formed at certain low temperatures, 426, 290, and 219 lb/lm at −20, −25, and −30°C, respectively. Thus FG can be used to melt ice at temperature levels much lower than is possible with sodium chloride, for which the corresponding and limiting eutectic temperature is about −21°C.

Experiments with SC and QS Using Blotter-S Method

Because QS is composed predominantly of SC, the ultimate ice-melting capability of the two deicers may be expected to be similar. However, it was believed that the rates of melting might differ somewhat as a result of the presence of a coating of magnesium chloride around the QS particles, which is known to be strongly hygroscopic (*12*) and to provide a low eutectic temperature with water. Also, the PCI added to incorporate its metal corrosion inhibition properties is a good surfactant (*10*).

In view of the utility found for the blotter-S method in evaluating the effects of variables on the functioning of FG, this procedure was applied in experiments conducted with SC and QS.

With these solid deicers, under most conditions studied, substantially all of the deicer solids rapidly became attached to the surface of the ice and were not taken up by the blotter. However, at low temperature, and especially at low RH and for treatment times less than about 8 min, it was observed that some deicer particles did not immediately form a bond with the ice but became attached to the blotting paper and introduced possible error into the results. These crystals could be observed visually and, as much as possible, were brushed off the blotting paper before it was weighed.

A commercial sample, identified as Qwiksalt or QS, was tested. The particle size distributions found for SC and QS (see experimental section) showed that the crystals or pellets fell mainly in the range of 8 to 14 mesh Tyler screens, although the QS consisted of about 15 percent fines, compared with about 3 percent for SC.

To permit the results to be compared on the same basis, the masses of net water formed were estimated by calculations based on the amount of saline solution collected. The existence of phase equilibrium was assumed and, in a few cases, this proposition was approximately confirmed. The concentrations of the subject salts in aqueous solutions in equilibrium with ice at the temperatures of interest are known from phase diagrams that are available for sodium chloride (*13*) and magnesium chloride (*11*).

For SC, neglecting impurities, the concentrations of the solute at equilibrium should be about 8.2, 14, and 21 g of solids per 100 g of solution at −5°, −10°, and −18°C. Thus the net amounts of water generated were estimated by multiplying the masses of brine collected by the factors 0.918, 0.86, and 0.79 for the three temperatures of interest.

QS consists of about 80, 2.5, 2.5, and 15 percent by weight of sodium chloride, magnesium chloride, water, and PCI, respectively. Because magnesium chloride is present in small proportion and because the equilibrium solubilities of sodium and magnesium chlorides are similar, the calculations were made by considering that the total mass of the two salts [i.e., (100)(0.80 + 0.025) = 82.5 mg/100 mg QS] behaves as does NaCl. On this basis and at −5°C, 100 mg of QS would generate (100)(0.825)/0.082 = 1006 mg solution. PCI, which is a polyelectrolyte with a number average molecular weight of around 3000, is assumed to dissolve in the formed brine without causing a major change in the solubility relationships. Because the PCI mass is (100)(0.15) = 15 mg, the mass of the total solution becomes 1006 + 15 = 1021 mg per 100 mg QS applied at −5°C. The total nonvolatile solids amounts to 82.5 + 15 = 97.5 mg/100 mg QS. Thus the estimated con-

TABLE 3 MELTING OF ICE IN THE PRESENCE OF SC AND QS[a]

Time (min)	SC GSSM(PWLM)	QS GSSM(PWLM)
	Temperature = - 5 C (23 F)	
4	148. (1763)	206. (2406)
8	153. (1825)	237. (2762)
15	197. (2341)	266.(3107)
30	296. (3513)	406. (4742)
	Temperature = - 10 C (15 F)	
4	111. (1240)	111. (1211)
8	115. (1278)	147. (1602)
15	146. (1626)	185.(2010)
30	159.(1765)	224. (2431)
	Temperature = - 18 (0 F)	
4	31.3 (320)	34.2 (337)
8	68.2 (698)	49.9 (491)
15	92.7 (948)	98.3 (967)
30	113. (1160)	120. (1181)

(a) Abbreviations are explained in footnotes to Table 2.
High RH: Application = 57.3 GDSM (745 PDLM)

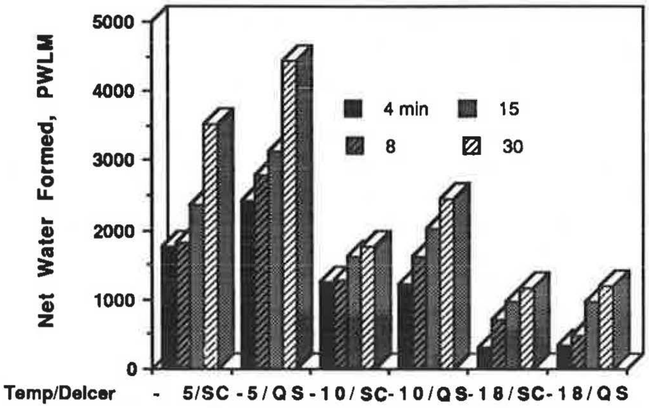

FIGURE 3 Ice melted by SC and QS at 745 PDLM and high RH versus time and temperature.

centration of solids at equilibrium is about 97.5/1021 = 9.8 mg/100 mg solution. Similarly, for equilibrium conditions at −10° and −18°C, the concentrations of nonvolatile solids in the generated solutions are estimated to be about 16 and 24 mg/100 mg solution, respectively. The multiplying factors for the three subject temperatures are 0.902, 0.84, and 0.76, respectively.

By the use of the blotter-S method, estimates were made of the net water formed after several different treatment times at −5°, −10°, or −18°C (Table 3 and Figure 3) and at high RH with an application rate of about 745 lb/lm. Generally, the water generated by QS was considerably greater than that generated by SC. With applications at levels of 573, 1,146, and 2,292 lb/lm and otherwise similar conditions (Tables 3 and 4 and Figure 4), the estimated differences are smaller. However, comparisons made at low RH at temperatures of −10° and −20°C (Table 4 and Figure 5) indicated a substantially greater brine-generating capability for QS than for SC.

Reducing SC and QS to a fine powder by grinding them with a mortar and pestle gave deicers that in 30 min generated relatively large masses of water.

Comparison of Results from Blotter-S Versus Blotter-Z Methods

In the course of a preliminary study of debonding of the ice-concrete interface with deicers, it was observed that crystals of SC and pellets of QS may penetrate a significant distance into the mass of ice (see below). Active deicer particles, viewed through the side wall of a transparent plastic container, were observed to form roughly conical or bullet-nose-shaped passages or wells as a result of penetration of the deicer particles downward into the ice. In many cases, the shape of these wells departed substantially from that of a simple cone. Thin, irregularly shaped streamers of brine (made visible by the presence of a red dye with an SC crystal or by the brown color of the PCI in the QS pellet) could be seen extending downward (sometimes 5 to 10 mm or more) from the remaining solid deicer particle, probably as a result of rapid movement of brine downward through the quasi-amorphous regions between the ice crystals.

TABLE 4 MELTING OF ICE IN THE PRESENCE OF SC AND QS: EFFECTS OF APPLICATION LEVEL AND RELATIVE HUMIDITY[a]

Time (min)	SC GSSM(PWLM)	QS GSSM(PWLM)
115 GDSM (126 PDLM); High RH: T = - 18 C (0 F):		
4	65.5(670)	70.3 (692)
8	137.(1400)	159. (1565)
15	171. (1747)	206. (2027)
30	186. (1898)	259. (2549)
2292 MDSC (2528 PDLM); High RH: T = - 18 C (0 F):		
4	137.(1402)	152. (1496)
8	223.(2276)	238. (2342)
Low RH: T = - 10 C (0 F): 57.3 GDSM (745 PDLM)		
1	17.0 (189)	33.0(359)
2	30.5 (340)	60.0 (653)
3	71.5 (796)	92.5 (1006)
4	86.5 (963)	117.(1272)
8	109. (1214)	158.(1722)
15	128. (1427)	181.(1969)
30	132. (1466)	198.(2158)
Low RH: T = - 20 C (0 F): 573 MDSC (745 PDLM)		
8	17.0 (171)	26.0 (253)
15	27.5 (276)	46.0 (447)
30	42.5 (427)	73.0 (709)

(a) Abbreviations are explained in footnotes to Table 2.

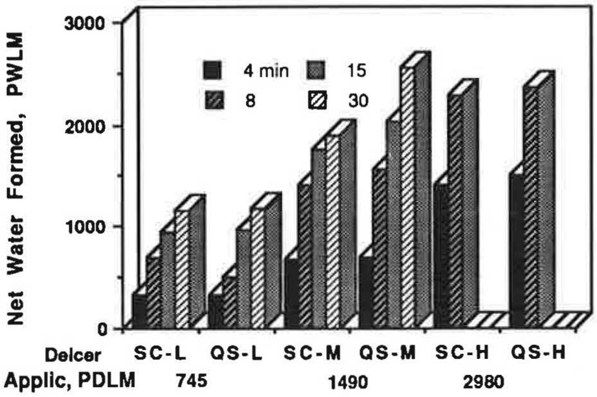

FIGURE 4 Ice melted by SC and QS at −18°C and high RH versus time and application rate.

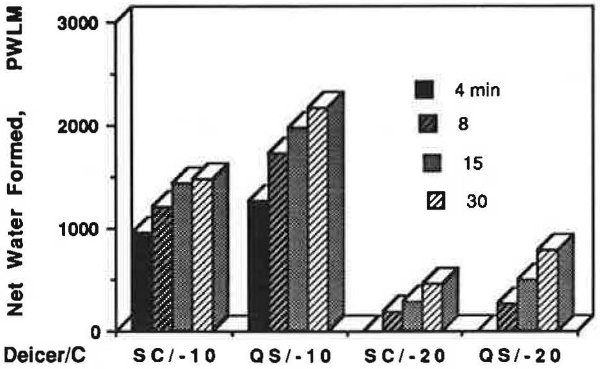

FIGURE 5 Ice melted by SC and QS at 745 PDLM and low RH.

Although the blotter-S method was found to function adequately in the experiments with FG, in which nearly all brine was generated near the surface of the ice, it appeared that the modified procedure, the blotter-Z method, was needed in order to collect the brine generated by the solid deicers, including both the surface and the imbedded liquids.

To complete the blotter-Z method, an ice container was turned upside down and shaken vigorously with a vertical motion to expel the brine from the ice mass "wells" onto a blotter paper for subsequent weighing.

Experimentation showed that significantly more brine was recovered using the blotter-Z instead of the blotter-S method. For example, in quintuplicate experiments with SC at −10°C, 750 lb/lm, and high RH for 30 min treatment time, the S method yielded 175, 190, 196, 188, and 182 g/m^2 (mean = 186 g/m^2); the Z method yielded 284, 290, 322, 314, and 356 g/ms^2 (mean = 313 g/m^2).

The authors conclude that the blotter-S method [and very probably the pour-off procedure of McElroy (*8*) as well] provides mainly for measurement of brine generated on or near the surface of the ice. With SC, a substantial fraction of the brine that forms appears to remain imbedded in the ice and is collected by the Z but not by the S method.

The results obtained by the S method with the particular QS sample studied are believed to be valid relative representations of the effects of variables on the performance of this deicer. However, the QS results probably cannot be compared directly with the results found for SC, mainly because of the 15 percent fines in QS (versus 3 percent in SC) and the resultant deeper penetration into ice by SC.

Experiments with SC and QS Using Blotter-Z Method

The blotter-Z method was utilized to study the ice-melting characteristics of SC and a Qwiksalt sample identified as QS-2. This sample was narrowly screened in the laboratory to provide particles sized as 12 to 14 mesh. The SC crystals studied were the same as those used in the above-reported experiments, and these particles were sized mainly within the range of 8- to 14-mesh Tyler screens.

Experiments were carried out at −10°C and at both high and low RH conditions using SC and QS-2 applications at a rate of about 745 lb/lm. Measurements were made after treating times of 10, 15, 30, and 60 min. Results (Table 5 and Figure 6) indicate that the extent of melting provided by the two deicers is similar and probably the same within experimental error. If anything, ice melting is slightly higher for SC at high RH but a little lower for SC at low RH.

Both deicers show less melting at low RH than at high RH. These differences are believed to be significant and probably arise because the deicer surfaces interact more slowly at lower levels of RH.

Additional experimentation was conducted at −18° and −20°C and low RH. The masses of ice melted (Table 5, Figure 7) are much less than those found at −10°C.

At these low temperatures and at low RH, the QS-2 sample yielded significantly more melting than did the SC. The authors believe that this difference arises mainly because of the hygroscopic and surfactant properties imparted to QS as a result of its surface layer of magnesium chloride and also of its content of PCI.

In the course of this experimentation at low temperatures, it was found that reproducible results were very difficult to obtain. Two main causes were identified. The ability to maintain experimental temperatures at a sufficiently constant level was inadequate—unavoidable changes in temperature up to ±2°C took place in the cold rooms, whereas (as is evident from the phase equilibrium data) variations of 1° or 2°C may give rise to substantial shifts in the maximum extent of melting, especially at temperatures near the eutectic. The authors also suspect that major variations took place in the characteristics of the ice preparations studied in terms of the form, size, and orientation of the crystals (as judged by viewing untreated ice samples under polarized light) formed under the conditions of rapid freezing (*14*) that were utilized. In such crystals, quasi-amorphous regions appeared to exist to differing degrees in samples prepared under similar conditions, with the result that imbedded brines were difficult to recover reproducibly.

TABLE 5 MELTING OF ICE IN THE PRESENCE OF SC AND QS AT LOW AND HIGH RH USING BLOTTER-Z METHOD[a]

RH	Time (min)	SC	QS-2
		GSSM (PDLM)	
		Temperature = - 10 C (15 F)	
High.	15.	284.(3162)	272.(2963)
	30.	306.(3403)	284.(3087)
	60.	326.(3635)	302.(3288)
Low.	10.	216.(2407)	229.(2491)
	15.	224.(2495)	226.(2453)
	30.	226.(2540)	256.(2783)
	60.	253.(2821)	271.(2969)
		Temperature = - 18 C (0 F)	
High.	15	81.3(837)	74.5(733)
Low.	20.	65.8(673)	97.8(963)
	30.	75.1(768)	97.5(960)
	40.	84.0(859)	122.(1200)
	50.	90.8(929)	126.(1244)
	60.	95.1(973)	134.(1323)
		Temperature = - 20 C (- 4 F)	
Low.	15.	23.7(238)	28.2(274)
	30.	48.8(490)	68.0(660)

(a) Abbreviations are explained in footnote to Table 2.
Application = 57.3 GDSM (745 PDLM)

Generally, the authors conclude that QS brings about rapid melting of ice, especially under conditions of low temperature and low humidity where its rate of action appears to be significantly faster than that of the SC sample studied.

Penetration of Ice by Salts

For salt preparations to be used successfully to debond the interface between ice and a roadway surface such as concrete, the salt must first penetrate through the layer of ice covering the roadway. To examine the rate and extent of penetration of ice by the preparations of interest, preliminary experiments were conducted in which the progress of the salt downward through ice was measured by observing horizontally through the transparent ice the position of the lowest boundary of the

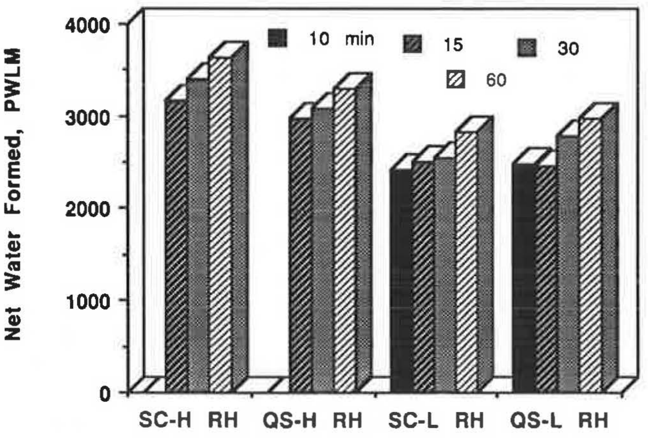

FIGURE 6 Ice melted by SC and QS at −10°C versus time and RH: Z method.

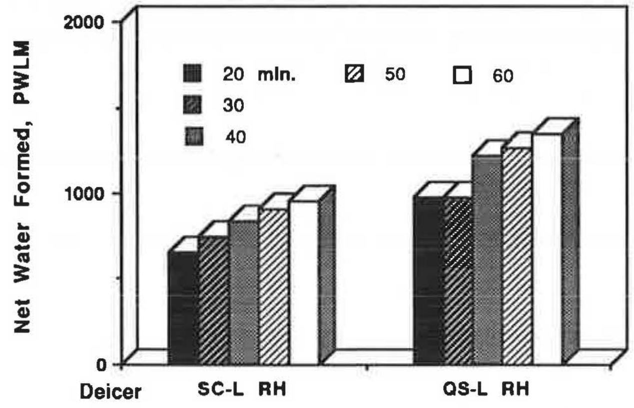

FIGURE 7 Ice melted by SC and QS at −18°C and low RH: Z method.

ice solution that formed with respect to the surface of the ice. The authors later learned that McElroy et al. applied this type of procedure in an extensive study of penetration (*8*).

The results were useful but not of high precision. For example, at −10°C and high RH with deicer application at a single spot at a level of 57 g/m^2 (745 lb/lm), the depths of penetration after 5, 30, and 60 min were found for SC and QS to be 5 and 4, 28 and 30, and 34 and 36 mm, respectively. Thus the behavior of the two preparations was similar. In general, the extent of penetration should be greater as the size of a deicer particle is increased. Assuming that ice-brine equilibrium conditions prevail and that a perfect cone-shaped well is formed as a particle penetrates into the ice, the following relationship can be derived to model the maximum depth of the penetration:

$$h = (2.165)(4)(r)(R)/(D) \tag{1}$$

where

h = maximum depth in millimeters,
r = radius of a spherical particle,
R = mass of brine generated per mass of deicer applied, and
D = density of formed brine.

Applications of this equation for a sodium chloride particle with R = 0.77 mm gives depths of 76, 43, and 27 mm for maximum penetration of ice at −5°, −10°, and −18°C. The depth of penetration observed in the experiments was only 10 to 30 percent of these calculated maximum values. This result is probably to be expected in view of heat transfer effects, partial horizontal spreading, and the complex patterns observed as a particle penetrates downward into ice.

Debonding of an Ice-Concrete Interface by Use of Salts

Debonding was measured by observing visually from above the surface and through a transparent layer of ice formed over a concrete surface the extent to which a colored deicing solution spread approximately horizontally over the surface of a concrete slab. QS is already brown by virtue of the presence of PCI; for SC, one small particle of a red dye was added. Experiments showed that the debonded areas closely approached perfect circles in shape. The authors therefore measured mean diameters and calculated the debonded areas assuming perfect circles.

In preliminary experiments, individual particles of SC and QS were placed on ice surfaces. Their rates of penetration downward through the ice and subsequent spreading and debonding of the ice-concrete interface were observed visually as functions of temperature and time. At a rate of 57.3 g/m^2 (745 lb/lm) and at −10°C (14°F), QS and SC penetrated a 2-mm layer of ice and debonded ice-concrete interfaces at nearly the same rates. The areas debonded increased nearly linearly with increases in the mass of the deicer applied.

CONCLUSIONS

The effectiveness of two commercially available deicing preparations was studied and significant characteristics were identified. Relative to SC, the results suggest that QS has an enhanced capability to accomplish rapid melting of ice, especially at low temperatures and low levels of relative humidity. FG acts rapidly. The challenge now ahead is to determine how best to apply these findings.

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Comparative Field Study of the Operational Characteristics of Calcium Magnesium Acetate and Rock Salt

D. G. MANNING AND L. W. CROWDER

A field study was undertaken during the winters of 1986–1987 and 1987–1988 to compare the performance of calcium magnesium acetate (CMA) and rock salt as deicing chemicals. The study included determination of the deicing effectiveness and the handling and storage characteristics of the two chemicals. The CMA was applied to a section of freeway and the adjacent sections of service roads near Beamsville, Ontario. Salt was applied to the adjoining freeway and service roads, which served as the control sections. The CMA and salt were applied at specified rates, and the frequency was dictated by the road conditions. The condition of the test sections was recorded by independent monitors at 1-hr intervals during all winter storms. The CMA was found to be comparable to salt in achieving bare pavement, though more CMA was used than salt. CMA was found to be relatively more effective in longer storms, and there was a residual effect from one storm to another. The storage and handling characteristics of CMA were similar to those of salt. Modifications to equipment were not required, and spreading procedures were changed only slightly. The corrosion of the CMA spreader unit was substantially less than that of the salt spreader unit.

In recent years, the Ontario Ministry of Transportation has attempted to reduce the negative impacts of rock salt used in winter maintenance operations through more judicious application, improved equipment controls, and better storage facilities. Simultaneously, there has been a continuing search for an effective, nonpolluting and noncorrosive alternative to rock salt. A possible alternative is calcium magnesium acetate (CMA), which is a mixture of calcium acetate and magnesium acetate manufactured from dolomitic limestone and acetic acid. CMA was identified in research studies in the late 1970s (*1*) and has been the subject of several laboratory and field investigations to determine its effectiveness as a deicer and its effect on the environment (*2–7*).

In order to assess the potential impact of CMA on the ministry's winter maintenance operations, a field trial was carried out during the winter of 1986–1987. The study was continued with minor modifications during the winter of 1987–1988.

SCOPE OF THE STUDY

The main objective of the study was to investigate the effectiveness of CMA as a deicer. Additional areas of investigation included storage properties, handling and spreading characteristics, and corrosion of the spreading equipment.

The CMA was applied to a 2.4-km section of the Queen Elizabeth Way (QEW) near Beamsville, Ontario, and to the adjacent service roads. The QEW is a four-lane freeway with an average annual daily traffic (AADT) of 38,500; the service roads are used only by local traffic and have an AADT of less than 500. The test section included both the eastbound and westbound lanes to prevent contamination from the adjacent roadway. Further, observations were based on the center 1 km of the test section to avoid the effects of tracking. The 7 km of the freeway and service roads immediately to the east, which were similar to the CMA test site in all aspects of concern (including wind direction and lake effects), were maintained using salt applied in accordance with standard ministry procedures and served as the control sections. All the roads had a bituminous surface.

Prior to the winter of 1986–1987, 200 tonnes of commercially produced CMA meeting FHWA specifications were purchased. The CMA was applied by ministry staff; the salt by a contractor. An additional 180 tonnes of CMA was purchased from the same supplier for use in 1987–1988. During the second winter, ministry staff applied both the CMA and the salt.

The deicing effectiveness was determined through the observations of two independent monitors (each working a 12-hr shift) who rated the condition of the roadway on an hourly basis. Observations with respect to storage, handling, and the condition of the equipment were made by the monitors and the patrol staff.

The CMA was stored under cover in two sheds, one of which contained the neat material and the other the CMA-sand mixture. The salt and salt-sand mixture were also stored under cover according to normal ministry practice.

APPLICATION CRITERIA

The responsibility for determining when deicing chemicals would be applied rested with the patrol supervisor, who based his decision on the condition of the roads and the ministry's Maintenance Quality Standards (*8*).

The standard for the freeway requires that the accumulation of snow not normally be allowed to exceed 25 mm and that bare pavement be achieved as soon as reasonably possible. The standard for the service roads requires that snow not be allowed to accumulate beyond 70 mm, but a snow-packed

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condition is acceptable. In practice, this meant that at the onset of a storm, CMA and salt were applied to the appropriate sections of the freeway at almost the same time. The specified application rate for salt was 130 kg per 2-lane km (130 kg per 2-lane km is equivalent to 230 lb per lane mile). At the beginning of the 1986–1987 winter, CMA was applied at a rate of 221 kg per 2-lane km (or 1.7 times the rate for salt), but this rate was reduced later in the winter. The initial ratio of the application rates of CMA to salt of 1.7 was based on the calculation of theoretically equal deicing performance. Subsequent applications of CMA and salt during the storm were determined by the road conditions. In other words, if the pavement was not bare, a further application of deicing chemical was made at the specified rate. However, no attempt was made to make the same number of applications to the CMA and salt sections, because the chemicals performed differently under different storm conditions.

The decision to use pure deicing chemical or a sand mixture on the freeway was based on weather forecasts and the patrol supervisor's knowledge of local conditions. In general, when there was a reasonable expectation of maintaining bare pavement, neat CMA or salt was applied. At other times, particularly during the most severe storms, or when temperatures were less than the optimum for deicing, or at night, sand mixtures were used to provide traction. Only sand mixtures were used on the service roads.

In 1986–1987, the salt-sand mixture was a manufactured sand and 10 percent salt by mass. The target application rate was 570 kg per 2-lane km. The manufactured sand-salt mixture was used because it was in stockpile from the previous winter. The CMA-sand mixture was a mix of natural sand and 14 percent CMA by mass and was applied at a target application rate of 800 kg per 2-lane km. The CMA content and the application rate for the CMA-sand mixture were calculated from the quantities used in the first storm (the CMA was delivered a few hours before the storm and the spreader was not calibrated until after the first storm). Since it appeared to be effective, the application rate was not changed. In 1987–1988, the salt-sand mixture was natural sand and 15 percent salt by mass, which is an established standard in the geographical area of the patrol. Less salt is used in manufactured sand mixtures than in natural sand mixtures because the former is more abrasive and provides better traction. The CMA-sand mixture was the same as in the first winter.

Because of the very low traffic volumes on the service roads, these had the lowest priority within the patrol area, and sand mixtures were applied as equipment became available during a storm. The primary purpose of applying the sand mixtures to the service roads was to provide traction, and no conscious attempt was made to provide bare pavement. Additional applications were made following plowing or if icy conditions developed.

HANDLING, STORAGE, AND SPREADING CHARACTERISTICS AND EFFECT OF EQUIPMENT

Dusting

Some dusting occurred during loading operations, but not sufficient to require the operators to wear face masks. The amount of dusting of the CMA-sand mixture was greater after a period of prolonged storage (six weeks or more), presumably because the CMA absorbed moisture from the sand. Although the dusting did not constitute a serious handling problem, a well-ventilated storage facility is needed.

Storage

The storage characteristics of the CMA were similar to those of salt, although the angle of repose was somewhat greater. Occasionally, a light crust formed over the stockpile, but this was easily broken and the material became flowable when disturbed by the loader. The principal difference between CMA and salt was in the amount of caking which occurred on the paved apron outside the storage shed. During periods of precipitation, CMA would stick to the wet tires of the loader and was carried out of the shed. This material, together with that spilled during loading, resulted in a thick layer of caked CMA (sometimes up to 75 mm thick) sticking to the apron. This material was allowed to dry, at which time it could be picked up by the loader and was sufficiently friable to be mixed with sand and used as CMA-sand mix.

Sticking

Upon contact with moisture, the CMA became sticky and adhered to the spreader hopper, the dispensing chute, and the spinner. The spreader hopper was smaller than that normally used for salt, and the relatively shallow slope of the hopper sides contributed to the amount of material sticking.

Neat salt is spread by dropping the material through the dispensing chute along the center of the roadway. This was not possible with the CMA because spray from the truck tires caused the CMA to stick and plug the chute. The problem was overcome by discharging the CMA over a slowly-rotating spinner. Although there was a buildup of material on the spinner, this did not affect its functional operation and the CMA was spread evenly in a band approximately 2 m wide along the center of the roadway. Salt-sand and CMA-sand mixtures were spread using the spinner operating at the normal speed of rotation and there was no buildup of material.

In order to limit the amount of CMA sticking in the hopper between loads, either the hopper was emptied or the unit was stored in the equipment garage. Before reloading, the sides of the hopper were struck with a large rubber mallet to loosen the sticking material. The unit was washed following each storm, at which time material sticking to the hopper, chute, and spinner was easily removed. The salt unit was also washed between storms. These procedures were effective in controlling the amount of sticking, which never became serious enough to interfere with normal equipment operations.

Effect on Equipment

An indication of the relative effects of CMA and salt on corrosion was obtained by observation of the spreader units after the first winter. On the unit used for CMA, which was new at the start of the study, exposed metal remained shiny and free from rust. On the salt unit, which was repainted prior to the study, the amount of paint lost was much greater, especially at seams and joints, and exposed metal was rusted. The CMA spinner remained free from rust, whereas the salt spinner became badly rusted.

DEICING PERFORMANCE DURING THE WINTER OF 1986–1987

Overall Observations

Fifteen storms were encountered during the winter. The dates and the weather conditions associated with each storm are given in Table 1. A summary of the number of applications of deicing chemicals, the quantity applied to the QEW during each storm, and the time to achieve bare pavement (the bare and wet condition) are given in Table 2. Table 2 represents the sum of the deicer which was applied neat and the portion of deicer in the appropriate sand mixture. Complete details of when neat deicers and when sand mixtures were applied are given in a ministry report (*9*).

After two months, the ratio of the application rates of CMA to salt of 1.7 seemed excessive and the ratio was reduced to 1.5. The relatively small number of storms later in the winter precluded any conclusions being drawn with respect to the effectiveness of the different application rates.

Table 3 shows the quantity of deicing chemicals applied to the service roads. Because there was no attempt to maintain bare pavement, a comparison of performance similar to that reported in Table 2 for the QEW is not possible. However, the quantities shown were sufficient to maintain the low-

TABLE 1 SUMMARY OF STORMS DURING THE WINTER OF 1986–1987

STORM No.	DATE	AVERAGE TEMPERATURE °C	SNOW cm	RAIN mm	AVERAGE WIND SPEED km/hr
1	NOV 20-21/86	-1.7	14.0	0.0	10.00
2	DEC 8/86	-4.0	7.0	13.4	12.00
3	DEC 11/86	-1.0	0.4	0.6	8.00
4	JAN 2/87	-1.0	9.2	0.6	10.00
5	JAN 10-12/87	-1.9	1.0	0.4	13.00
6	JAN 18/87	-1.0	5.4	0.0	14.00
7	JAN 19-20/87	-4.0	15.0	0.0	10.00
8	JAN 22/87	-3.0	2.0	0.0	18.00
9	JAN 26/87	-7.0	1.0	0.0	6.00
10	JAN 30/86	-3.0	4.8	0.0	8.00
11	FEB 2-3/87	0.0	1.8	0.0	10.00
12	FEB 8/87	-9.3	2.0	2.0	34.00
13	FEB 14/87	-10.0	0.8	0.0	14.00
14	FEB 16/87	-1.4	1.0	0.0	6.00
15	MAR 30-APR 1/87	-2.8	16.5	0.0	10.00

TABLE 2 COMPARISON OF QUANTITIES AND DEICING TIMES FOR CHEMICALS APPLIED TO THE QEW IN 1986–1987

	CMA			SALT		
STORM No.	No. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H	NO. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H
1	8	1270	23.50	11	2000	23.50
2	5	1830	14.50	8	1050	14.50
3	2	420	2.00	2	220	2.50
4	8	1520	19.50	12	1420	19.75
5	7	1530	41.00	8	1230	41.00
6	4	1090	6.50	7	1000	6.50
7	5	1340	20.75	9	810	20.75
8	3	770	6.25	3	510	6.25
9	2	170	2.50	4	220	2.50
10	7	1460	23.75	11	1770	23.75
11	2	310	15.00	1	120	15.00
12	2	330	10.00	1	220	10.50
13	2	230	8.25	1	100	9.00
14	2	160	9.00	1	400	9.00
15	8	1450	20.00	9	560	34.00
TOTAL	67	13880		88	11630	

RATIO OF TOTAL QUANTITY USED, CMA:SALT = 1.2:1

TABLE 3 QUANTITIES OF DEICING CHEMICALS APPLIED TO THE SERVICE ROADS IN 1986–1987

	CMA		SALT	
STORM NO.	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED
1	4	2690	3	4360
2	3	1640	3	2430
3	1	740	1	1000
4	3	1270	4	3520
5	3	1670	4	3650
6	2	1740	2	2230
7	2	1520	2	1710
8	1	1420	1	1090
9	2	1230	1	1140
10	3	2290	3	2330
11	1	760	1	1140
12	2	1470	2	1640
13	0	0	0	0
14	1	760	1	960
15	2	890	2	2270
TOTAL	30	20090	30	29470
RATIO OF TOTAL QUANITY USED, CMA MIX : SALT MIX = 0.68:1				
CORRECTED RATIO, CMA : SALT = 0.95:1				

volume roads to ministry standards and there were no substantial differences between the condition of the CMA and the salt sections. The ratio of CMA-sand mixture to salt-sand mixture used over the entire season was 0.68. Since the CMA-sand mixture contained 14 percent CMA and the salt-sand mixture contained 10 percent salt, the ratio of CMA to salt used on the service roads was 0.95.

In general, most of the storms occurred when the temperature was between 0 and −5°C, which is typical of winter storm conditions in the Niagara Peninsula. Within this range, temperature did not appear to affect the relative performance of salt and CMA. The storms ranged from a few hours to three days in duration, with the majority lasting less than one day. In some storms, more CMA than salt was used and in others, less. The ratio of CMA to salt usage over the entire winter was 1.2. Fewer applications of CMA than salt were made during the winter (although the application rate was greater), and the difference in the number of applications was most apparent during the storms of longer duration. The times to achieve bare pavement in the CMA and salt sections were comparable and, with one exception, within 45 minutes of each other.

Although the foregoing general observations are useful, it is equally revealing to examine the relative performance of the CMA and salt during individual storms.

Observations During Specific Storms

Storm No. 3, December 11–12, 1986

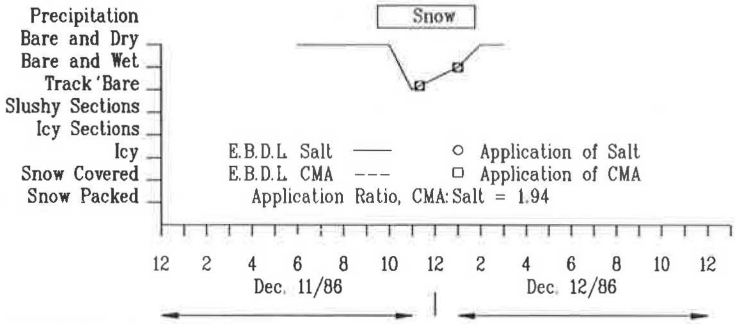
The time of application of the CMA and salt and the condition of the roadway are shown in Figure 1(a). This storm can be considered a typical illustration of the relative performance of CMA and salt during a storm of short duration. One application of pure material and one application of sand mixture were made at the same time to each section during the storm. The effect of each chemical on pavement condition was the same. The ratio of CMA to salt used was 1.9.

Storm No. 4, January 2–3, 1987

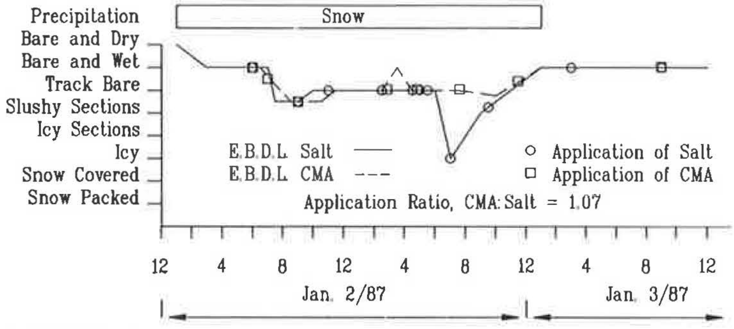
Details of deicer usage and pavement condition throughout the storm are given in Figure 1(b). This storm can be considered representative of the storms of longer duration with significant snowfall. There were six applications of salt, six applications of salt-sand mixture, four applications of CMA, and four applications of CMA-sand mixture. Roadway conditions during the storm were comparable except for a period of about 3 hr when the salt section became snow covered despite three applications of salt in rapid succession. Only one application of CMA in the same period was required to maintain track-bare pavement. The ratio of CMA to salt used during the storm was 1.1.

Storm No. 15, March 30–April 2, 1987

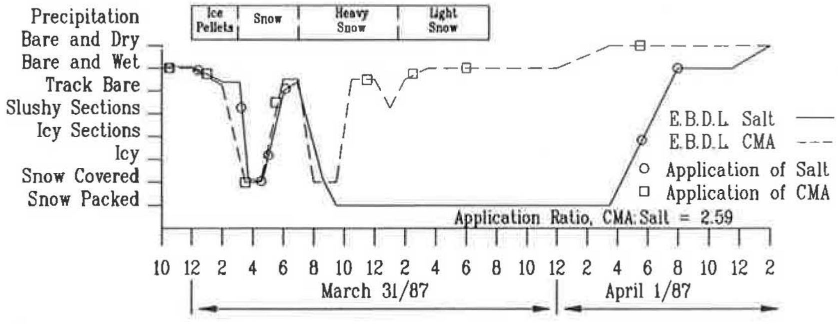
This was the storm having the longest duration and heaviest snowfall of the winter. It was also exceptional in that it was the only time that the performances of the CMA and the salt were not comparable. Six applications of CMA and two of CMA-sand mixture were made over a 32-hr period. As shown in Figure 1(c), the roadway became snow covered for a period of approximately 1 hr on two occasions, but was otherwise track-bare or better. By contrast, the salt section became snow packed such that the application of salt was suspended and maintenance consisted of plowing. Three applications of salt were required after the last application of CMA for a total of three applications of salt and six of salt-sand. The final application of salt was made at 8:00 a.m. on April 2 and is not included in Figure 1(c). Bare pavement was not achieved in the salt section until 14 hr after the CMA section. Since



a) STORM No. 3



b) STORM No. 4



c) STORM No. 15

FIGURE 1 Roadway conditions during (a) Storm No. 3 (b) Storm No. 4, and (c) Storm No. 15 in 1986–1987.

CMA continued to be applied throughout the storm, the quantity used was much greater and was 2.6 times as much as the salt.

Effect of Wind During Application

There was no significant difference between the behavior of salt and CMA under windy conditions. It was not found necessary to cover the loads with a tarpaulin. Under strong wind conditions, both deicers were blown after discharge from the hopper, resulting in uneven application.

Retention on the Road Surface

The spreading characteristics of the two materials were similar and, although the CMA was lighter, the particles did not bounce appreciably more than salt particles. Once on the road surface, the two deicers behaved differently. When applied to a moist pavement, the CMA stuck to the pavement surface. The action of traffic embedded the material in the road surface, where the pellets continued to dissolve. As the roadway surface dried, the excess CMA remained bonded to the pavement until there was further precipitation. The salt did not bond to the pavement and was more easily removed from the road surface by traffic, wind, and any subsequent plowing.

The retention of the CMA on the pavement explains two important differences in the performance of CMA and salt. First, it was found that CMA was relatively more effective during the longer storms. As the storm progressed, fewer applications of CMA were needed and the ratio of CMA to salt used was much less during the storms of two to three days duration than in those which lasted a few hours. Second, the CMA had a residual effect from one storm to another, with the result that the ratio of CMA to salt usage tended to decrease through January and February. The presence of CMA embedded in the pavement meant that, at the onset of a storm, a solution formed and prevented icing of the roadway surface. Observations of the pavement up to two weeks after the last application revealed particles of CMA embedded in the surface. The CMA that was retained on the pavement did not attract moisture, and there was no tendency for the pavement to ice as reported in an earlier study (*5*). An extended mild period, during which there were several periods of rain, meant that this residual effect was not apparent during the final storm of the winter.

Penetration Through Snow Pack

The two deicers reacted differently when applied to a snow-packed road surface. The salt formed a brine on the surface of the snow pack. Conversely, the CMA pellets dissolved more slowly and penetrated through the snow pack to the road surface. This was particularly apparent on the service roads. Following plowing, sand and CMA could be found adhering to the pavement. In the salt control section, the sand and salt mixture remained suspended within the snow pack and was scraped off by the plow. The penetration of the CMA meant that it was more effective than salt in breaking up snow pack. The CMA also created a pothole effect in the snow pack, and the rough surface increased pavement noise, which caused drivers to reduce speed. By contrast, the salt tended to glaze the surface, creating an illusion of wet pavement, especially at night.

Acceptance by Patrol Staff

One of the objectives of the study was to determine the impact of the use of CMA on normal patrol operations. Consequently, the reactions of the patrol staff were important. As the winter progressed, the patrol became comfortable with the CMA and confident it would perform as required. Minor irritations such as sticking on the apron and inside the spreader were resolved quickly by the operators at their initiative. Following the full winter's field trial, the overall response of the patrol staff to CMA was favorable.

DEICING PERFORMANCE DURING THE WINTER OF 1987–1988

Overall Observations

The field trial was continued in 1987–1988 with the following minor changes:

- The deicers in both the CMA and the control sections were applied by ministry staff, and
- The salt-sand mixture consisted of natural sand and 15 percent salt by mass.

Following the analysis of the results from the first winter, the decision was made to use an application ratio of 1.4 at the start of the 1987–1988 winter. However, in late January, the patrol staff expressed the view that the performance of the CMA was less than expected and the ratio was increased to 1.7 for the remainder of the winter. The application rates of the CMA-sand and the salt-sand mixtures used in 1987–1988 were the same as those used in 1986–1987.

Twenty separate storms were identified during the 1987–1988 winter, but many of these were very short. The dates of the storms and the weather conditions associated with them are given in Table 4. Summaries of the data for 1987–1988, corresponding to Tables 2 and 3 for 1986–1987, are given in Tables 5 and 6. During Storm No. 20, an equipment breakdown made it necessary to apply CMA to the salt section of the QEW. Consequently, the quantities of deicer used in Storm No. 20 are not included in Table 5.

A major difference between the results of 1986–1987 and 1987–1988 is that in the first winter, the number of applications of CMA was usually less than that of salt in each storm. In the second winter, the number of applications of CMA often exceeded the number of salt applications. This occurred because a truck was dedicated to the short CMA section so that, in all except the worst storm conditions, CMA could be applied when needed. The salt section was longer and more distant from the patrol yard so that not only was the frequency

TABLE 4 SUMMARY OF STORMS DURING THE WINTER OF 1987–1988

STORM NO.	DATE	AVER. TEMP. °C	SNOW cm	RAIN mm	AVERAGE WIND km/h
1	DEC 4/87	-0.1	8.4	0.0	5.0
2	DEC 5/87	-0.4	0.6	0.0	---
3	DEC 15/87	-2.7	5.2	22.0	---
4	DEC 28-29/87	-5.5	8.6	9.0	25.0
5	JAN 4/88	-3.5	0.8	0.0	10.0
6	JAN 14/88	-11.0	1.4	0.0	4.0
7	JAN 21/88	-1.2	0.4	0.2	7.0
8	JAN 23/88	-2.5	2.0	0.0	2.0
9	JAN 25-26/88	-4.5	4.4	0.0	5.0
10	FEB 2-4/88	-3.2	16.2	5.6	10.0
11	FEB 7-8/88	-9.0	1.2	0.0	15.0
12	FEB 9/88	-8.0	0.8	0.0	5.0
13	FEB 11-12/88	-5.0	10.0	0.0	17.0
14	FEB 13/88	-8.0	0.0	6.4	7.0
15	FEB 19/88	-1.0	0.0	12.2	2.0
16	FEB 26/88	-5.0	0.8	0.0	18.0
17	FEB 27/88	-2.0	0.6	0.0	18.0
18	FEB 29/88	0.5	0.2	0.0	12.0
19	MAR 14/88	-2.2	1.2	0.0	5.0
20	MAR 19-20/88	-2.0	4.0	1.2	5.0

--- data not available

TABLE 5 COMPARISON OF QUANTITIES AND DEICING TIMES FOR CHEMICALS APPLIED TO THE QEW IN 1987–1988

	CMA			SALT		
STORM No.	No. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H	NO. OF APPLIC.	kg/ 2-LANE km APPLIED	TIME TO BARE PAVEMENT H
1	1	170	0.75	1	130	0.75
2	2	350	2.00	1	130	2.00
3	2	290	15.75	2	300	15.75
4	8	1060	17.75	6	980	17.25
5	2	210	1.00	2	280	1.75
6	1	100	4.00	1	90	4.00
7	1	180	N/A	1	150	N/A
8	3	540	4.75	3	480	4.75
9	11	1530	25.50	5	750	25.50
10	11	1700	61.00	10	1470	61.00
11	4	630	13.00	3	310	12.50
12	4	730	8.50	3	390	8.00
13	13	2100	31.25	11	1270	31.25
14	5	340	N/A	6	380	N/A
15	2	310	3.50	1	150	3.50
16	1	110	N/A	1	50	N/A
17	2	310	2.50	2	220	2.50
18	1	200	0.50	1	130	0.50
19	1	180	N/A	1	150	N/A
TOTAL	75	11040		61	7810	

RATIO OF TOTAL QUANTITY USED, CMA MIX : SALT MIX = 1.4:1
N/A NOT APPLICABLE - LOCALIZED DRIFTING ONLY

TABLE 6 QUANTITIES OF DEICING CHEMICALS APPLIED TO THE SERVICE ROADS IN 1987–1988

	CMA		SALT	
STORM NO.	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED	NO. OF APPLICATIONS	kg/2-LANE km OF MIX APPLIED
1	1	250	0	0
2	1	720	1	500
3	1	700	1	500
4	3	1710	3	1160
5	1	720	1	600
6	1	720	1	780
7	0	0	0	0
8	3	1720	2	780
9	2	1440	3	1500
10	5	3810	5	2400
11	1	790	1	600
12	0	0	0	0
13	3	2140	3	1280
14	2	1510	1	500
15	1	790	0	0
16	0	0	0	0
17	0	0	1	40
18	0	0	0	0
19	0	0	0	0
20	2	1350	1	500
TOTAL	27	18370	24	11140

RATIO OF TOTAL QUANTITY USED, CMA MIX : SALT MIX = 1.6:1
CORRECTED RATIO, CMA : SALT = 1.5:1

of applying salt less than CMA, but a heavier application than the standard sometimes had to be made.

The occurrence of numerous short storms, during which it was often problematical whether deicing chemicals would be needed, also made it more difficult to analyze the results of the second winter than the first. Several "storms" during which there were one or two applications of deicing chemicals could be better described as squalls. In these cases, the patrol supervisor had to decide whether the road would remain serviceable without deicing or whether it was more prudent to apply a deicer. Because the CMA and the salt were not necessarily applied at the same time, and weather conditions often changed rapidly, the ratio of the deicers used in short storms can be misleading. Because the response time to the CMA section was less than to the salt section, more CMA was applied in short storms during which the weather conditions improved. Conversely, when the weather conditions deteriorated, less CMA was used because of its more timely application, and additional applications of salt were sometimes needed to bare the pavement.

Another factor that was more noticeable in 1987–1988 than 1986–1987 was the occurrence of small drifts in the test sections. Under such conditions, sand mixes were applied selectively to the problem areas, but the quantities used were calculated as an average over the appropriate test section. This explains why the quantities shown in Table 5 were sometimes less than the prescribed application rates, as, for example, in Storm Nos. 6 and 16.

To the extent that overall observations can be drawn from the experiences in short storms, the relative performance was the same as that in short storms in the first winter—roadway conditions were comparable throughout the storm, but considerably more CMA than salt was used.

Although the ratio of deicers used in individual short storms can be misleading, the anomalies that resulted from different times of application and drifting conditions tend to cancel out over an entire winter. This averaging effect, together with the fact that much larger quantities of deicers are used in the longer storms, means that the ratio of the total quantities of CMA and salt used is considered to be a reliable indicator of relative performance. The ratio of CMA to salt used on the QEW sections in 1987–1988 was 1.4, compared to 1.2 in 1986–1987. In all other respects, the relative performance of the two deicers in terms of both application and effectiveness during the two winters was very similar.

Table 6 gives the quantities of deicers applied to the service roads. It indicates that considerably more CMA-sand mixture than salt-sand mixture was used. However, the difference is more a reflection of the operational procedures than an indication of relative performance. The CMA truck could carry sufficient CMA-sand mixture to service both the QEW and the service roads, so that sand mix was usually applied to the CMA section early in the storm. After servicing the QEW, the salt truck had to return to the yard to pick up another load of sand mix for the service roads. During severe storms, the truck made another application to the QEW, rather than the service roads, because priority had to be given to maintaining the freeway. In the longer storms there was a substantial difference between the quantity of CMA-sand mixture and salt-sand mixture applied, but a direct comparison is not possible because the CMA section was maintained to a higher standard than the salt section. A much more comparable level of service was provided on the service roads during the first winter, and comparison of the data in Table 3 is more valid than comparisons drawn from Table 6.

Observations During Specific Storms

The experience in short storms has already been discussed, and it is illustrative to take two longer storms, one in which the salt section was in slightly better condition during the storm and the other in which the CMA section was slightly better, as being representative of the relative performance of the two deicers.

Storm No. 4, December 28–29, 1987

The storm began at 8:00 p.m. on December 28 and lasted for 17 hr. The temperature was −3°C at the beginning of the storm and fell to −7°C by the time precipitation ended. The road conditions deteriorated rapidly and icy conditions developed in the first hour. The first application was neat deicer, but as the temperature fell, sand mixtures were used throughout the night. Neat deicers were again applied on the morning of December 29 to remove the remaining slushy sections from the pavement. Details of the usage of the deicers and the condition of the pavement are given in Figure 2(a). The salt section was in slightly better condition than the CMA section for most of the storm and bare, dry pavement was achieved 2 hr sooner. The ratio of the quantities of CMA and salt used during the storm was 1.1.

Storm No. 13, February 11–12, 1988

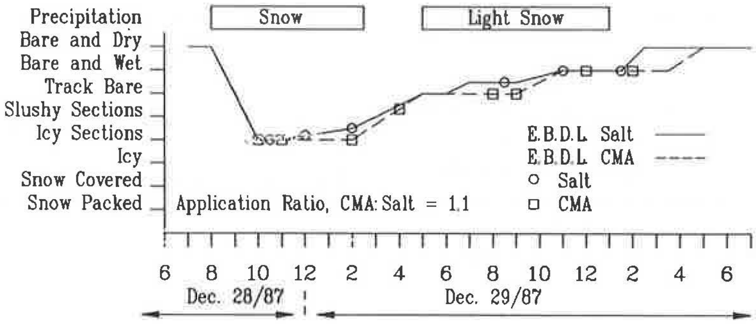
Storm No. 13 was the worst storm of the winter, beginning at 2:00 a.m. on February 11 and lasting for 36 hr. During the storm there were eight applications of CMA and five of CMA-sand mixture, seven applications of salt, and four of salt-sand mixture. Temperatures ranged from −10°C to −1°C. The condition of the roadway is illustrated in Figure 2(b). Except for brief periods when slushy sections developed, the roadway was maintained in a track-bare condition or better throughout the storm. The condition of the CMA section was slightly, though not significantly, better than the salt section. The ratio of the quantities of CMA and salt used in the storm was 1.6.

COSTS

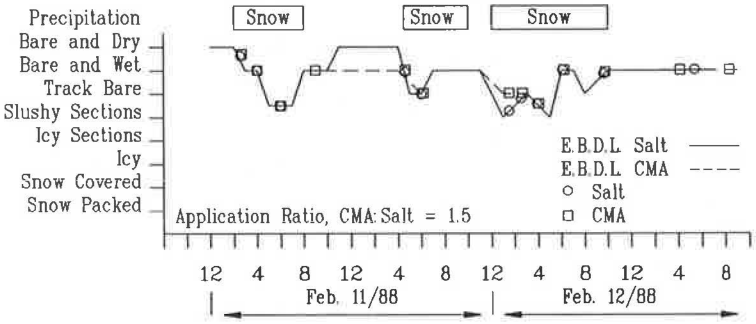
Although an analysis of costs was not within the scope of the current study, it is important to recognize that CMA is only available in limited quantities and at a very high cost. In 1986–1987 the CMA was purchased at $500 (U.S.) per ton f.o.b. plant. The cost at the patrol yard, including freight, duties, and taxes was $1050 (Can.) per tonne. The cost of salt was $29.41 (Can.) per tonne f.o.b. patrol yard. The costs in 1987–1988 were $1060 and $30.20, respectively. A comprehensive analysis of the financial implications of using CMA has been made in a separate study (*10*).

CONCLUSIONS

1. The CMA was used on the test sections throughout two winters. Under the conditions of use, the performance of the CMA was similar to that of salt in achieving bare pavement.



a) STORM No. 4



b) STORM No. 13

FIGURE 2 Roadway conditions during (a) Storm No. 4 and (b) Storm No. 13 in 1987–1988.

2. The initial application rate of CMA of 1.7 times that of salt appeared excessive and an application rate of 1.4 appeared insufficient, but the optimum application rate was not determined.
3. The ratio of the total quantities of CMA and salt used on the freeway test sections was 1.2 in 1986–1987 and 1.4 in 1987–1988.
4. CMA was retained on the pavement longer than salt with the result that it was relatively more effective in longer storms. There was also a residual effect of CMA from one storm to another such that the ratio of CMA to salt used decreased as the winter progressed. This effect was more apparent in 1986–1987 than in 1987–1988.
5. The storage and handling characteristics of CMA were comparable to those of salt.
6. The use of CMA required no changes in equipment and only small changes in normal maintenance procedures. The tendency of the material to stick to equipment and loading areas was a minor inconvenience. Patrol staff readily accepted the CMA.
7. The salt spreader unit exhibited significant corrosion; the CMA unit remained free from rust.

FURTHER RESEARCH

The results from the two winters' field trials have shown that CMA is an effective deicer on both freeway and low-volume roads under the relatively mild conditions of the Niagara Peninsula. Further research is required to determine the optimum application rate for CMA and to evaluate its performance under conditions of lower temperatures, higher snowfall, and on two-lane highways with traffic volumes more representative of highways in Ontario.

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1987–1988 City of Ottawa, Ontario, Canada Deicer Field Trials

G. B. HAMILTON, W. M. MINER, AND J. SIMMONDS

An earlier alternative deicer assessment study conducted for the city of Ottawa by Sypher:Mueller International Inc. recommended calcium magnesium acetate (CMA) and sodium formate (NaFo) for further evaluation in a set of winter-long urban field trials. Although this program encompassed associated subject areas—such as a citywide public opinion survey, an environmental assessment of NaFo, CMA, and road salt (NaCl), and an assessment of imposing a Canadian Standards Association standard for upgraded parking garage construction into a city bylaw—this paper only summarizes the technical evaluation of the effectiveness of each deicer: CMA, NaFo, and NaCl. The environmental assessment addressed current research being conducted by other organizations on the impact of all three deicers on soil and vegetation, aquatic biota, water quality, vehicle corrosion, structures, and health and safety. The field trials involved a vehicle instrumented with an electronic decelerometer which was dispatched during storm conditions over a controlled route of city of Ottawa roads to gather quantifiable data (in percent g deceleration) vehicle braking performance on deicer effectiveness. It was found that both CMA and NaFo are effective chemical deicers; however, both lag in speed of effect relative to salt to varying degrees. The residual effect of any of the three deicers tested appeared to be negligible in an urban bare pavement policy environment. The application factors relative to that of road salt were confirmed to be 1.0 for NaFo and 1.6 for CMA.

The pursuit of alternatives to sodium chloride (NaCl) for snow and ice control has grown dramatically in recent years, and several U.S. state governments, provincial governments, the city of Ottawa, and private agencies are actively exploring alternatives.

In response to this need for an evaluation of alternatives to NaCl, the city of Ottawa contracted Sypher:Mueller International Inc. An initial deicer assessment study identified calcium magnesium acetate (CMA) and sodium formate (NaFo) as promising alternatives. Preliminary field trials with both CMA and NaFo were promising. However, to be confident that these alternative deicers are effective, safe, and environmentally sound in an urban environment, a more extensive program was initiated for the 1987–1988 winter. This program included

- A full season of field trials with a vehicle instrumented with an electronic decelerometer gathering data on the effectiveness of CMA, NaFo, and NaCl;
- A survey of public attitudes toward salt damage and willingness to pay for potential gains resulting from the use of alternatives;
- An examination of the impact of passing into bylaw the draft Canadian Standards Association specification for salt resistant structures;
- A benefit-cost analysis on the economic impact of using the alternative chemicals; and
- An environmental assessment of NaCl, CMA, and NaFo as a deicers.

However, it is the actual field trials data gathering and the associated analysis of deicer effectiveness that is the subject of this paper. The benefit-cost exercise is also summarized.

FIELD TRIALS PREPARATION

The effectiveness of CMA, NaFo, and NaCl was measured using an electronic decelerometer installed in a dedicated test vehicle and a predefined test procedure over a controlled route of city streets. This data was averaged to determine the effectiveness of each deicer. This section of the report describes each of these elements in greater detail.

Test Instrument—Electronic Decelerometer

The decelerometer was equipped with a high-speed microprocessor utilizing electronics technology to achieve low power consumption, wide operating temperature range, and accurate results. Mounted on top of the decelerometer was an eight-character liquid crystal display used for communicating the test results and various messages to the operator. The decelerometer used an elimination algorithm to determine the deceleration a vehicle experienced when the brakes were applied. The decelerometer required the vehicle deceleration to remain constant for a minimum of 0.25 sec for it to have recorded that value as a valid stop.

The elimination algorithm used by the decelerometer was activated as soon as the brake was applied. The decelerometer measured the vehicle deceleration every 2.4 msec until 16 values had been acquired. These readings were averaged and compared to the average of the previous 16 readings. If the difference was less than 6 percent of the current value, the decelerometer assumed constant deceleration had not been reached; all measurements acquired to that point were cleared and the algorithm was restarted.

When the brakes were released, the algorithm stopped. If less than 96 valid, consecutive measurements were recorded, the decelerometer did not display any value; instead it displayed ":ERROR" to indicate an invalid stop. After the max-

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imum number of deceleration values had been recorded, the decelerometer automatically printed the values, the average of the values, and the date and time the tests were performed.

Test Routes

Two skid friction test routes were defined at the onset of the winter: a low-traffic-volume circuit (Pleasant Park) and a high-traffic-volume circuit (Smyth Road). Both routes were selected for several common reasons:

1. The proximity to a winter maintenance yard with weigh scales made it possible to determine exact weights of deicer spread.
2. The historical traffic data indicated uniform traffic flow throughout each deicer test section.
3. The length of each route was long enough to accommodate a number of skid friction test patches, which makes possible (a) a large number of points per deicer per test loop for averaging purposes, (b) reviewing of test patches per loop to confirm repeatability of results, and (c) allowing the test vehicle enough room to perform test patches away from the junction of deicer sections in order to minimize the effect of "tracking."
4. The uniform direction of the route (east-west) eliminated the wind direction variable from the deicer comparison.
5. The small number of peripheral salt beats feeding onto the test route minimized chemicals from "tracking" onto other deicer test sections and skewing the test results.

Pleasant Park Route—Low Volume

The low-volume route used for the trials was Pleasant Park, a two-lane, low-speed (40 kph), low-traffic residential street with an average daily 12-h traffic level (7:00 a.m.–7:00 p.m.) of 4,047. The test vehicle performed 25 predefined skid test patches per test loop: 4 patches per deicer per direction, plus 1 final skid test on an adjacent untreated section of road. The CMA test section was 1.21 km in length, the NaFo test section was 1.98 km (including the two feeder salt routes), and the NaCl test section was 1.25 km.

Smyth Road—High Volume

The high-volume route used for the trials was Smyth Road, a four-lane, moderate speed (60 kph), high-volume commercial road with an average daily 12-h traffic level (7:00 a.m.–7:00 p.m.) of 17,167. In order to minimize the interruption of traffic flow, the test vehicle was limited to executing 18 predefined skid test patches per test loop: 3 patches per direction per deicer. No adjacent untreated section was tested. The CMA test section was 2.2 km in length, the NaFo test section was 1.5 km, and the NaCl test section was 2.6 km.

Test Vehicles

Five vehicles were dedicated to the project: a skid test vehicle, a warning van, and three dedicated spreader trucks. The test vehicle was a 1984 Ford LTD [Figure 1(a)] instrumented with digital Tapley meter [Figure 1 (b)]. A warning van trailed the skid test vehicle during testing events to discourage regular traffic from following the test vehicle close enough to create an accident situation. A typical spreader truck used is shown in Figure 1(c).

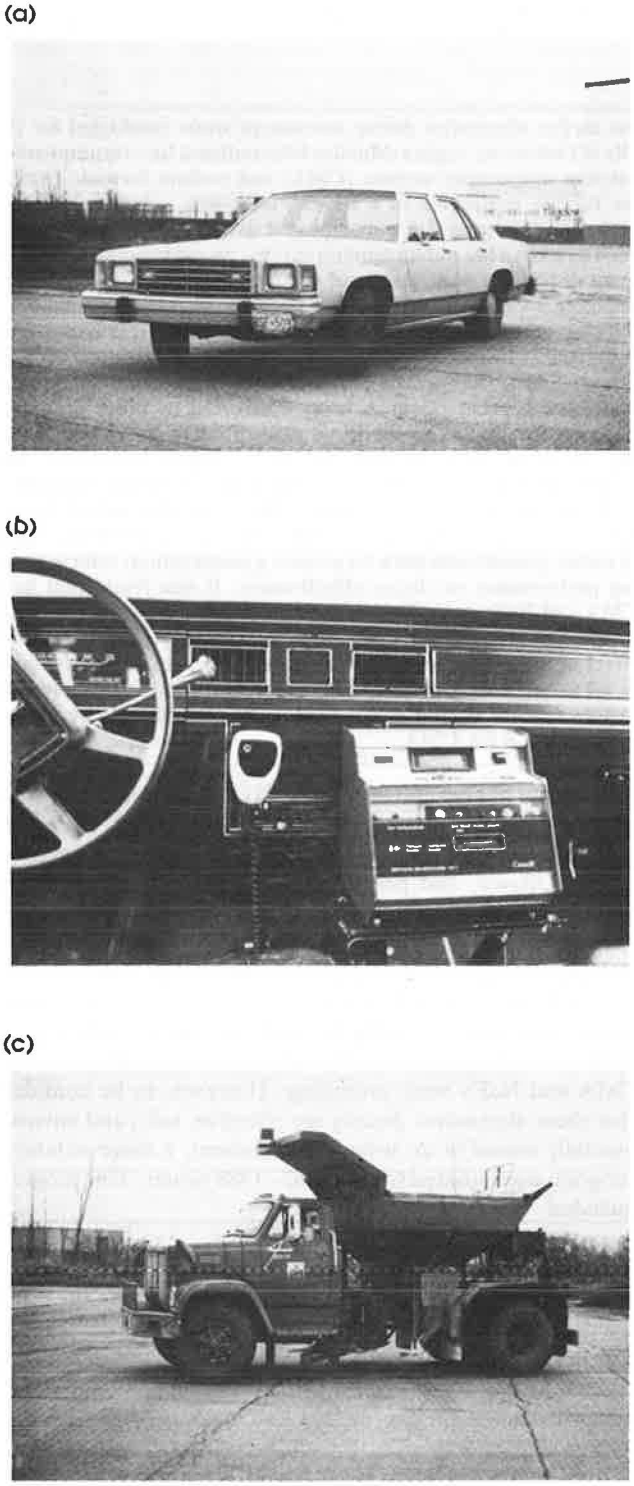


FIGURE 1 (a) Test vehicle, (b) digital decelerometer, (c) spreader truck.

Test Procedure

The test procedure used by the test team throughout the winter is summarized as follows:

1. Storm confirmation by the city of Ottawa;
2. City contacts spreader drivers, test vehicle driver, and the warning vehicle driver;
3. Spreader drivers weigh loads and record weights before dispatching from yard;
4. Spreader drivers also agree on and record start time for spreading the deicer sections before dispatching;
5. Test vehicle and warning vehicle meet at the last skid test patch on the route of interest before initiating skid tests;
6. Spreader trucks weigh loads and record weights after stripping their respective sections; and
7. Skid test patches were continued until the road conditions stabilize, as seen by the actual skid test results (all skid test patches were performed with the test driver initiating the brakes after attaining a speed of 40 kph).

Analysis Procedure

Data was digested from three sources:

1. Deicer usage data—this data included date, spread start time, amount spread, and distance (2-lane km) of road the deicer was applied to for each deicer application. The spreader drivers supplied this data after each storm.
2. Skid friction data—this data included a time stamp of each skid friction test loop and a printout of the 25 predefined test patches (in percent g deceleration) for each storm. The test vehicle drivers supplied the electronic decelerometer printouts after each storm.
3. Weather data—this data included hourly ambient dry bulb temperature readings (°C), wind speed (knots), storm classification (i.e., light snow, freezing drizzle), and the time of day of each reading. This information was obtained from Environment Canada in the form of a Surface Weather Record.

The data from each of these three sources was entered into a database format using dBase III+. Three dBase III+ routines were written to reduce the raw information and to display this information in a legible, usable report format:

1. Deicer usage report—this routine produced a storm summary and a winter summary to date. The storm summary displayed

- Storm date,
- Storm time (24-hour clock),
- Storm number,
- Applications required,
- Application rate per deicer (kg used/2-lane km),
- Application factor (application rate of alternative/application rate of NaCl), and
- Deicer used (kg used/2-lane km).

The winter-long summary table displayed the same headings as the storm summary, with averages and totals reflecting each chemical's use throughout the winter to that date.

2. Skid friction report—this routine produced an average skid friction reading (percent g deceleration) per deicer and the number of valid stops included in that average for each test loop during the storm. Also contained on the printout were directional comparisons (eastbound skid friction averages versus westbound skid friction averages) for each deicer per test loop.
3. Weather report—this routine simply displayed the deicer application number, time, temperature (°C), wind speed (kph), and storm class at the time of each deicer application.

The information produced from each data reduction routine combined to produce a deicer braking force comparison plot used to evaluate the relative performance of each deicer. The plot tracked the performance of each deicer in percent g braking force deceleration as a function of time from the deicer application.

FIELD TRIALS ANALYSIS

The 1987–1988 City of Ottawa Deicer Field Trials were a unique set of tests where alternative chemical deicers were evaluated in a winter-long urban environment. The trials also appeared to be the first set of field tests to use a skid friction measurement device to gather quantifiable data on the performance of deicers in order to verify visual field observations. As a result, even though the original set of proposed tests only included the low- and high-traffic volume skid friction tests, the city and the project team remained flexible enough to pursue additional, alternative tests to further explore specific deicer behavior. As the field trials progressed, this appeared to be the case; several other subject areas became worthy of testing and analysis. In total, seven areas of discussion were included within this section:

- Low-traffic-volume skid friction tests,
- Directional skid friction comparisons,
- Single-lane skid friction cross-sections,
- Particle gradation tests,
- Deicer residual effects,
- High-traffic-volume skid friction tests, and
- Specific storm correlations.

Supporting the discussion and results of these seven subject areas are the data collected from 53 storm events, 100 deicer applications in all. A total of 88.3 tonnes of CMA was spread over the winter, compared with 60.8 tonnes of NaFo and 53.1 tonnes of NaCl. The NaFo initial target application rate in kg/km was 1.0 times that used for NaCl, and the application rate for CMA was 1.6 times that used for NaCl. These application factors of 1.0 for NaFo and 1.6 for CMA were determined through past field trial experience. Of the 53 storms, the skid tests vehicle and the electronic Tapley meter monitored the deicer performance in 28 storms. These 28 storms provide the foundation for the remaining discussions.

Low Traffic Volume Tests

Of the 28 storms monitored by the skid friction device, 21 compared the three deicers on the low-traffic-volume route.

These 21 sets of test results were then separated by storm temperature range into four groups:

- Greater than 0°C (greater than 32°F),
- 0°C to −5°C (32°F to 23°F),
- −5°C to −10°C (23°F to 14°F), and
- Less than −10°C (less than 14°F).

One set of test results which best represented the target deicer application rates was then selected from each temperature range. These four deicer braking force comparisons are shown in Figures 2(a) through 2(d). Figure 2 tracks the absolute performance of each deicer; in order to emphasize the relative performance between the two alternatives and salt, a second set of graphs was generated to display the percentage difference in performance between CMA and NaCl and between NaFo, and NaCl. The resultant plots are shown in Figures 3(a) through 3(d).

On both set of graphs, one point on the graph was arrived at by averaging eight skid friction test patches per deicer per loop. Therefore, one or two invalid or aborted skids per test loop had a minimal effect on the overall trends in performance produced by each chemical.

Figures 2(a) through 2(d) indicate a significant performance improvement from the untreated test section to any chemically treated test section for all temperature ranges. The salt test section, however, consistently showed a better performance than the NaFo test section. Similarly, the NaFo test section consistently showed a better performance than the CMA test section.

Directional Comparison

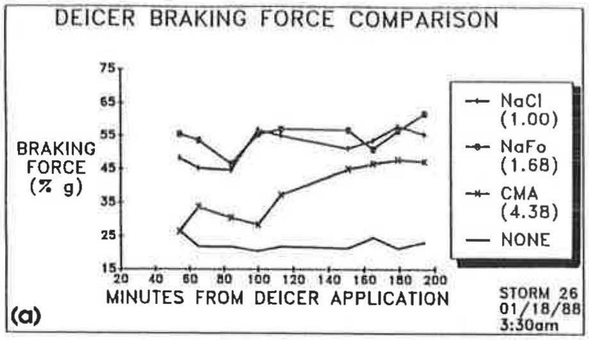
In order to verify that there were no unexpected anomalies in the traffic flows on the Pleasant Park loop, a directional analysis was performed on the first 10 monitored storms. Tests encompassing both a.m. and p.m. rush hour periods were analyzed to detect any directional dependencies.

Figure 4 shows both the eastbound and westbound skid test results for each deicer during Storm 9. Storm 9 began at 5:15 a.m. and continued until approximately 3:00 p.m. the next afternoon. This storm was a particularly long test, running over 10 hours. Although small differences can be seen in each graph, for the most part the eastbound skid friction averages tracked quite well with the westbound skid friction averages. The differences could be a result of

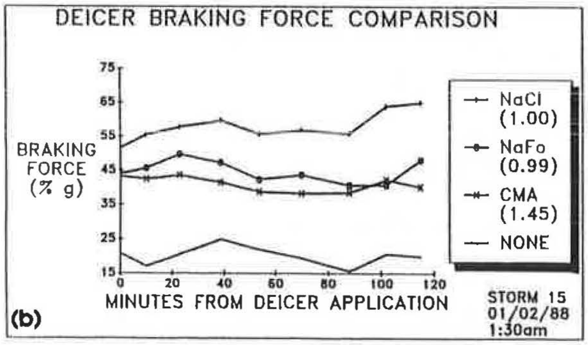
- Slightly increased traffic flow due to the morning rush hour,
- Cars temporarily parked on the side of the road forcing one direction of traffic out over the center line of the road, or
- Cars temporarily parked on the side of the road forcing the spreader truck driver out over the crown of the road.

It was assumed for the duration of the field trials that the eastbound and westbound skid friction readings tracked reasonably well and would be averaged to form a single skid friction number representative for that deicer test section. Figure 5 supports the similar conclusion with skid friction data from Storm 3, which included the evening rush hour period.

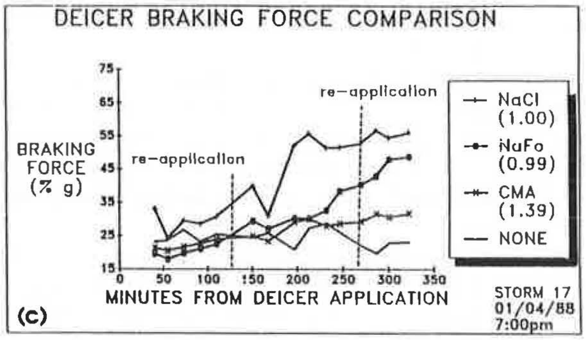
TYPICAL STORM FOR > 0 deg C



TYPICAL STORM FOR −5 deg C to −10 deg C



TYPICAL STORM FOR 0 deg C to −5 deg C



TYPICAL STORM FOR < −10 deg C

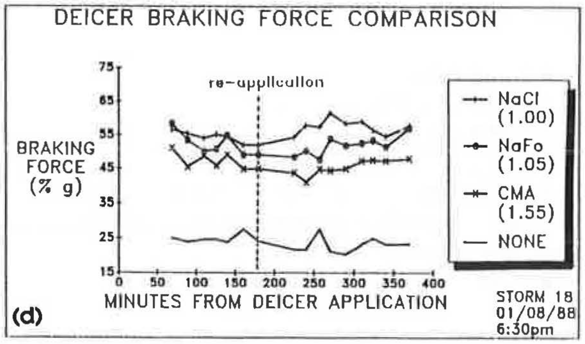
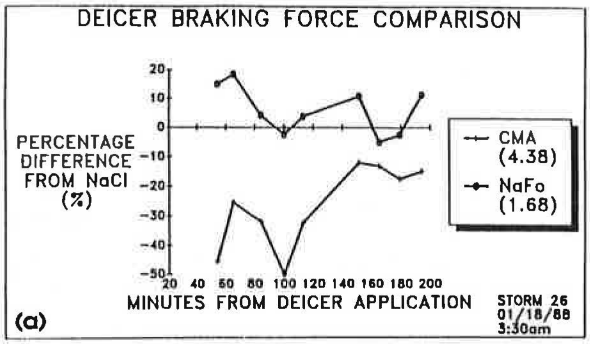
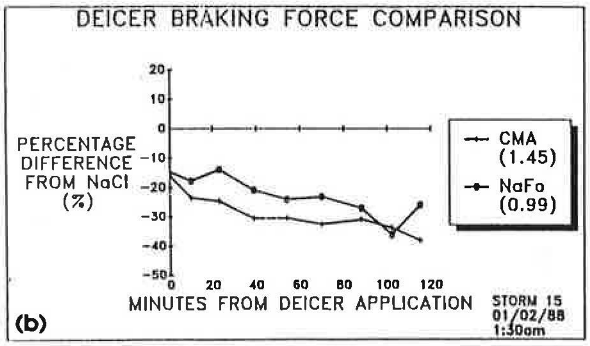


FIGURE 2 Braking performance at different temperatures.

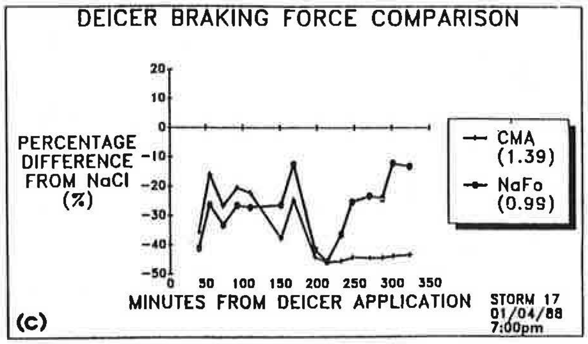
TYPICAL STORM FOR > 0 deg C



TYPICAL STORM FOR −5 deg C to −10 deg C



TYPICAL STORM FOR 0 deg C to −5 deg C



TYPICAL STORM FOR < −10 deg C

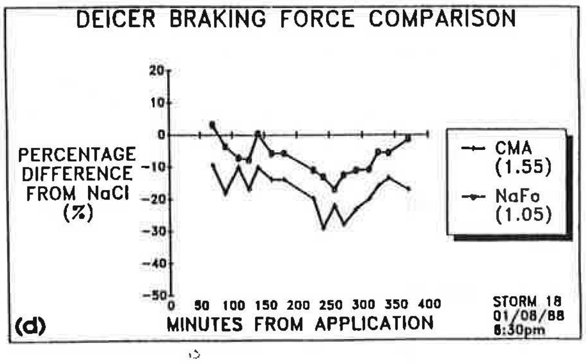


FIGURE 3 Deicing performance of CMA and NaFo compared with NaCl at different temperatures.

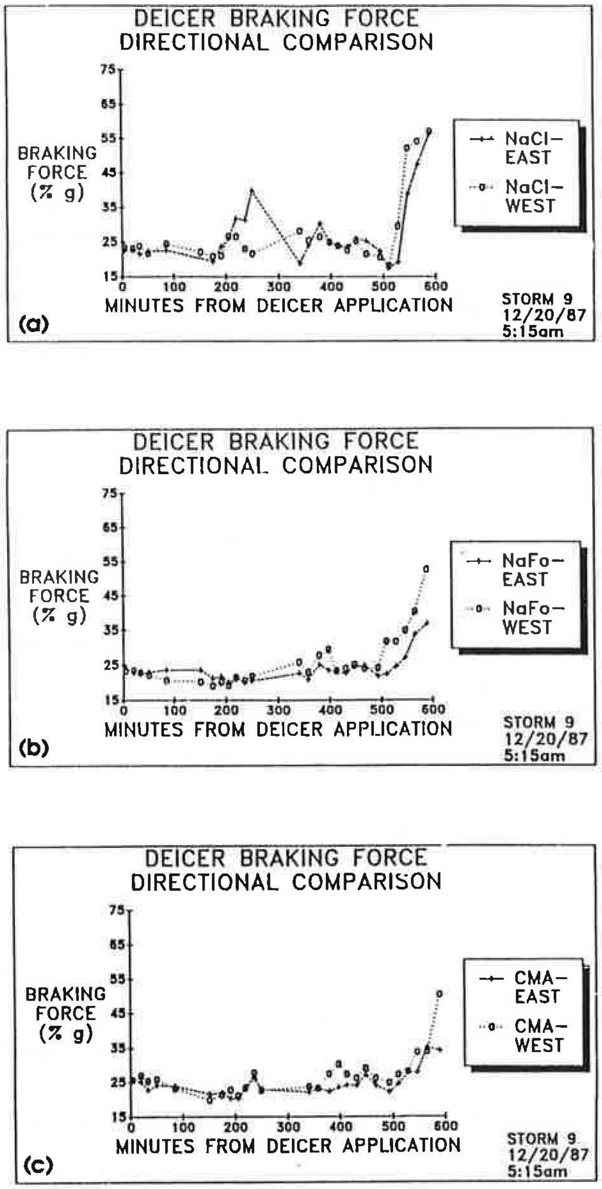


FIGURE 4 Comparison of eastbound and westbound skid test results for a.m. rush hour: (a) NaCl, (b) NaFo, (c) CMA.

Single Lane Cross-Sectional Tests

After some 26 storms the test team noticed that, even though the alternatives performed adequately in the skid friction tests to date, they did not appear to melt the snow "curb to curb" in the same manner as NaCl. Although, for the most part, cars will be running on the cleared tire paths in the center of each lane, there will be instances where a car is forced into a corrective maneuver outside the cleared tire paths. For example, a car parked on the side of the road would force the traffic out onto and over the center of the road. If sudden braking action was required at this point, the braking action would occur on a slushy section of the road. This was one reason why the city of Ottawa has adopted a "bare pavement policy."

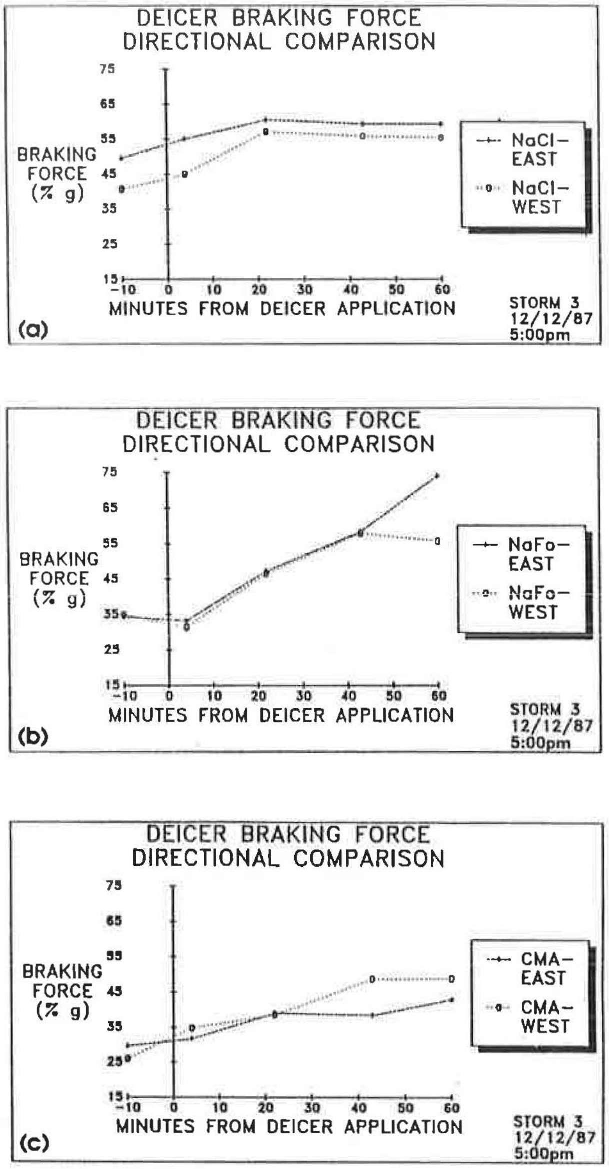


FIGURE 5 Comparison of eastbound and westbound skid test results for p.m. rush hour: (a) NaCl, (b) NaFo, (c) CMA.

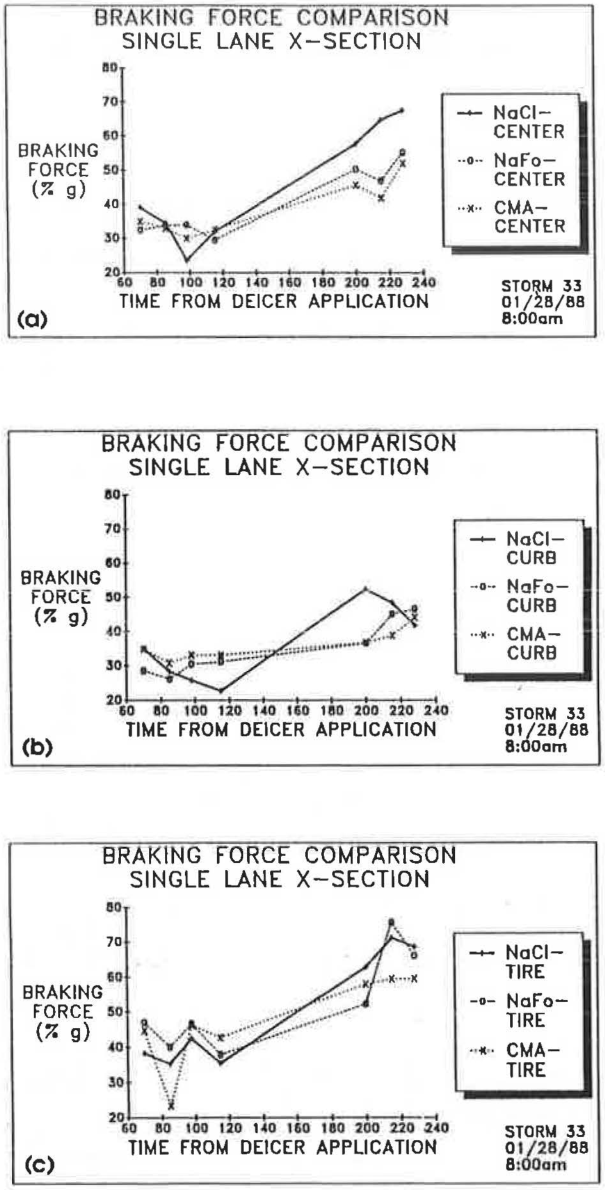


FIGURE 6 Comparison of single lane cross-sectional skid tests: (a) center, (b) curb, (c) tire.

In order to better understand this situation, cross-sectional skid friction test patches were conducted in a number of storms. The test loop was reduced to three test patches per deicer per direction. One test patch was performed as close to the shoulder as safety would allow the right tire to go. One test patch was performed where the normal traffic flow had cleared the tire paths, and the final test patch was performed as close to the centerline as safety would allow the left tire to go. Each point on these graphs now represents the result of an average of two skid friction test patches as opposed to eight on the graphs in the previous discussions.

Figures 6(a), (b), and (c) are typical results for a storm where the cross-sectional procedure was used. Figure 6(a) shows that the NaCl test section attained a higher center line skid friction reading than the NaFo and CMA test sections. Similar results occurred for the curbside test patches [Figure 6(c)]: the NaCl test section reached a higher skid friction reading than the NaFo and CMA test sections. However, in the skid test patches performed in the tire tracks, the NaFo test section achieved the highest skid friction reading. The tire paths test patches produced slightly closer results between all three deicers than did the curbside test patches or the centerline test patches.

Upon further discussion with the two alternative deicer manufacturers it was postulated that neither alternative possessed the distribution in particle size that NaCl displayed. This wide range of particle size was required for better overall melting action. This phenomenon is discussed in greater depth in the next section.

Particle Gradation

Upon closer examination of the CMA and NaFo test sections during a storm, it was discovered that the alternatives were laying dormant in the slush.

The NaFo gradation was a large uniform-sized particle (see Figure 7). With its weight and melting abilities, the NaFo particle had little trouble penetrating the snow pack to the road surface. However, once on the road surface this large particle no longer was in contact with the snow pack. The particle essentially had nothing to react with. The results of a sieve analysis performed on each deicer are shown in Figure 8. This plot illustrates the percent weight of each deicer sample that passed through various sized screen apertures.

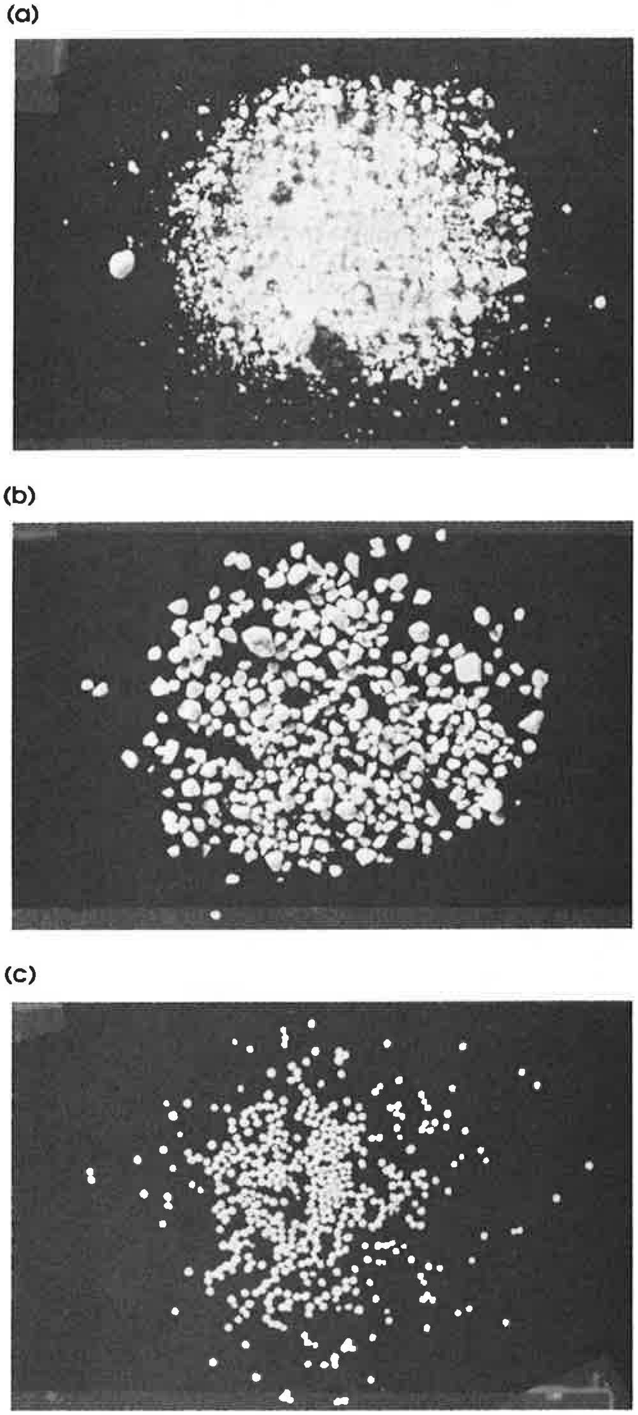


FIGURE 7 Size distribution of deicer particles: (a) NaCl, (b) NaFo, (c) CMA.

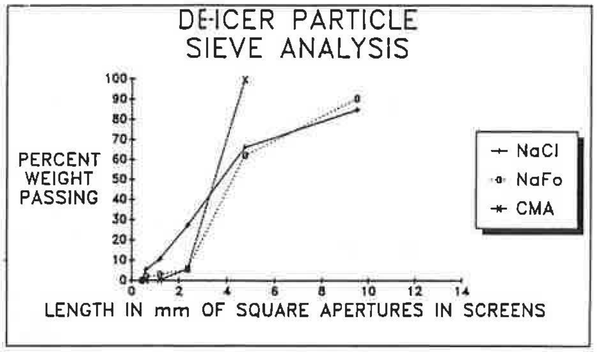


FIGURE 8 Deicer particle sieve analysis.

NaCl, on the other hand, contained a wide range of particle sizes. NaCl contained large particles to penetrate the snow pack to the road surface, which started a brine forming, as well as a range of smaller particles. This combination of particle sizes gave salt a better overall melting action.

CMA experienced the same time lag in its ability to produce curb-to-curb melting action as NaFo. The CMA gradation was also a uniform size. However, the CMA particle was much smaller. This combination of uniform and small particle size resulted in an increased period of time required to clear the road curb to curb.

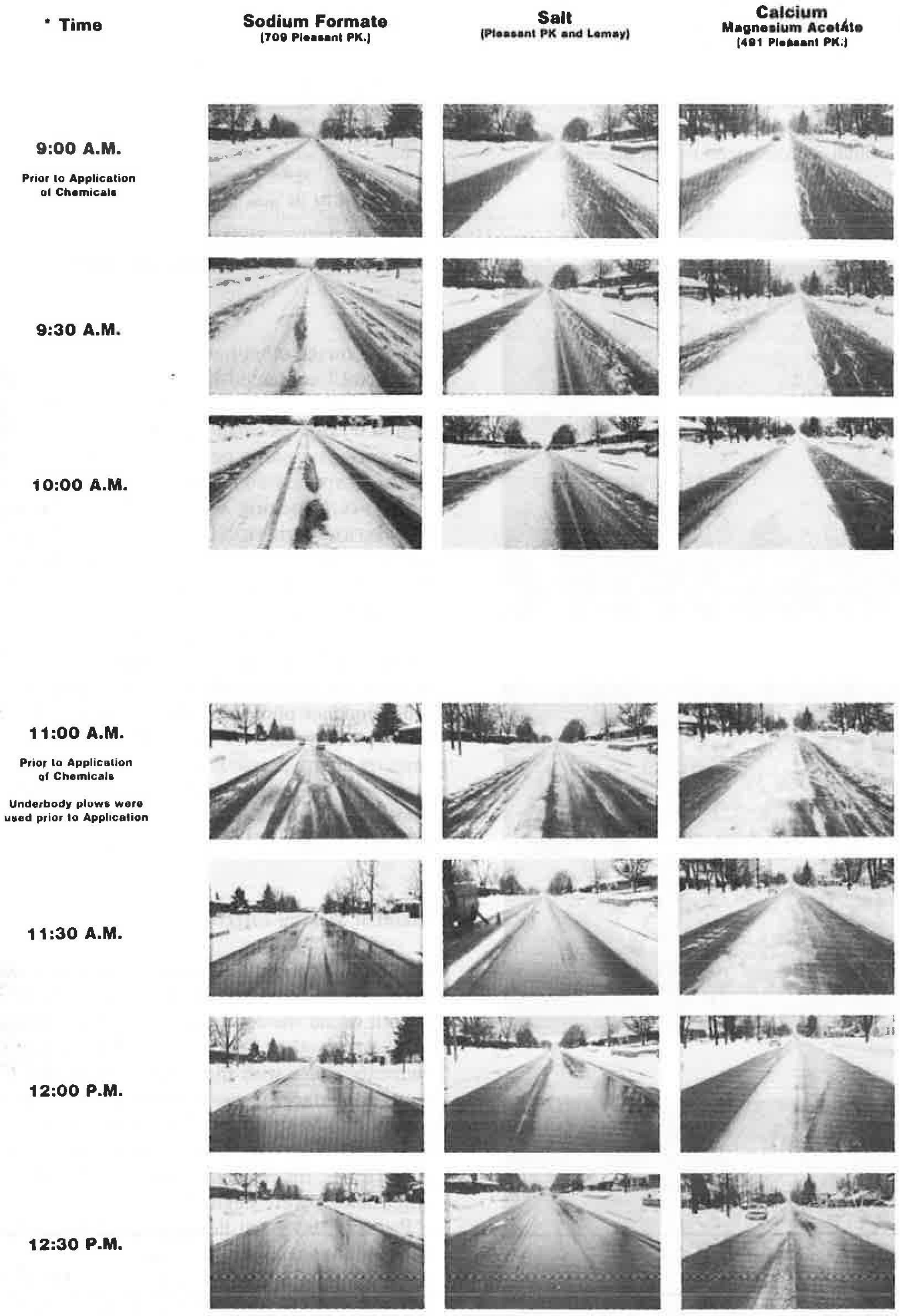
As final evidence to support the time-lag experienced by the alternative deicers (relative to NaCl), photographs were shot at even time increments over the course of a storm. These time sequence photos are shown in Figure 9 (for low-volume traffic) and Figure 10 (for high-volume traffic). Again, in support of the previous discussion, Figure 9 shows that the NaCl and NaFo cleared the road, curb to curb, after 2 hr. The CMA test section still showed a center slush 3.5 hr into the photographic sequence. Figure 10 illustrates similar results.

Residual Melting Effects

Residual deicer melting effects consist of residual or unused chemicals remaining on the road surface from one storm that benefit or aid the road conditions of a following storm.

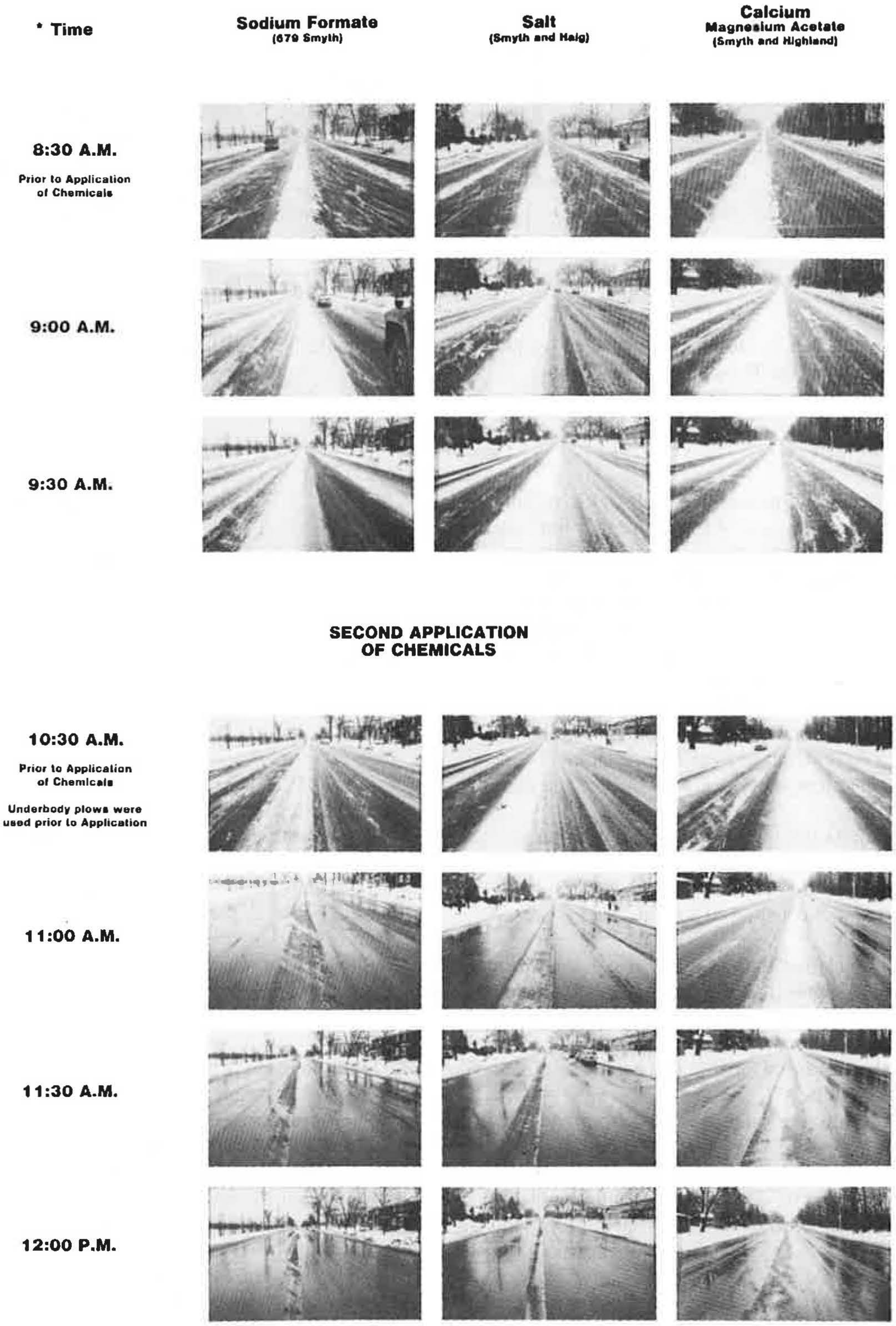
Based on other field trials conducted with CMA and our own experience with the "sticky" brine that CMA forms on the road surface, it was envisaged that CMA would possess some storm-to-storm benefits. However, based on this set of field trials in an urban environment where a bare pavement policy exists, the residual melting effects of CMA and the two other deicers were negligible.

Proof of this point lies in a storm where the skid friction test team happened to have started their testing ahead of the deicer spreader trucks (see Figure 11). This test duration was 400 minutes. The horizontal scale on the graph was truncated to better reproduce the first two hours of the test. The first test patch, 20 minutes before the first deicer application, shows very little difference between the skid friction resistance of the deicer test sections. The side road where the single untreated test patches were taken shows a slightly higher skid resistance reading. This was due to the fact that there was no measurable traffic on the untreated section and the road surface would remain as dry snow. Dry snow inherently possesses a higher



* Times given are approximate to within minutes

FIGURE 9 Time sequence photographs of deicer performance: Pleasant Park; March 2, 1988; low-volume traffic; temperature −14°C; winds SE at 9 km/hr.



* Times given are approximate to within minutes

FIGURE 10 Time sequence photographs of deicer performance: Smyth Road; March 2, 1988; high-volume traffic; temperature −14°C; winds SE at 9 km/hr.

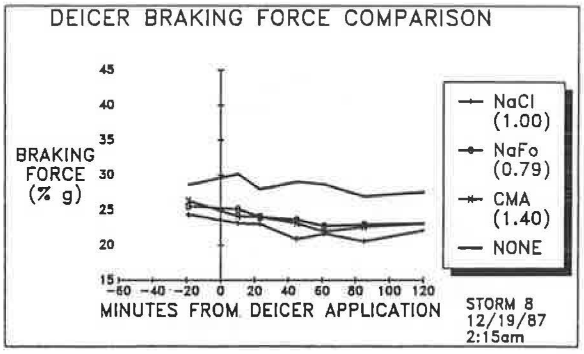


FIGURE 11 Residual skid resistance effect.

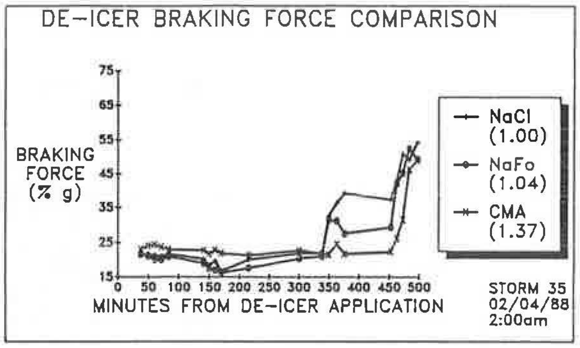


FIGURE 12 Storm 35 deicer braking performance.

skid resistance than the wet or slushy snow created by the higher volume of traffic on the Pleasant Park test loop.

High Traffic Volume Tests

Only two storms were monitored on the high-traffic-volume route, Smyth Road. Both of these storms were four and five deicer application storms that lasted upwards of ten hours. Storm 35 produced overall application rates slightly lower for the CMA test section than was targeted for the project (1.4 versus the target of 1.6). All deicer test sections tracked comparably until the morning rush hour. At that point the heavier traffic increased skid friction resistance on the NaCl test section to the highest reading (see Figure 12). NaFo obtained the second-highest skid friction, and the CMA test section experienced the lowest skid friction of all three sections. These results were quite consistent with the low-traffic-volume findings to date.

However, in Storm 34 the targeted CMA application rate was reached with quite a different result. The CMA test section attained the highest skid resistance once the evening rush started. The NaFo and NaCl showed similar skid resistance profiles (see Figure 13).

Thus, it can be concluded that, when CMA is spread in adequate volumes (1.6 times that required for NaCl) at temperatures above −10°C, CMA performs quite comparably with NaCl if there is an alternative snow removal mechanism. The snow removal mechanism in this case was the higher volume of rush hour traffic.

Although these results are quite different from the low-traffic-volume tests, they are consistent with findings from other field tests. CMA seemed to be more of a snow and ice "de-bonder" than a "melter." Thus, CMA required a mechanism for snow removal, which could either be a plow blade or high traffic volumes, to push the snow to the roadside. Also, CMA appeared to be reasonably effective when applied at the pavement-snow interface as an anti-icer. When applied on top of a snow pack, CMA required substantially more time.

Storm Correlations

Midway through January the city of Ottawa operations staff, participating directly in the deicer trials, began documenting their visual observations of the deicer test section road conditions during storms. These visual observations were initiated for three reasons:

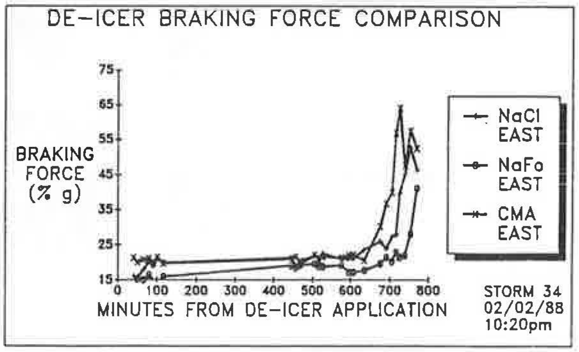


FIGURE 13 Storm 34 deicer braking performance.

- To compare visual observations to the actual skid friction measured between the tires and the road surface;
- To further investigate or document the earlier findings that the alternatives provided a skid resistance comparable to salt but did not clear the entire road of slush and snow; and
- To provide some documented log of storms during which, for coordination or mechanical problems, the test team was unable to monitor the storm with the electronic decelerometer.

The time at which specific observations were noted was plotted and compared with the electronic decelerometer results. The findings of this exercise were that the plotted visual observations were not always consistent with the electronic decelerometer results. Figures 14(a) through 14(d) shows examples.

Storm 26 [Figures 14(a) and 14(b)] indicates a good correlation between the visually observed road conditions and the skid friction measurements. The visual observation plot clearly shows CMA lagging in effectiveness throughout the test, as does the braking force comparison. Similarly, both graphs reflect the closeness in effectiveness between NaFo and NaCl.

However, Storm 30 [Figures 14(c) and 14(d)] does not provide consistent results. The visual observation plot shows CMA clearly lagging in effectiveness as compared with the other deicers. The braking force comparison plot shows NaFo as the deicer clearly lagging in performance for all but the final test loop.

Although visual observations complemented the use of the electronic decelerometer, it was felt that visual observations

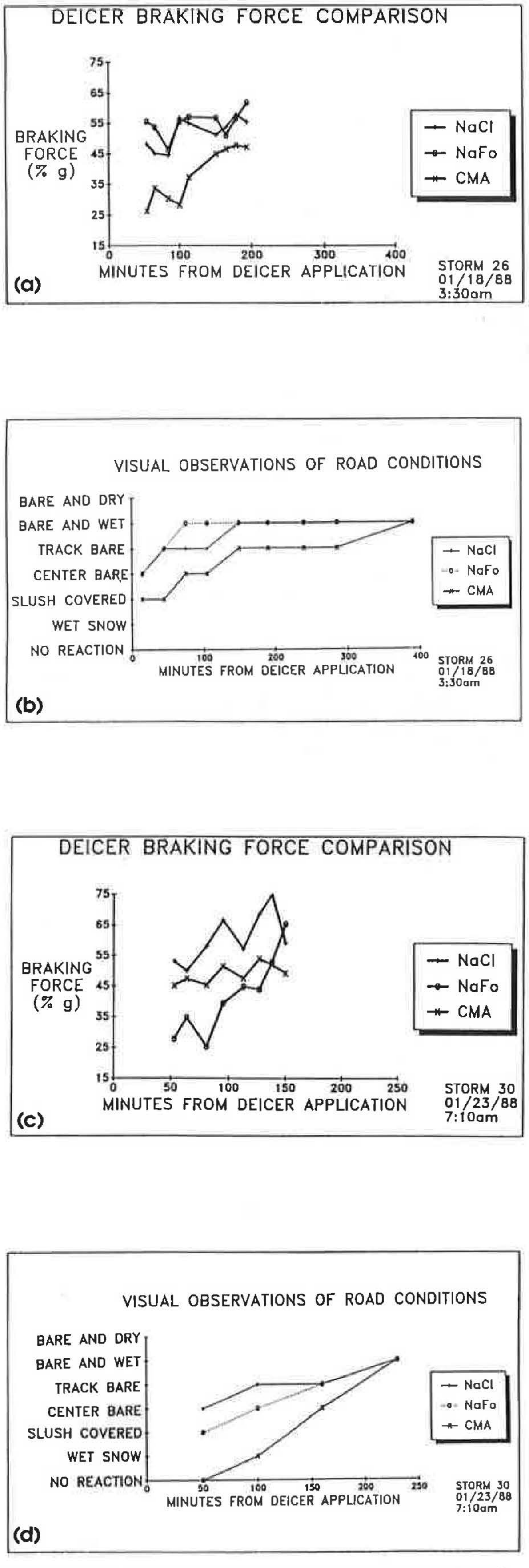


FIGURE 14 Comparisons of decelerometer results and visual observations: (a) and (b), Storm 26; (c) and (d), Storm 30.

alone did not tell a consistently accurate story. In addition, although the electronic decelerometer did provide measurable results in this set of field trials (e.g., the skid resistance between a car's tires and the road surface in hazardous conditions), it was the visual observations that helped to identify the inability of alternative deicers to produce a total melting effect while still producing comparable skid friction results.

BENEFIT–COST ANALYSIS

In comparing alternative chemical deicers to NaCl, the benefits and costs were examined from an incremental perspective; that is, what were the extra benefits and what were the extra costs.

Many of the benefits of using alternative deicers are very difficult to quantify: reduced damage to groundwater and vegetation and reduced impact on human health as a result of lowering the sodium content of drinking water. It was possible, however, to quantify reduced automobile corrosion and reduced damage to bridges and parking structures. Drawing on data from other studies, it appeared that the use of noncorrosive deicers would reduce automobile depreciation by approximately \$146/year/household based on the vehicle/household ratio in Ottawa. The effect of reduced damage to bridges and parking structures was calculated to be approximately \$154/year/household. This effect would not be recognized directly by the taxpayers but would flow through to them as a result of reduced provincial taxes, municipal taxes, parking charges, rents, and condominium fees.

The costs of using alternative deicers would be significant. In the city alone the use of CMA would add \$46 million/year to the City budget, while the use of NaFo would add \$11 million/year. These costs are based on an average annual winter salt use by the city of Ottawa of 24,000 tonnes, a salt cost of \$36/tonne, a CMA cost of \$1200/tonne, and a NaFo cost of \$480/tonne. On a household basis this translates to an additional cost of \$342/year for CMA and \$82/year for NaFo.

Unfortunately, these benefits would not be realized unless the entire region was salt free, so similar costs would be borne by neighboring municipalities. The annual incremental benefits and incremental costs of using an alternative chemical are as follows:

Description	*Amount (millions of dollars)*	*Amount (dollars per household)*
Cost		
Incremental cost of CMA	46.3	342
Incremental cost of NaFo	10.9	82
Benefits		
Reduced automobile depreciation	19.4	146
Reduced structural damage	20.5	154
Total quantified benefits	39.9	300

This tabulation results in benefit-cost ratios of 0.88 for CMA and 3.66 for NaFo. Benefits related to reduced groundwater damage, vegetation damage, and health impacts have been quantified and are included in this calculation.

CONCLUSIONS

A detailed examination in an urban environment of the two alternative deicers (CMA and NaFo) led to the following conclusions:

- Both CMA and NaFo provide roadway deicing.
- NaFo lags in speed of effect relative to NaCl by up to 0.5 hr.
- CMA lags in speed of effect relative to NaCl by approximately 1 hr or more.
- For the gradation used in these field trials, both CMA and NaFo lag in their ability to melt snow and ice curb to curb in order to meet Ottawa's bare pavement policy.
- In a bare pavement policy urban environment, the residual melting effects (as determined by measuring skid resistance) of any of the three deicers tested appear negligible.
- The CMA deicer appeared to possess more of a debonding and anti-icing ability than a melting ability, as demonstrated by its much improved performance when high traffic volumes provided the mechanical removal of the snow.
- The endurance factor of all three deicers in the urban environment was near equivalent, as shown by the fact that in the majority of the storms all three deicer test sections had to have reapplications performed at the same times.
- Visual observations alone did not provide a consistent, accurate measure of surface friction.
- Electronic decelerometer readings did provide consistent, repeatable results for surface friction, but visual observations are recommended to flag any anomalies outside the tire–road surface interface.
- Because storms possessing higher than targeted application factors did not affect the relative effectiveness between alternatives, there appeared to be no reason to alter the previously published application factors (relative to that for salt) of 1.0 for NaFo and 1.6 for CMA.

RECOMMENDATIONS

- From a benefit-cost perspective and from the perspective of effectiveness, CMA is not recommended at this time for use as a deicer to achieve urban bare pavement policies. CMA should be considered as a deicer if it can be obtained for $1040 (Can.)/tonne FOB Ottawa or less.
- From a benefit-cost perspective and from the perspective of effectiveness, NaFo is recommended as a deicer to support urban bare pavement policies. However, effective use of NaFo as a deicer in Ottawa requires (a) satisfactory results of spalling and corrosion tests (which are currently under way) and (b) satisfactory results from environmental tests (which need to be undertaken), such as:

1. Soil lysimeter leaching tests;
2. Aquatic toxicity tests (i.e., short-term, static bioassays and long-term, renewal bioassays); and
3. Vegetation impact tests using NaFo in solution as irrigation water.

- Sucessful negotiations with local municipalities are required to move collectively to alternative deicers.
- Public awareness and public forum meetings are needed to confirm willingness to pay.

Publication of this paper sponsored by Committee on Winter Maintenance.

Field Deicing Comparison of Calcium Magnesium Acetate and Salt During 1987–1988 in Wisconsin

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During the 1987–1988 winter maintenance season, calcium magnesium acetate (CMA) and CMA-coated sand were applied to the northern half of a 7.5-mile section of four-lane freeway, US-14, located just south of Madison, Wisconsin. Road salt (sodium chloride) was applied to the southern half of the section for comparison purposes. The moderately severe winter, with 52.4 inches of snow during the application period, provided a good basis for comparison of the two deicers. In order to achieve "bare pavement" on US-14, 48 percent more tons of CMA and CMA-coated sand than salt were applied, based on lane-mile-adjusted driver estimates of material used. About one percent less total "effective" or pure CMA (i.e., excluding the weight of the sand) was required compared with salt. The CMA application required 70 percent more miles and 143 percent more hours compared with salt; however, some part of the additional CMA application effort can be attributed to the dedication of a truck to the CMA section while the salt truck had other highway sections to cover. Deicer performance measures were provided by subjective truck driver ratings and by objective field observations. As used in Wisconsin, CMA had distinct disadvantages in handling and transport and somewhat poorer deicing performance than salt, but CMA did provide at least a minimum level of deicing performance. Given the lower level of use of CMA-coated sand and satisfactory performance in all but the coldest conditions, additional research on the economic feasibility of more extensive use of CMA-coated sand may be warranted. Reductions in the cost of CMA-coated sand may be possible by producing the CMA locally and using locally available sand.

The Wisconsin Department of Transportation (DOT) contracted with Bjorksten Research Laboratories, Inc., during the winter of 1986–1987 to evaluate the use of calcium magnesium acetate (CMA) as an alternative to salt for road deicing. The research was conducted on a 6.6-mile section of US-14 in Dane County, just south of the city of Madison. CMA was applied to the southbound two lanes of the four-lane divided highway and salt to the two northbound lanes by the Dane County Highway Department (*1*).

Because the winter of 1986–1987 was unusually mild, with the lightest snowfall since 1981 and the mildest temperatures in 35 years, only about 100 tons of the 300 tons of available CMA was used. The mild temperatures provided limited opportunity to evaluate the effectiveness of CMA under a full range of winter temperatures. Also, 14 of the 18 snowfalls occurred during the morning hours so that there was more traffic on the northbound lanes (where salt was used) than on the southbound lanes.

For the research conducted during the 1987–1988 winter, the difference in the traffic flows was eliminated by using CMA in both directions on the northern section of US-14 from Badger Road to Irish Lane. Salt was used on the southern section of the four-lane divided portion of US-14, which ends approximately 5,650 feet south of County Highway MM.

For the 1987–1988 winter maintenance season, an estimated 120 tons of CMA and 77 tons of factory produced CMA-coated sand, for a total of 197 tons, were available. The application rates reported by the drivers showed that 110 tons of pure CMA and 85.5 tons of CMA-coated sand, for a total of 195.5 tons, were spread on the northern test section of US-14. Overall, the estimated stockpile tons were within 1 percent of the driver estimates of use. The drivers, however, underreported the CMA spread by 8 percent and overreported the CMA-coated sand used by 11 percent. A total of 127 tons of salt was spread on the southern portion of the test section. The purpose of this paper is to document the data collection procedures and present the results of the evaluation of the effectiveness of pure CMA and CMA-coated sand compared with road salt. A mixture of CMA and sand was not tested, primarily because salt-sand mixtures are not typically used on state highways in southern Wisconsin.

RESEARCH OBJECTIVES

The overall objective of the research was to compare the deicing effectiveness of CMA and CMA-coated sand with that of road salt under a wide range of winter environmental conditions in southern Wisconsin. The specific objectives of the research were the following:

1. To apply CMA and CMA-coated sand to a designated 3.8-mile section of US-14 in Dane County during storm conditions and to compare the deicing characteristics of the CMA with those of road salt applied to the adjoining section of US-14 south of the designated section;
2. To evaluate the results of the comparison treatments, including rate of application, timing of noticeable results, and overall effectiveness, and to modify the CMA treatments as warranted to achieve optimum road deicing results for the CMA (salt applications followed normal application procedures, which varied depending on conditions);
3. To identify specifically the elapsed time from the time of application to brine formation and to bare pavement;

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4. To monitor meteorological and pavement sensor data from the test site and correlate these data with the deicing field data;

5. To evaluate the effectiveness of CMA and salt as deicers as a function of temperature, traffic volume, snowfall rate, wind effects, and storm duration (overall CMA/salt application ratios were used as one measure of effectiveness);

6. To identify possible differences in effectiveness on concrete and bituminous surfaces; and

7. To identify possible causes of the darkening of concrete pavement that was observed in 1986–1987.

METHODOLOGY

The research methodology was designed to evaluate the effectiveness of CMA compared with road salt under actual winter storm and roadway conditions that were as similar as possible. Consequently, the roadway configuration shown in Figure 1 was developed. The 7-mile section of four-lane divided, fully access controlled freeway is located just south of the city of Madison, Wisconsin, in gently rolling terrain. It is constructed primarily of portland cement concrete (PCC) pavement with two short sections of bituminous concrete pavement. In order to equalize exposure to traffic, CMA was spread on the 3.84-mile northern section from Badger Road to the bridge over Irish Lane, while road salt was spread on the 3.65-mile southern section from Irish Lane to the end of the four-lane section south of County Highway MM. Operationally, the CMA truck continued spreading CMA southbound across the Irish Lane bridge to a crossover just south of the bridge. Northbound, the CMA truck crossed over the Irish Lane bridge and began spreading at the crossover on the north side of the bridge. The salt truck followed the same procedure to spread salt only on the northbound Irish Lane bridge. Both sections contain standard diamond interchange ramps of approximately equal length, which were treated with CMA and salt, respectively. Including the ramps, the salt section has a total of 15.4-lane miles, while the CMA section is 4.5 percent longer with 16.1-lane miles.

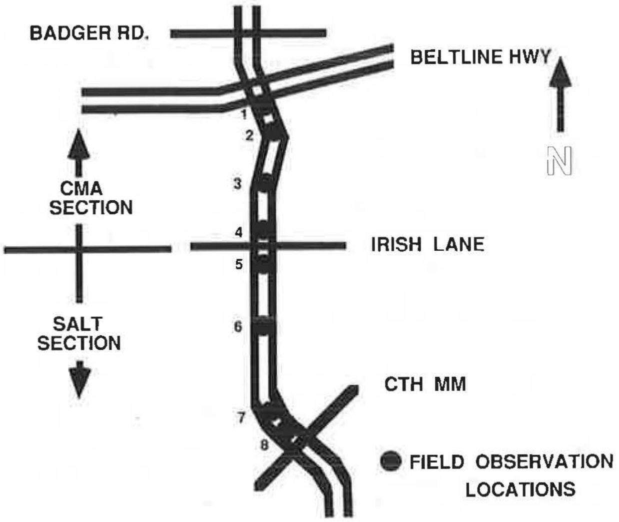

FIGURE 1 Map of US-14 test sections.

Two Dane County Highway Department trucks were dedicated to spreading CMA. The truck boxes were sealed to prevent the CMA from leaking out and full tarps were added to prevent the CMA from blowing out. One truck was used to spread pure CMA, while the second truck was reserved for CMA-coated sand. Two trucks were also assigned to cover the salt test section, but these trucks were also responsible for other sections of highway in the maintenance area. Only one truck at a time was used in both the CMA and salt sections. The drivers were instructed to use their best judgement in deciding when and at what rate to spread the CMA or salt.

While the truck drivers were asked to provide a subjective rating of the overall results of the CMA compared with salt, the primary source of deicer performance data was designed to be field data collected independently at key points. The field data were supplemented with weather and pavement temperature data from a special facility at the Irish Lane overpass, additional weather data from Truax Field in Madison, and traffic counts by lane at Irish Lane.

Initially, the field observations were to be supplemented with 35-mm slides of pavement conditions. Examination of test slides indicated that it was difficult to determine the condition of the snow on the pavement from the slides. Also, the time recording camera equipment needed to correlate the slides to the field observations was not available. Consequently, no further attempt to use 35-mm slides was made. Videotape, however, was used to document the overall test procedure, including the use of CMA under winter storm conditions.

DATA COLLECTION PROCEDURES

Driver Data

The drivers were required to record data on each application of deicer. The key data items obtained from the "driver's report form" are (a) the duration of each application, (b) the estimated miles spread, (c) the estimated tons of deicer used, and (d) the driver's opinion of the results—CMA versus salt on a three point scale of "better," "same," or "poorer." Data on the truck speed, auger setting, and ramps treated were also obtained for each application. The duration of the application does not necessarily imply that deicer was spread continuously during that period.

The "estimated miles spread," in general, was based on the length of the one-way sections covered times the number of passes. The additional miles travelled in covering the ramps were not generally included. Thus, the salt section drivers generally used six miles per "application" with the salt applied down the centerline to cover both lanes in one pass. In contrast, the CMA section drivers generally applied CMA to each lane individually, resulting in 16 miles spread based on a 4-mile section length.

In theory, given the auger calibration data, the amount of deicer used could be computed from the auger setting, the truck speed, and the actual miles spread. In practice, however, the driver's estimate of the tons of deicer used was not always consistent with the other data reported by the driver. The drivers were asked to estimate the tons used based on direct observation of the amount of deicer in the truck box at the beginning and end of each application. The CMA drivers frequently emptied their truck on one application, resulting in a precise estimate of the tons of CMA used. In contrast, the salt trucks typically made one pass ("application") and then worked on other highways before returning to make a second application.

Field Observations

Field observations of the results of the deicer applications were made by students at the eight locations shown in Figure 1. Observations were made in each direction, resulting in a total of 16 observation points with equal numbers in the CMA and salt test sections. Where appropriate, data for both the left and right lanes were collected.

The students used two cars provided by the Wisconsin DOT to travel along the test sections, recording data at each observation point. One round trip required about one-half hour. Thus, by starting the field data collection simultaneously at the northern and southern ends of the overall test section, field data could be obtained at 15-minute intervals for each observation point. For most storms, however, only one car was used, resulting in 30-minute intervals between field observations.

The observation points were selected to cover a ramp, PCC pavement, and bituminous concrete pavement for both the CMA and salt test sections in both directions. In addition, observations were made for the approach and the bridge deck at Irish Lane in order to permit direct correlation with the local weather station and pavement sensor data at Irish Lane.

The students initially collected data on (a) level of "action" of the deicer, (b) average of the left and right wheel track width in feet, (c) average snow depth outside the wheel tracks, (d) type of snow, (e) estimated level of application of the deicer, and (f) comments related to the depth of snow on the shoulder and the presence of drifting. Initial data collection efforts revealed that track width was not always relevant, particularly when only one set of tracks existed for the two lanes. Consequently, a "percent clear" data item was added to supplement and clarify the track width data.

The data on deicer "action" were recorded using the following codes: 1 = no action, 2 = penetration, 3 = brine-begin, 4 = brine-good, 5 = clear-wet, and 6 = clear-dry. The codes represent the full range of steps in the deicing process. First, as melting begins, some degree of penetration of the deicer is observed. At the next stage enough melting and mixing has occurred so that the consistency of the snow has changed (brine-begin), followed by the formation of slush (brine-good). Finally, the slush disappears (clear-wet) and the pavement dries out (clear-dry).

Weather, Pavement Surface, and Traffic Data

Data on air temperature, dew point, and wind speed and direction were available from a special facility located adjacent to the bridges at Irish Lane. The Irish Lane weather station also recorded pavement surface temperatures and moisture conditions for seven sensors located on the approaches and bridge decks of the Irish Lane overpass. An eighth sensor located in the ground 18 inches below Sensor 7 was not used in this research.

The weather station data were stored in computer files, with one file for each sensor. Whenever a change in a sensor condition occurred, the computer wrote all of the weather data plus the new data for that sensor to the appropriate file. A malfunction in the communications link resulted in unusable data for Storms 8 through 12 and Storm 14. For these storms air temperature data from the U.S. Weather Bureau Station at Truax Field in Madison were used. Data on total snowfall by storm were also obtained from the Truax Field weather station.

Traffic count data by lane were available from a continuous, inductive-loop automatic counter located at Irish Lane. The data were summarized by 15-minute intervals. The traffic counter was not functioning during the first storm (November 25).

DATA ANALYSIS

Overview

The basic characteristics of the 28 storms during the winter of 1987–1988 when CMA and CMA-coated sand were applied to US-14 are presented in Table 1. The winter provided a good test of the effectiveness of CMA because of the wide range of temperatures and substantial amount of snowfall. Through the end of December, 6 of the 12 storms had maximum air temperatures at or above the freezing mark, while minimum air temperatures were 24°F or above for all but one storm. During this same period, maximum pavement surface temperatures probably were at or above the freezing mark, although no data were available for the last five storms in December (Storms 8 to 12).

Pavement surface temperatures are critical in the formation of the ice-pavement bond. Both CMA and salt inhibit bond formation down to the 15 to 20°F range. Thus, while air temperatures during January and February were typically in the low 20s and below, temperatures at which CMA in particular is only marginally effective, maximum pavement surface temperatures were still 22°F or above for all but one minor storm. Thus, for at least part of all but one storm both CMA and salt could function as effective deicers, although the speed of deicing was slowed by the cold air temperatures. Mixing by traffic to bring the deicer-snow mixture in contact with the warmer pavement was critical to effective deicing. For most storms there was enough traffic in the right lanes to provide for substantial mixing. In the left lanes, however, traffic was generally much lighter.

Pure CMA was used exclusively through the end of December. With the advent of colder temperatures in January, CMA-coated sand was used almost exclusively until the available supply was exhausted on January 26. The remaining pure CMA was then used during the subsequent three storms with measurable snowfall, despite the limited effectiveness of the pure CMA given the low air temperatures. The pavement surface temperatures, however, were still high enough to permit some deicing to occur.

Driver Application Data

The two principal items of interest recorded by the truck drivers, the total deicer used and the rating of deicing effec-

TABLE 1 BASIC WEATHER, TRAFFIC, AND DEICER EFFECTIVENESS DATA BY STORM

STORM	DATE/DAY OF WEEK	TIME BEGAN	STORM DURATION (Hrs)	SNOWFALL		TEMPERATURE RANGE (F°)		PEAK TRAFFIC[a]		TOTAL DEICER		RATING BY:[b]	
				Inches	Water Equiv.	AIR (Hi/Low)	SURFACE[c] (Hi/Low)	SOUTH BOUND RL/LL	NORTH BOUND RL/LL	CMA (tons)	SALT (tons)	CMA DRIVER	SALT DRIVER
1	NOV 25/WE	2:30	2.5	3.0	0.21	32/31	34/27	--	--	4.5	4.0	2	2
2	DEC 2/WE	22:00	2.0	0.2	0.01	29/28	32/31	62/17	30/5	3.0	3.0	2	3
3	DEC 3/TH	6:15	5.6	2.5	0.28	30/30	34/29	62/15	188/137	9.0	5.0	3	3
4	DEC 6/SU	17:45	4.75	4.3	0.26	32/31	33/30	86/18	45/12	10.0	6.0	3	3
5	DEC 7/MO	4:30	2.0	0.2	0.06	33/32	33/30	22/2	100/31	1.5	4.0	2	2
6	DEC 15/TU	13:00	11.0	13.2	0.87	31/27	34/25	30/6	14/16	15.5	19.0	3	2.5
7	DEC 16/WE	4:00	10.0	T	T	27/25	36/25	63/27	186/125	5.0	8.0	2.5	3
8	DEC 20/SU	2:30	13.25	1.4	0.17	33/30[d]	--	84/15	101/28	13.0	9.5	3	1
9	DEC 22/TU	6:15	1.33	0.3	0.01	33/32[d]	--	65/14	190/98	2.0	3.0	3	3
10	DEC 28/MO	4:10	18.33	9.7	0.79	32/14[d]	--	106/66	169/106	18.5	12.75	3	2.5
11	DEC 29/TU	4:30	6.0	0.0	0.00	27/24[d]	--	50/13	24/253	4.5	6.0	3	--
12	DEC 30/WE	8:00	3.5	T	T	30/26[d]	--	56/18	167/115	1.0	--	2	--
13	JAN 11/MO	6:15	5.25	T	T	25/15	29/7	62/16	197/164	6.0[e]	3.0	2.5	2
14	JAN 13/WE	4:45	0.5	--	--	1.0	--	8/1	11/1	--	--	--	--
15	JAN 18/MO	6:15	3.0	--	--	32/29	38/31	55/16	162/110	5.0[e]	3.0	2.0	2
16	JAN 20/WE	0:30	10.0	0.9	0.11	31/29	36/29	66/10	169/160	10.0[f]	8.5	3	3
17	JAN 21/WE	5:30	4.5	T	T	22/17	32/20	69/41	215/143	2.0[e]	0.5	2	2
18	JAN 22/FR	15:30	7.0	0.4	0.02	24/20	36/24	162/150	84/30	13.0[e]	11.0	3	3
19	JAN 23/SA	17:00	7.0	3.2	0.13	14/10	23/19	95/28	61/6	11.5[e]	--	3	--
20	JAN 24/SU	3:00	9.5	1.2	0.05	19/6	35/11	58/4	77/11	34.0[e]	8.0	3	3
21	JAN 25/MO	5:00	8.25	8.1	0.30	16/9[g]	27/20[g]	204/118	193/162	4.0[e]	1.0	3	--
22	JAN 26/TU	4:30	7.0	T	T	11/2	31/8	49/5	204/97	7.0[h]	6.5	3	3
23	JAN 28/TH	9:00	0.5	T	T	11/5	22/10	45/9	129/54	--	0.5	--	--
24	FEB 1/MO	9:00	9.5	1.1	0.13	18/11	29/19	203/88	144/52	9.5	0.5	3	--
25	FEB 2/TU	8:00	0.5	T	T	4/3	15/11	70/14	232/133	--	0.5	--	3
26	FEB 4/TH	13:35	1.2	0.1	0.01	14/11	28/26	88/11	65/15	2.0	2.0	3	3
27	FEB 5/FR	15:00	0.5[i]	T	T	1/-1	27/20	103/31	65/11	--	--	--	--
28	FEB 8/MO	13:30	3.5	2.6	0.11	15/11	28/25	181/114	76/15	4.0	1.5	3	3
Total			157.96	52.4	3.52	33/-1	38/7	204/150	232/253	195.5	126.75		

[a] Traffic in vehicles per hour per lane (RL - right lane, LL - left lane).
[b] Deicer effectiveness rating: 1 - CMA better, 2 = equal, 3 = salt better.
[c] Pavement surface temperature at approaches to bridge at Irish Lane.
[d] U.S. Weather Bureau temperature at Truax Field. Sensor data not available.
[e] CMA-coated sand.
[f] 5.0 tons CMA-coated sand and 5.0 tons pure CMA.
[g] Partial data—lack data for 4:15 to 9:15.
[h] 5.0 tons CMA-coated sand and 2.0 tons pure CMA.
[i] Field data collection only.

tiveness, are also summarized by storm in Table 1. A further summary of deicer usage by type of CMA used is presented in Table 2. During the first part of the test period, when pure CMA was used, air temperatures (°F) were typically in the upper 20s to low 30s. The total amount of CMA used to obtain similar deicing performance was only 4 percent greater than the amount of salt. As shown in Table 1, CMA effectiveness compared to salt was viewed at least somewhat positively for 8 of the 12 storms (rating of 2.5 or smaller by at least one of the drivers).

During the second part of the test period, when CMA-coated sand was used nearly exclusively, the total tons of CMA-coated sand plus pure CMA exceeded the tons of salt by over 120 percent, but the effective amount of CMA (subtracting the weight of the sand) was only 65 percent of the salt tonnage based on 25 percent CMA by weight in the CMA-coated sand. The driver ratings for the first half of this time period indicated nearly equal deicing effectiveness between the CMA-coated sand and salt. But with the colder air and pavement surface temperatures of the second half of the time period, salt was uniformly rated as a better deicer than CMA-coated sand.

During the final part of the overall test period, when pure CMA was again used, the level of CMA use exceeded that of salt by nearly three to one. The storm-by-storm ratio of CMA to salt use was highly variable, however, ranging from 19 to 1. Again, the poor performance of the CMA appears to be related to temperature.

The comparison of CMA-coated sand with salt shown in Table 2 must tempered by the inherent differences between a pure deicing material and a mixture of deicer and sand. If the salt had been mixed with sand, the ratios based on total weight as well as on "pure" deicer no doubt would have been quite different.

The overall deicing effectiveness of CMA and CMA-coated sand compared with salt as viewed by the drivers is summarized in Table 3. Considering all storms, the truck drivers rated salt better 64 percent of time, while CMA was rated better only once (2 percent of the time). The salt truck drivers rated CMA slightly more positively (salt better 62 percent of the time) than the CMA drivers. The ratings for CMA-coated sand were similar to salt, rated better 62.5 percent of the time. Again, the salt drivers were somewhat more positive toward CMA (salt better 57 percent of the time).

The detailed data on deicer application by storm as recorded by the drivers are summarized in Table 4. The storms are divided into three groups: (a) early pure CMA, (b) midseason CMA-coated sand, and (c) late pure CMA. As discussed earlier, the deicer use and miles data recorded by the drivers were often estimated rather than measured precisely. Also,

TABLE 2 SUMMARY OF TONS OF DEICER APPLIED BY TYPE

TEST PERIOD STORMS	PURE CMA	CMA-COATED SAND (EFF. CMA)[b]	TOTAL: CMA + SAND[b] (EFF. CMA)[b]	SALT	RATIO OF TOTALS[a] [CMA + SAND]/SALT[b] (Eff. CMA/SALT)[b]
			All Storms		
1-12	87.5	--	87.5	80.25	1.04
13-22	7.0	85.5 (21.4)	92.5 (28.4)	41.5	2.13 (0.65)
23-28	15.5	--	15.5	5.0	2.97
All	110.0	85.5 (21.4)	195.5 (131.4)	126.75	1.48 (0.99)
			Pure CMA-Storms		
1-12 23-28	103	--	103	85.25	1.21
			Only CMA-Coated Sand Storms		
13-15 17-21	--	75.5 (18.9)	75.5 (18.9)	26.5	2.85 (0.71)

[a] Adjusted for the difference in lane-miles between the salt and CMA sections. Salt lane-miles/CMA lane-miles = 15.4/16.1 = 0.957.

[b] Effective or "pure" CMA in CMA-coated sand based on 25 percent by weight.

TABLE 3 TRUCK DRIVER RATINGS OF DEICING EFFECTIVENESS, CMA VERSUS SALT

DEICING EFFECTIVENESS RATING[a]	ALL STORMS			STORMS WITH CMA-COATED SAND		
	CMA DRIVER	SALT DRIVER	BOTH DRIVERS	CMA DRIVER	SALT DRIVER	BOTH DRIVERS
1 - CMA Better	--	1	1	0	0	0
2 - CMA and Salt Equal	6	5	11	2	3	5
2.5 - Salt Marginally Better	2	2	4	1	0	1
3 - Salt Better	16	12	28	6	4	10
Total Observations	24	20	44	9	7	16

[a] Drivers Report Form: Response to question on "Your Opinion of Results: (compared to Salt) _______Better, _______Same, _______Poorer."

an "application" could consist of one or more passes. Thus, the detailed driver data only provided a general indication of differences in deicer use and the level of effort required.

The basic application data shown in Table 4 indicate that much more effort in both hours and miles was expended applying CMA compared with salt. Overall, CMA required 143 percent more hours and 70 percent more miles. The higher level of effort for CMA was consistent across all three time periods.

The application rates shown in Table 4 reveal that CMA was spread at a substantially higher rate per lane-mile, but at a lower rate per hour. The apparent inconsistency in the two rates is explained in part by differences in application procedures. The per lane-mile data presented here assume that the salt was applied to two lanes at once, while the CMA was applied one lane at a time. The much higher application rates per hour for salt compared with CMA reflect both a higher rate for salt from the coverage of two lanes at once by the salt truck and a lower rate for CMA resulting from the nonproductive application hours reported by the CMA drivers.

A fully unbiased comparison of the deicers would require adjustment to account for the slightly smaller number of lane miles in the salt section (15.4 versus 16.1, or 4.3 percent less). The adjustment would make CMA slightly more competitive with salt. The adjustment, however, is not explicitly made here because the impact is overshadowed by the uncertainties in the base data on tons of deicer, miles, and hours.

TABLE 4 SUMMARY OF DEICER APPLICATION DATA

APPLICATION EFFORT[a]				APPLICATION RATES[b]				
MILES		HOURS		(LBS/LANE-MI)			(TONS/HOUR)	
CMA	SALT	CMA	SALT	CMA	SALT	RATIO CMA/SALT	CMA	SALT
Pure CMA Storms--Nov 25 to Dec 30 - 12 Storms								
382	226	47.2	24.1	460	360	1.3	1.8	3.3
CMA-Coated Sand Storms--Jan 11 to Jan 26 - 10 Storms								
241	150	39.2	13.2	770	280	2.8	2.4	3.1
Pure CMA Storms--Jan 28 to Feb 8 - 6 Storms								
69	30	10.6	2.5	450	330	1.4	1.5	2.0
All Storms								
692	406	97.1	39.9	560	310	1.8	2.0	3.2

[a] Vehicle miles and hours of application including plowing reported by the drivers.
[b] Based on driver estimates of the amount of deicer applied.

Field Observations Data

Field observations were recorded for nine storms, but during Storm 27 no deicer was used and only one set of observations was made. For Storm 27 the pavement surfaces were relatively warm (in the 20 to 27°F range) despite very cold air temperatures. In this situation the traffic volumes were sufficient to create essentially clear and dry pavement conditions. The details of the range of pavement conditions observed for the remaining eight storms are presented in Table 5. While the extremes of the observations (lows and highs) presented in Table 5 provide a convenient means of summarizing a much larger set of data, a full understanding of the differences between CMA and salt requires analysis of the complete data set, which relates the field observations to key variables such as air and pavement surface temperatures, wind speeds, traffic volumes, and deicer application rates at 15-minute intervals. The pavement condition data are averages of the three observation points in each section excluding the ramps and considering the Irish Lane location as a single observation point. An alternative format for the complete data base that facilitates comparison of CMA performance by direction as well as salt performance by direction was also developed.

The field observations data cover nearly the full range of winter storm conditions, including both warm and cold pavement surface and air temperatures, low and high wind speeds and traffic volumes, and small and large snowfalls. The type of CMA used, pure CMA versus CMA-coated sand, is another factor to be considered.

TABLE 5 SUMMARY OF FIELD OBSERVATION DATA

Data Item	Southbound								Northbound							
	Right Lane				Left Lane				Right Lane				Left Lane			
	CMA		Salt		CMA		Salt		CMA		Salt		CMA		Salt	
	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi	Low	Hi
Storm 10 Mon., Dec. 28 9.7 in. snow 14-32°F Began 4:10 Data: 6:08-7:33																
Action[a]	1.0	2.3	1.0	3.0	1.0	1.5	1.5	3.0	2.0	3.0	1.3	2.7	2.0	3.0	1.7	3.0
Tr. Width[b]	0.0	1.1	0.0	2.0	0.0	1.0	0.0	1.0	0.4	1.2	0.0	0.7	0.7	0.8	0.0	1.1
% Clear	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Snow Depth[c]	0.5	0.7	0.5	1.0	0.5	0.8	0.5	2.3	0.5	1.0	0.7	1.2	0.5	1.0	0.7	1.2
Sur. Temp.		--	--			--	--			--	--			--	--	
Traffic		7	36			1	15			79	169			18	106	
Storm 15 Mon., Jan 18 ? in. snow 29-32°F Began 6:15 Data: 8:45-11:45																
Action	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Tr. Width	1.4	3.0	0.5	3.0	0.0	1.3	0.0	0.6	1.0	2.5	0.6	1.8	0.4	1.4	0.0	1.0
% Clear	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Snow Depth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sur. Temp.		32	36			32	38			34	38			34	36	
Traffic		24	54			2	8			57	102			7	37	
Storm 18 Fri., Jan. 22 0.4 in. snow 20-24° Began 15:30 Data: 15:56-19:58																
Action	4.0	4.3	4.0	5.0	3.3	4.0	4.0	5.0	4.0	4.5	3.7	5.0	2.5	3.5	3.7	5.0
Tr. Width	2.0	4.0	0.0	2.0	1.2	3.3	0.0	1.5	0.0	4.0	0.0	3.7	1.0	2.5	0.0	2.7
% Clear	60	80	75	90	43	67	70	90	45	95	67	100	10	45	47	97
Snow Depth	0.1	0.3	0.1	0.2	0.1	0.3	0.1	0.2	0.1	0.2	0.0	0.1	0.1	0.2	0.0	0.1
Sur. Temp.		25	30			25	31			24	28			24	28	
Traffic		46	162			9	150			21	77			5	14	
Storm 19 Sat., Jan. 23 3.2 in. snow 10-14°F Began 17:00 Data: 18:38-22:06																
Action	3.7	4.0	4.0	4.0	1.0	2.3	1.0	1.0	3.0	4.0	3.7	4.0	1.0	1.0	1.0	1.7
Tr. Width	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Clear	47	70	50	75	0	10	0	0	25	50	40	57	0	0	0	0
Snow Depth	0.4	0.4	0.3	0.3	0.8	1.0	1.0	1.0	0.3	0.8	0.4	0.5	1.0	1.0	0.8	1.0
Sur. Temp.		20	20			21	22			19	19			18	18	
Traffic		27	46			0	8			7	43			0	4	
Storm 20 Sun., Jan. 24 1.2 in. snow 6-19°F Began: 3:00 Data: 7:01-10:25																
Action	1.0	4.0	1.0	4.5	1.0	2.3	1.0	4.0	1.0	4.5	1.7	4.3	1.0	3.0	1.7	4.0
Tr. Width	0.0	0.8	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Clear	72	87	70	95	0	7	8	50	80	85	57	87	5	25	10	57
Snow Depth	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Sur. Temp.		11	29			13	21			10	23			9	27	
Traffic		3	31			0	1			7	56			0	3	
Storm 21 Mon., Jan. 25 8.1 in snow 9-16°F Began: 5:00 Data: 5:51-7:12																
Action	2.0	3.4	3.0	3.5	1.7	2.5	1.5	3.0	4.0	4.0	4.0	4.0	2.0	3.5	2.0	3.3
Tr. Width	3.7	4.3	1.5	4.5	2.3	3.3	0.5	3.0	4.0	4.5	4.3	5.0	2.5	3.5	3.3	3.3
% Clear	37	43	45	65	15	67	30	95	35	70	17	87	45	80	33	77
Snow Depth	1.0	1.2	1.3	1.5	1.0	2.0	1.5	1.8	1.0	1.0	8.3	8.3	1.0	2.0	1.3	1.30
Sur. Temp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Traffic		13	31			1	3			56	192			1	82	
Storm 24 Mon., Feb. 1 1.1 in. snow 11-18°F Began: 9:00 Data: 10:10-12:52																
Action	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tr. Width	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
% Clear	83	90	85	95	22	32	32	65	90	95	95	97	15	25	47	57
Snow Depth	0.0	3.0	0.0	1.5	0.8	5.0	0.5	2.5	1.0	3.0	1.0	1.5	2.0	4.0	0.5	2.3
Sur. Temp.		25	29			24	25			25	26			-	-	
Traffic		43	68			1	6			43	75			2	7	
Storm 28 Mon., Feb. 8 2.6 in. snow 11-15°F Began: 13:30 Data: 13:44-17:50																
Action	4.0	4.0	4.0	4.0	3.0	4.0	3.5	4.0	4.0	4.0	4.0	4.0	3.0	4.0	1.0	4.0
Tr. Width	0.0	0.0	0.0	0.0	0.0	3.3	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Clear	86	95	93	95	3	67	15	70	80	95	86	92	10	13	3	37
Snow Depth	0.5	1.7	0.5	2.0	1.7	3.0	2.0	3.0	0.5	3.0	1.0	3.0	3.0	5.0	2.3	4.6
Sur. Temp.		19	24			21	24			18	20			-	-	
Traffic		58	181			2	114			42	67			0	15	

[a] Code: 1 - No Action, 2 - Penetration, 3 - Begin Brine, 4 - Good Brine, 5 - Clear-Wet, 6 - Clear-Dry.

[b] Average of left and right tracks in feet.

[c] In inches.

"Time to Brine" and "Time to Clear and Wet" Evaluation

Field data on two key items of interest, time to brine formation and time to clear and wet pavement conditions, are summarized separately in Table 6. The time and the corresponding "deicer action level" for the first and last field observation are also shown in Table 6. The time recorded is the time from the first application of the specific deicer as reported by the drivers. In general, the applications of CMA and salt did not begin at the same time.

The "time to brine" pavement condition is based on the elapsed time in 15-minute increments until the "deicer action level" exceeds 2.0, which corresponds to "begin brine" conditions on one or more observation points on the section. A careful review of Table 6 reveals that the transition from "no action" to "begin brine" or greater action level was not recorded for every storm. In several storms, the transition had already occurred when field data collection was begun. In one storm brine formation was not observed during the time when field data were being collected.

When pure CMA was spread on relatively warm pavement, with surface temperatures above 22°F, the "time to brine" was generally shorter for the CMA sections. The "time to brine" ranged from 1.0 to 2.0 hours for CMA and 2.0 to 3.25 hours for salt. By contrast, when the CMA-coated sand was spread on colder pavement, the "time to brine" was generally longer for the CMA sections. The "time to brine" ranged from 3.75 to 4.5 hours for salt and 6.75 to 7.25 hours for CMA-coated sand. Some of the variation in "time to brine" appears to be related to traffic volumes. At least one storm, Storm 21, provided evidence of "CMA carryover," in which brine formation is enhanced by residual CMA left from the prior storm. In this case, brine formation occurred before the CMA-coated sand application began. The "time to brine" measured from the start of the salt application, however, was slightly greater for CMA than for salt.

The "time to clear and wet" pavement conditions is based on the elapsed time until the "deicer action level" exceeds 4.0, which corresponds to "clear and wet" conditions on one or more observation points on the section. The focus here is on "clear and wet" conditions rather than "clear and dry" conditions because of the limited number of observations of "clear and dry" conditions. Table 6 shows that, in general, the time to "clear and wet" conditions was longer for CMA-coated sand, with a range of 0.5 to 4.75 hours for salt versus 4.0 to 7.25 hours for CMA-coated sand. For the one storm with shorter times to "clear and wet" conditions for CMA-coated sand, Storm 21, the shorter times may be explained in part by the later start in spreading CMA.

Weather Data

The primary concern in analyzing the weather data is to determine if the temperature at Truax Field is a reasonable surrogate for the local US-14 air temperature. The correlation between the two air temperatures over the 28 storms for which data are available is 0.989. Thus, if the weather station at Irish Lane was not in operation, the Truax Field temperature will provide a good estimate of the local air temperatures.

The Irish Lane air temperature has a moderately high degree of correlation with the pavement surface temperatures, ranging from 0.80 to 0.86, which means that air temperature explains 64 to 74 percent of the variation in pavement surface temperature. The amount of energy from the sun, which is dependent on cloud cover and time of day, is a major reason for differences between pavement and air temperatures. Pavement surface condition, including snow cover, depth, and moisture content, is also an important factor. Traffic volume may be significant under some conditions. At night the degree of cloud cover is important, but this is generally not a factor during storms.

The local wind speed data at Irish Lane typically varied considerably from one 15-minute time period to the next, but the maximum values generally were consistent with wind speeds reported by Truax Field. Local wind speed data provide more precise information on when blowing snow and drifting conditions were likely to have occurred.

SUMMARY AND CONCLUSIONS

The 1987–1988 winter provided a good test of the effectiveness of CMA and CMA-coated sand because of the substantial number of storms with a wide range of temperatures and amount of snowfall. Pavement surface temperatures were high enough to permit significant deicing in all but 1 of the 28 storms.

Based on lane-mile-adjusted driver estimates, 48 percent more tons of CMA and CMA-coated sand than salt were required to achieve "bare pavement" on US-14. Considering only the pure or "effective" amount of CMA used, however, about 1 percent less CMA was required per lane-mile. In contrast, 87 percent more CMA than salt was required on US-14 during the previous winter (1986–1987). The lower amount of pure CMA used, however, was the result of extensive use of CMA-coated sand; no comparable sand-salt mixture was used. CMA-coated sand accounted for 44 percent of the total tons of CMA and CMA-coated sand used.

The application of CMA and CMA-coated sand on US-14 required 70 percent more miles and 143 percent more hours compared with the application of salt. Some part of the additional application effort can be attributed to the dedication of a truck to the CMA section, whereas the salt truck had other highway sections to cover.

The truck drivers rated salt as a more effective deicer in over 60 percent of the storms. In contrast, CMA was rated better only once. The overall driver ratings for CMA compared with CMA-coated sand were about the same. The salt truck drivers rated CMA and CMA-coated sand slightly more positively than the CMA truck drivers did.

Detailed field observations were made for 8 of the 28 storms, covering a reasonable range of temperature and snowfall conditions. Pure CMA was applied during three of the eight "field observations" storms. Overall, the deicing performance of CMA was similar, but often slightly lower than that of salt. Both CMA and salt were more effective with increasing traffic volumes and temperatures. The pavement surface temperature appeared to be more important than air temperature. The performance of CMA was typically lower than that of salt under low-traffic-volume conditions.

TABLE 6 SUMMARY OF TIME TO BRINE AND TIME TO CLEAR AND WET

Data Type	Southbound								Northbound							
	Right Lane				Left Lane				Right Lane				Left Lane			
	CMA		Salt		CMA		Salt		CMA		Salt		CMA		Salt	
	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)	Time[a] (hrs)	Action[b] (1-6)
Pure CMA STORM 10 -- Mon., December 28 Began: 4:10 @ S. Temp. n.a.																
First Data	0.5	1.0	2.0	1.0	0.5	1.0	2.0	1.5	1.0	2.0	2.0	1.3	1.0	3.0	2.0	3.0
First Brine[c]	1.5	2.3	3.25	3.0	--	--	2.5	3.0	2.0	3.0	2.75	2.7	1.0	3.0	2.0	3.0
Last Data	1.5	2.3	3.25	3.0	1.5	1.5	3.25	2.0	2.0	3.0	2.75	2.7	2.0	2.5	2.75	3.0
CMA/Sand STORM 15 -- Mon., January 18 Began: 6:15 @ S. Temp 31-33																
First Data	2.25	5.0	1.75	5.0	2.25	5.0	1.75	5.0	2.5	5.0	2.25	5.0	2.5	5.0	2.25	5.0
First Cl-Wet[d]	2.25	5.0	1.75	5.0	2.25	5.0	1.75	5.0	2.5	5.0	2.25	5.0	2.5	5.0	2.25	5.0
Last Data	5.25	5.0	4.5	5.0	5.25	5.0	4.5	5.0	5.25	5.0	4.5	5.0	5.25	5.0	4.5	5.0
CMA/Sand STORM 18 -- Fri., January 22 Began: 15:30 @ S. Temp 30-32																
First Data	0.25	4.0	0.5	5.0	0.25	4.0	0.5	5.0	0.75	4.0	0.75	4.7	0.75	2.5	0.75	5.0
First Brine[c]	0.25	4.0	0.5	5.0	0.25	4.0	0.5	5.0	0.75	4.0	0.75	4.7	1.75	3.5	0.75	5.0
First Cl-Wet[d]	4.0	4.3	0.5	5.0	--	--	0.5	5.0	4.25	4.5	3.5	5.0	--	--	0.75	5.0
Last Data	4.0	4.3	4.0	4.5	4.0	3.8	4.0	4.5	4.25	4.5	4.25	4.3	4.25	3.5	4.25	4.3
CMA/Sand STORM 19 -- Sat., January 23 Began: 17:30 @ S. Temp. 18-22																
First Data	1.5	3.7	--	4.0	1.5	2.3	--	1.0	2.25	4.0	--	3.7	2.25	1.0	--	1.7
First Brine[c]	1.5	3.7	--	4.0	1.5	2.3	--	--	2.25	4.0	--	3.7	--	--	--	--
Last Data	4.25	4.0	--	4.0	4.25	1.3	--	1.0	5.0	4.0	--	4.0	5.0	1.0	--	1.0
CMA/Sand STORM 20 -- Sun., January 24 Began: 3:00 @ S. Temp. 15-22																
First Data	4.0	1.0	1.75	1.0	4.0	1.0	1.75	1.0	4.75	1.0	2.0	1.7	4.75	1.0	2.0	1.7
First Brine[c]	6.75	4.0	4.5	4.5	6.75	2.3	3.75	3.5	6.75	3.5	4.0	4.0	7.25	3.0	4.0	4.0
First Cl-Wet[d]	--	--	4.5	4.5	--	--	--	--	7.25	4.5	4.75	4.3	--	--	--	--
Last Data	6.75	4.0	4.5	4.5	6.75	2.3	4.5	4.0	7.25	4.5	4.75	4.3	7.25	3.0	4.75	4.0
CMA/Sand STORM 21 -- Mon., January 25 Began: 5:00 @ S. Temp. n.a.																
First Data	--	2.0	1.0	3.0	--	1.7	1.0	1.5	--	4.0	1.25	4.0	--	2.0	1.25	2.0
First Brine[c]	--	3.4	1.0	3.0	3.0	3.0	1.75	3.0	--	4.0	1.25	4.0	0.0	3.5	2.0	3.3
First Cl-Wet[d]	3.75	6.0	6.0	5.0	--	--	--	--	3.75	5.0	5.5	4.7	4.25	5.0	6.0	4.3
First Cl-Dry[e]	3.75	6.0	7.0	6.0	--	--	--	--	10.0	6.0	6.0	6.0	--	--	--	--
Last Data	10.75	1.0	12.75	1.0	10.75	1.0	12.75	1.0	11.0	1.0	13.0	1.0	11.0	1.0	13.0	1.0
Pure CMA STORM 24 -- Mon., February 1 Began: 9:00 @ S. Temp. 24-25																
First Data	0.5	1.0	1.25	1.0	0.5	1.0	1.25	1.0	0.75	1.0	1.0	1.0	0.75	1.0	1.0	1.0
Last Data	2.75	1.0	3.5	1.0	2.75	1.0	3.5	1.0	3.25	1.0	3.5	1.0	3.25	1.0	3.5	1.0
Pure CMA STORM 28 -- Mon., February 8 Began: 13:30 @ S. Temp. 24																
First Data	0.0	4.0	0.25	4.0	0.0	4.0	0.25	4.0	0.75	4.0	0.25	4.0	0.75	4.0	0.25	1.0
First Brine[c]	0.0	4.0	0.25	4.0	0.0	4.0	0.25	4.0	0.75	4.0	0.25	4.0	0.75	4.0	1.0	3.7
Last Data	3.75	4.0	3.75	4.0	3.75	4.0	3.75	4.0	4.25	4.0	3.75	4.0	4.25	3.0	3.75	3.0

[a] Time from the first application of the specific deicer.

[b] Deicer Action Level: 1-No Action, 2-Penetration, 3-Begin Brine, 4-Good Brine, 5-Clear & Wet, 6-Clear & Dry.

[c] "Deicer action level" exceeds 2.0 so that "begin brine" conditions exist at one or more observation points on the section.

[d] "Deicer action level" exceeds 4.0 so that "clear & wet" conditions exist at one or more observation points on the section.

[e] "Deicer action level" exceeds 5.0 so that "clear & dry" conditions exist at one or more observation points on the section.

Local weather data were available for six of the eight field observation storms. Air temperatures at the U.S. Weather Bureau station at Truax Field were found to be a reasonable surrogate for the local air temperatures. Local air temperatures are correlated with pavement surface temperatures but only explain 64 to 74 percent of the variation in pavement surface temperature. Thus, separate measurement of pavement surface temperatures are needed. Maximum local wind speeds were highly correlated with Truax Field wind speeds, but typically there was considerable variation in wind speed during a storm.

The field observations data provided some information on both the "time to brine formation" and the "time to clear and wet pavement." The amount of data available on "time to brine" was limited because the transition to brine had already occurred before the field data collection was begun. The "time to brine" was found to be shorter for pure CMA being spread on relatively warm pavement, but longer for CMA-coated sand being spread on colder pavement. The level of traffic volumes appeared to influence the time required. In general, the time to "clear and wet" pavement conditions was longer for CMA-coated sand than for salt. No data on the transition to "clear and wet" conditions were available for pure CMA.

Overall, storm duration did not appear to have a significant impact on the relative effectiveness of CMA. CMA received ratings by the drivers of "equal to salt" or better for both short- and long-duration storms. The field observations data did not provide enough information to identify any potential differential impacts of storm duration.

No obvious differences were noted in the deicing effectiveness of either CMA or salt between concrete and bituminous surfaces on US-14. Also, the darkening of concrete pavement by CMA observed in the winter of 1986–1987 was not observed during 1987–1988.

Overall, the comparison of CMA and CMA-coated sand on US-14 demonstrated that CMA can produce results similar to salt, but more deicer and application miles and hours were required. Also, the deicing by CMA tended to occur more slowly, although the differences may not have been noticeable to motorists.

As used in Wisconsin, CMA had distinct disadvantages in handling and transport. CMA was shipped and stored in 1,000- and 1,500-pound fabric bags. Using a mobile crane to hoist the bags over the truck body and then pulling the rip cord to release the CMA was a two-person job. The time-consuming loading of individual bags must be replaced by bulk storage and handling if CMA is to be used more extensively. The tendency of CMA to cake and harden when wet was an annoying but not insurmountable problem.

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

Given the reasonably favorable experience with CMA-coated sand in all but the coldest conditions, an investigation of the economic feasibility of more extensive use of CMA and possibly CMA-sand mixtures may be warranted. A mixture of sand and CMA may have cost advantages over the manufactured CMA-coated sand used in this study. The benefits of reduced corrosion on bridge decks and non coated reinforcing bars in some pavements need to be compared with the higher material and operational costs associated with CMA. Additional field tests are needed to determine the performance of CMA-coated sand and CMA-sand mixtures under the warmer pavement and air conditions typically occurring in November and December. Field trials of CMA-sand mixtures are also needed. Costs for CMA-coated sand may be reduced significantly by producing the CMA in Wisconsin and using local sand.

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Vegetation Enhancement via Species and Cultivar Selection: A Perspective

Robert W. Duell

Roadside maintenance personnel are limited, in large part, in what they can do with a roadside condition by the type of vegetation that was sown there originally. The grasses and legumes that were initially sown as cover along the roadsides may not have persisted. Their place may have been taken by weeds, or the intended balance of sown species may have shifted. Species persistence in a region and their roles in mixtures are generally understood in agronomic circles, but cultivars (cultivated varieties) are a newer concept and not sufficiently appreciated by many who deal with establishing vegetative covers to allay erosion and to beautify and protect our environment. Cultivar selection may be as important to the maintenance and acceptability of roadsides as the selection of species in a mixture. Seed of any species labeled as "common" is often seed of a cultivar that did not meet certification standards, and may not be appropriate for a given roadside. Older "standard" varieties such as "Kentucky 31" tall fescue and "Pennlawn" red fescue, even if certified, are now variable commodities, and some may not be appropriate. Expanded lists of cultivars of several important species and their characteristics are available. Cultivars of proven performance may be selected from lists of data generated from widespread testing under intensive management. Much less testing of cultivars of promising species has been done under extensive management, such as roadsides. The rewards of superior turf with less maintenance costs are available for those who select appropriate combinations of superior cultivars for roadside mixtures.

A landscape architect's legacy is a reflection of the species and cultivars (cultivated varieties) that he or she specifies, or fails to specify, in a roadside seed mixture. Grass mixtures, alone or in combination with legumes, cover most roadsides and are the focus of maintenance activities on the 25 to 30 acres per mile of Interstate roadside. Experience has taught that grass serves best in these various habitats, hence grasses are the focus of this paper, with special emphasis on experiences in the Middle Atlantic states, particularly New Jersey.

UTILITY, SAFETY, ECONOMY, AND BEAUTY

According to Federick (*1*), four basic elements are to be incorporated into the design of a modern highway: utility, safety, economy, and beauty. Although originally aimed at highway construction per se, these points are also pertinent to roadside vegetation.

The "utility" of vegetative cover refers primarily to its erosion control in protecting the roadbed and its appurtenances. It also extends to minimizing transport of sediment off site and subsequent problems.

A good roadside turf contributes to "safety" by providing support for vehicles leaving the paved surface and by enabling them to reenter the highway in a controlled fashion. Vegetation should not grow so tall that it causes snowdrifts to build on road surfaces, nor should it decrease line of sight.

"Economy" of roadside vegetation maintenance was emphasized most stringently following the fuel crisis of 1973, when mowing was drastically curtailed. Interest in "no mow" or minimum maintenance vegetation increased. Opportunities for reduced mowing (and lower maintenance costs) are greater now with the use of various plant growth regulators (PGRs) and herbicides. Responses to questionnaires distributed by the Committee on Roadside Maintenance in 1986 indicated that there has been a decrease in roadside mowing over the last 10 years (*2*). The reasons cited were the increased use of herbicides and PGRs on roadsides. The increase in use of herbicides appeared to be greater than the increase in use of PGRs.

Emphasis on "beautification" increased during the presidency of Lyndon B. Johnson, particularly through the interest of the President's wife, Lady Bird. The pressure of economy on maintenance temporarily suppressed interest in wildflowers for roadsides, but recent interest in this topic is at an all-time high.

Wildflower plantings are strategically located for maximum visual impact at sites where erosion potential is minimal. With few exceptions, notably bluebonnets (*Lupinus texensis*) in Texas, the modes of establishment and range of adaptation of the large number of wildflower species is very poorly understood.

THE UNMOWED ROADSIDE

The process of "naturalization" is largely dependent on the availability of seeds nearby, and these may or may not be desirable species. Attempts at seeding selected woody species to roadsides were pursued by Thornton (*3*), with successes largely limited to the sumac species, some of which appeared to be quite attractive and appropriate.

Plant succession usually starts with weedy species, which are often undesirable in roadside situations. Excessive amounts of ragweed (*Ambrosia* spp.), poison ivy (*Rhus radicans*), crabgrass (*Digitaria* spp.), and foxtail species (*Setaria* spp.) volunteer where sown species have failed. Annual weed species frequently give way to perennial grasses. In New Jersey this succession typically includes species such as the bluestems (*Andropogon* spp.), purpletop (*Tridens flavus*), and the paspalums (*Paspalum* spp.).

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These persistent warm-season grasses are C_4 photosynthesizers, which operate more efficiently at high midsummer temperatures than the C_3 cool-season grasses (e.g., tall fescue and Kentucky bluegrass) that were sown on the roadsides. The sown species suffer in competition and their stands are further depleted. These warm-season perennial grasses cannot currently be selectively removed from a cool-season turf with herbicides. Weedy growth generally necessitates extra roadside mowings. The eventual ingress of woody species such as sumacs (*Rhus* spp.) and dogwood (*Cornus* spp.) may be acceptable, although taller-growing timber type trees such as oaks (*Quercus* spp.), maples (*Acer* spp.), and pines (*Pinus* spp.) may become hazardous to motorists and require expensive clearing operations.

Crown vetch (*Coronilla varia*) seedlings start so slowly that a grass associate is needed to allay erosion during the first 2 or 3 years. Subsequently, crown vetch typically becomes so vigorous (where adapted) as to eliminate the grass associate and (to a large extent) preempt the ingress of weeds and brushy species. Crown vetch is well adapted to northern New Jersey, Pennsylvania, and southern New England, where moisture is favorable. Even here, after a decade or two, perennial weeds and woody species may invade. Crown vetch adaptation extends appreciably beyond the above limits (from southern Canada to Alabama), but it is not adapted to droughty, sandy soils like those of southern New Jersey.

"MANAGED" ROADSIDE VEGETATION

Species shifts in sown mixtures are commonplace and can be expected to vary with the management imposed. Stand composition is also dependent upon the soil, moisture regime, and fertility of the specific roadside site. These factors are likely to vary along the road and up and down the slope, as well as within and beyond the mow or spray line.

Contractors generally like to have a lot of ryegrass (*Lolium multiflorum* or *L. perenne*) in a roadside turfgrass mixture because, in addition to being inexpensive (especially common types), they are particularly fast to emerge, quick to green up the newly sown area, and make rapid growth. The ryegrasses, however, are strongly competitive and are likely to be detrimental to the other species in the mixture, particularly if frequent close mowing (such as 1-½ in. at least once a week) is not practiced (*4*). As little as 10 percent ryegrass in a mixture that is unmowed until after heading may give the appearance of a solid ryegrass stand. Lawn mixtures generally have no more than 25 percent ryegrass. Contractors' "economy" mixes often exceed 25 percent ryegrass and may contain only ryegrass. This is false economy for any perennial low maintenance turf. Even improved, truly perennial ryegrasses, such as "Manhattan," fail to persist beyond the second or certainly the third year under roadside conditions. Rust diseases (*Puccinia* spp.) and *Anthracnose* build up when mowing is infrequent (more than 3 weeks between mowings during the growing season); they are the probable causes of the failure of "perennial" ryegrasses under roadside conditions. However, under modest home lawn conditions, Manhattan has maintained an attractive, complete turf for at least 14 years.

Tall fescue (*Festuca arundinacea*), particularly the cultivar "Kentucky 31," has been extensively sown on roadsides since the mid 1950s. Tall fescue commonly dominates turf at the toe of slopes and other productive roadside sites. Its persistence on the sandy acid soils of southern New Jersey, however, or on the difficult-to-vegetate shoulders or roadside banks on various soils throughout the state, falls far short of desirable. Where tall fescue is eliminated by such environmental stresses, fine fescues often persist.

Kentucky bluegrass (*Poa pratensis*) is commonly found along roadsides in productive sites, sometimes in association with tall fescue. Kentucky bluegrass is not as tall or coarse-textured as tall fescue. Various species of fine fescues are found throughout the area, persisting on roadsides sown prior to the popular use of tall fescue.

Infrequent mowing of roadsides allows the ingress of various broadleaf weeds, brushy species, tree seedlings, and certain grass species. The latter include the bluestems, paspalums, and purpletop, none of which can be readily controlled with herbicides. These are warm-season species that compete severely with the sown cool-season species when the latter are at their low ebb of growth during summer.

Excessively close mowing, particularly in late spring, favors the ingress of warm-season annual grasses such as the crabgrasses (*Digitaria* spp.) and foxtails (*Setaria* spp.). Tall growth of these species necessitates more summer mowing than the originally sown turfgrasses. Low mowing also generates larger quantities of unsightly clippings that are more apt to smother remaining cool-season grasses. Warm-season annual grasses are prolific producers of seeds, which assures the continuation and aggravation of these problems.

Excessive application of certain PGRs may also suppress sown species and promote dramatic shifts toward the above grassy weeds. Figures 1 and 2 illustrate the severe retardation of tall fescue following PGR treatment and a subsequent shift to foxtail.

Damage through mismanagement, errors, or poor initial choice of turf species frequently necessitates roadside renovation. Currently there are extensive lists of cool-season grass cultivars from which to choose more appropriate grasses for better roadside mixtures.

FIGURE 1 Excessive PGR and herbicide have retarded roadside growth dominated by tall fescue (May 15, 1987).

SOLUTION

Vegetation that is poorly adapted to a site or management situation will give way to better-adapted plants that may or may not be desirable roadside vegetation. By selecting appropriate vegetation, however, it is possible to build in minimum maintenance.

Improved cool-season turfgrasses began with the selection of "Merion" Kentucky bluegrass in 1936. The next major step occurred with the release of Manhattan ryegrass in 1967. Since that time, a host of improved turfgrass cultivars of these species, plus tall fescue and various species of fine fescues, have continued to emerge. Most of these cultivars have been bred and tested primarily for fine turf use. Only "Fortress" (*Festuca rubra* subsp. *rubra*, a strong creeping red fescue), "Banner" Chewings fescue (*F. rubra* subsp. *comutata*), and "Wabash" Kentucky bluegrass (*Poa pratensis*) were bred and tested specifically for use on roadsides. Fortress and Banner were developed in New Jersey and are being used on its roadsides (*5,6*). Wabash was developed in Indiana and has not been promising in low maintenance testing in New Jersey.

FIGURE 2 Roadside is dominated by foxtail (*Setaria* spp.), a summer annual grassy weed; surviving tall fescue will probably succumb to competition from the foxtail (September 15, 1987).

Uniform trials of the performance of the major cool-season turfgrass species are conducted in many states, with the results compiled and published every few years by the U.S. Department of Agriculture (USDA). The extent of testing and the proliferation of cultivars over time is shown by the data presented in Table 1. The number of fine fescue entries, for example, doubled between 1983 and 1989. This testing is conducted primarily under lawn-type management.

The Variety Review Board of the Lawn Institute has also published a list of cultivars of lawn grasses recognized for excellence (*7*). Their criteria included vigor as well as insect and disease resistance. The list includes the names of 18 Kentucky bluegrass cultivars, 11 turf-type perennial ryegrasses, 5 fine fescues, 6 tall fescues, 2 bentgrasses (*Agrostis* spp.), and 3 specialty grasses. Cultivars of all but the last two categories are evaluated largely from data derived from the USDA National Turfgrass Evaluation Trials described above. Unfortunately, this list makes no reference to suitability for low maintenance use, nor does it specify area of adaptation.

Fine turfgrasses and roadside grasses should be evaluated on quite different parameters. One of the criteria of quality for roadside grasses, for example, involves their appearance when unmowed. An abundance of seed stalks indicates partitioning of photosynthates away from attractive green foliage. Seedheads are therefore undesirable along roadsides and become aesthetically unattractive as they senesce. Figures 3 and 4 show marked differences in seedhead development between two cultivars of Kentucky bluegrass and between two fine fescues.

Major seed companies want proprietary rights over the various cultivars of these species in order to offer customers their own full line of improved grasses for blends (two or more cultivars of a species, particularly important with Kentucky bluegrasses) or mixtures (two or more species). This competition stimulates development of new cultivars, but the proliferation causes some concern over finding appropriate names. At least one company resolved this by developing an alphanumeric code to identify new cultivars.

Too little testing of these cultivars has been done on roadsides and other minimum maintenance situations. The performance of improved turf-type tall fescues under such conditions is unknown. Some of these new tall fescues produce

TABLE 1 NATIONAL TURFGRASS EVALUATION TRIALS (INCLUDING CANADA)

Turf species	Year begun	No. of* locations	States/ provinces	Cultivars or selections
Ryegrass	1982	28	21	47
Tall fescues	1983	37	19	30
Fine fescues	1983	20	14	47
Kentucky bluegrass	1985	27	20	72
Bermudagrass	1985	10	7	28
Fine fescues	1989	-	-	94

*Some states tested at multiple locations

FIGURE 3 Cultivars of Kentucky bluegrass "Newport," in the rear, consistently produces more seed stalks (which mask foliage) than "Kenblue."

FIGURE 4 Cultivars of fine fescue "Highlight," in the rear, consistently produces more seed stalks (which mask foliage) than "Ruby."

more seed per acre than Kentucky 31 and have been sown on roadsides.

Improved turf-type Kentucky bluegrasses, including Merion, have high maintenance requirements and will not persist under typical roadside conditions. Kentucky bluegrass cultivars such as "Kenblue," "Park," "Troy," "Delta," "Arboretum," and "South Dakota" have tolerated the stresses of low maintenance and persisted better than the low growing, dense, and compact types developed for fine turf use. The six cultivars mentioned above are characterized as "common types" in that they are taller and less dense than other cultivars of the species.

The brightest development presently available for roadside mixtures are the hard fescues (*F. longifola*). They are newer and less well known than the creeping red fescues, Chewings fescues, and sheeps fescues. Hard fescue cultivars include the older "Biljart" and "Scaldis" and the newer "Reliant" and "Spartan." They are fine leafed and low growing. Of all the cool-season utility grasses, the hard fescues are the densest and have the best summer green color, particularly under low maintenance. Once established, their dense turf effectively excludes most weed encroachment. The weed-free aspect, low growth, plus rich green summer color provides quality roadside turf. The hard fescues also require minimum mowing and tolerate low fertility and low soil moisture.

IMPROVED GRASSES WITH ENDOPHYTES

Endophytes are certain types of fungi living inside grasses and other plants (Figure 5). This relationship has been known for over a hundred years but has only recently become of interest to turf scientists. They knew of the seed-born form of *Epichloe typhina*, for example, but only in the early 1980s did they discover that the association provides pest resistance to the turfgrass (*8*). Figure 6 shows that grasses containing an *Acremonium* endophyte were protected from attacks by bluegrass billbugs (*Sphenophorus parvulus*) and show superior recovery in spite of prevailing dry conditions. Major turfgrass species, excepting Kentucky bluegrass and bentgrasses, have been reported by others to have enhanced pest tolerance, resistance to weed invasion, and recovery from summer stresses.

Plant breeders are top-crossing their best genetic materials onto plants of the species that have passed microscopic examination for endophytes. After several generations of selecting and top-crossing, commercial quantities of seed having certain insect protection will be available.

CONCLUSION

Improved cultivars for fine turf abound. There is a need for more testing of these grasses under roadside conditions. There very likely are combinations of species and improved cultivars

FIGURE 5 White stroma atop stems of strong creeping red fescue are the outward manifestation of an endophyte (*Epichloe typhina*).

FIGURE 6 Presence of endophyte (*Acremonium* spp.) gives turfgrass resistance to insect attack and enhances recovery from drought.

that will maintain a more attractive appearance, exclude weeds, and resist drought. It would be unwise to buy "common" seed of any species as long as there are cultivars that would better suit specific roadside needs. For example, buyers should not accept seed whose label says simply "Kentucky bluegrass" or "perennial ryegrass" or "tall fescue" without a cultivar name that denotes superior characteristics for the site, use, and management to which it will be subjected.

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Priority Rating of Highway Routine Maintenance Activities

TIEN F. FWA, KUMARES C. SINHA, AND JOHN D. N. RIVERSON

This paper presents a procedure for determining priority ratings of highway routine maintenance activities by highway class and distress condition. In contrast to the common practice of assigning priority ratings based on an aggregated pavement condition index, a scheme that generates maintenance activity specific priority ratings was adopted in this study. Since there exists a large number of maintenance activity–highway class–distress severity combinations to be rated, a partitioned two-stage survey procedure was adopted to reduce the number of factors in each rating phase to a size manageable by raters. This rating procedure was used to obtain priority factors for routine maintenance activities in Indiana. These priority data have been incorporated into an optimal routine maintenance programming model proposed for use at the district and subdistrict levels of the Indiana Department of Highways. Using the application as an example, the paper describes the salient features of the procedure and the steps involved in computing the final priority scores for individual maintenance activities. It also provides an analysis of the Indiana data to demonstrate how other useful information on routine maintenance practice could be derived from this form of study.

Efficient programming and scheduling of routine maintenance activities are vital to the success of pavement maintenance management at both project and network levels. More and more agencies are now using or looking into the possibility of using computer mathematical models to perform the work of programming and scheduling pavement maintenance activities (*1–5*).

While mathematical programming of routine maintenance activities using the computer undoubtedly has great potential for improving efficiency and reducing costs, the applicability and usefulness of the results obtained from such an analysis depend on the accuracy and reasonableness of input and constraint factors (*1*, *5*). The priority ratings of various routine maintenance activities are one of the most important input factors, with a great impact on the final outcome of a mathematical programming analysis. Unfortunately, the complete priority information that is required for a meaningful programming and scheduling analysis is very often not available.

Because of the lack of priority information on routine maintenance activities, a survey was recently conducted in Indiana to acquire the necessary data. This paper describes the rating procedure adopted and the steps involved in arriving at the final priority ratings for different routine maintenance activities by highway class and severity level of road distress condition. Using the Indiana data, analyses were performed to illustrate how other useful information on routine maintenance practice could be derived from this form of study. Finally, the need for each highway agency to establish maintenance priority ratings appropriate for its own program is stressed.

CONSIDERATIONS IN PRIORITY RATING ASSESSMENT

A number of different priority assessment schemes have been reported in the literature (*1*, *3*, *6–8*). Practically all of these schemes rely on defining certain numeric indices, such as pavement condition index, maintenance needs index, and defect rating value, which are computed using data obtained from pavement condition surveys. These indices form the basis for priority assessment purposes. The key difference between these schemes and the scheme proposed in this study is that, instead of using an aggregate index to represent maintenance needs and to set priorities, the present study developed maintenance-activity-specific priority ratings. In other words, priority ratings are assigned explicitly to routine maintenance activity types.

Advantages and Disadvantages of Present Approach

The form of priority ratings generated by the scheme described in this study has been incorporated in a highway routine maintenance optimization programming model (*9*). The experience shows that the advantages of this approach include the following:

1. Maintenance-activity-specific priority ratings have a clear-cut physical meaning that is easily understood by both planning and field maintenance personnel. In contrast, using a numeric index to represent different distress conditions involves data transformation and subjective judgment that may not be shared by the maintenance personnel at different levels.
2. Specific routine maintenance activities can be easily matched with labor, material, equipment, construction productivity, and time requirements. This link is particularly useful in programming and scheduling routine maintenance activities for agencies directly involved with planning and executing field maintenance. The establishment of such a link is not straightforward in schemes where aggregate pavement conditions indices are used as the basis for priority rating.
3. Data collected in the maintenance-activity-specific priority rating scheme can be further processed, as illustrated in a

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later section of this paper, to extract useful information on routine maintenance practice. Much of this information would be lost if maintenance needs data are aggregated into a common numeric index.

The disadvantage of the proposed approach is with the acquisition of priority rating data. The number of entries to be priority rated is much bigger and more difficult to handle, compared with a single index variable in most condition-index-based priority-setting schemes.

Factors Affecting Priority Ratings

The relative priorities of various routine maintenance activities are influenced by a number of factors. The following possible factors were identified in the present study:

1. Routine maintenance activity type. Highway pavement routine maintenance encompasses activities undertaken on a regular or continual basis to serve as (a) preventive measures against pavement deterioration or as (b) corrective measures to repair minor pavement damages. Each of these activities has a different impact on restoring pavement condition and lengthening of pavement service life.
2. Highway class. Highways of different classification receive different degrees of attention from highway agencies. A highway with a higher degree of importance will receive maintenance earlier than another highway needing the same type of maintenance.
3. Road distress condition. A highway section with a more severe distress would be repaired sooner than one with a less severe distress condition.
4. Seasonal effect. Not all maintenance activities can be performed throughout the year. For instance, certain activities may have to be suspended in the winter because of either weather constraints or considerations of repair effectiveness. These activities would therefore be given no priority during the winter months, even though they might have high priorities in the other seasons of the year.
5. Climatic and environmental factors. Pavements in regions with different climate and environmental conditions behave differently. The prevailing types of pavement distresses in different regions are not likely to be the same. The priority ratings for different maintenance activities would therefore be different.
6. Maintenance practice and policy. Highway agencies with different maintenance practices and policies place different emphases on different aspects of maintenance. Their priority ratings for various routine maintenance activities would not be the same.
7. Miscellaneous factors. Priority ratings of maintenance activities may also be affected by safety consideration, environmental concern, political influence, and other factors.

In theory, if n_1, n_2, n_3, n_4, n_5, n_6, and n_7 represent respectively the number of variables in each of the seven factors above, one would have to rate in priority order a total of ($n_1 \times n_2 \times n_3 \times n_4 \times n_5 \times n_6 \times n_7$) combinations. This is, however, rarely the case in practice. For example, Factors 5 and 6 are likely to be location specific and would not vary greatly over a relatively large area. To account for Factor 4, one may choose to produce different sets of priority lists for different seasons.

In the present study, Factors 1, 2, and 3 were considered explicitly. Factors 5 and 6 were addressed at the survey sampling stage, when areas with different conditions in the two factors were identified and sampled separately. Because the survey was conducted in the summer, the results may not be applicable to winter months due to seasonal effects. Factor 7 was not included, but it is likely that miscellaneous factors influenced individual raters in arriving at their priority scores.

THE SURVEY PROCEDURES

The survey began with a statistical sampling of surveyed units, followed by field interviews of maintenance personnel in the selected units. Details of the two phases are described below.

Statistical Sampling

The survey units in this study were selected from a stratified random sampling process (*10*, *11*). A stratified random sampling is a restricted randomization sampling design in which the experimental units are first sorted into homogeneous groups or blocks. The required number of experimental units is then randomly selected within each group.

There are three levels of maintenance management in the Indiana Department of Highways (IDOH): central office level, district level, and subdistrict level. Figure 1 shows the district locations in Indiana. The six districts clearly provide a logical

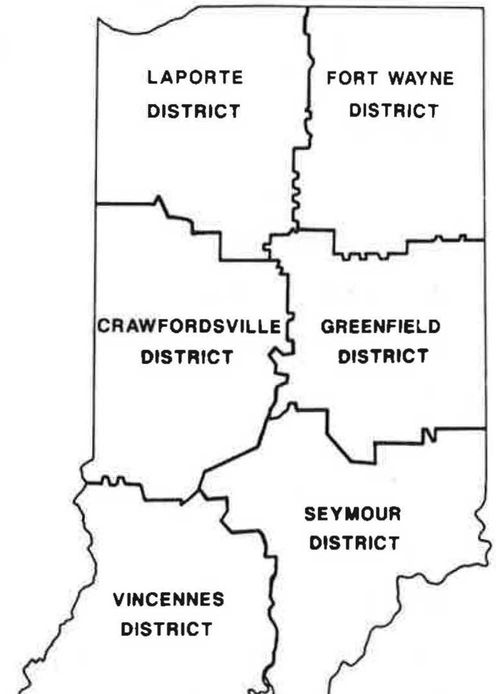


FIGURE 1 Highway districts in Indiana as stratification basis for survey sampling.

basis for stratification. Two subdistricts were randomly selected from each district to form the survey units.

The stratification by district also serves well to represent two distinct climatic conditions found in Indiana. Past studies in Indiana (*12,13,14*) have indicated the presence of two climatic regions: the colder north region, represented by the two northernmost districts; and the relatively warmer south region, which includes the remaining four districts. A total of 36 representatives of maintenance staff from the survey units were surveyed. Sixteen of the staff surveyed were from the north region and 20 from the south region.

Priority Rating Procedure

The factors included in the survey were maintenance activity type, highway class, and distress severity level of the road needing the activity. Fourteen routine maintenance activities involving pavement, shoulder, and drainage were investigated. Table 1 presents the list of maintenance activities investigated.

The highway classes defined were (a) Interstate and (b) other state highways (OSH). OSH was further broken into two categories: high-traffic-volume OSH, with more than 400 vehicles per day (vpd); and low-traffic-volume OSH, with less than 400 vpd. The traffic volume classification was chosen to provide broad guidelines for differentiating maintenance priorities of the various highways. For road conditions, three levels of distress severity were considered—severe, moderate, and slight.

TABLE 1 LIST OF HIGHWAY MAINTENANCE ACTIVITIES INVESTIGATED

Code	Description
201	Shallow Patching
202	Deep Patching
203	Premix Leveling
204	Full Width Shoulder Seal
205	Seal Coating — Chip Seal
206	Sealing Longitudinal Cracks and Joints
207	Crack Sealing
208	Sand Seal
210	Spot Repair of Unpaved Shoulders
211	Blading Unpaved Shoulders
212	Clipping Unpaved Shoulders
213	Reconditioning Unpaved Shoulders
231	Clean and Reshape Ditches
234	Motor Patrol Ditching

A simple calculation shows that there are 14 × 3 × 3 = 126 entries to be priority rated. Simultaneous rating of all 126 entries was out of the question. Pairwise comparison was theoretically possible but not practical due to the large number of possible combinations. To reduce the problem to a manageable size, the contributing factors were partitioned into two categories and examined independently. Figure 2 shows the flow diagram of the survey. Part 1 of the survey dealt with assigning priority scores to individual routine maintenance activities in accordance with their relative importance in preserving highway pavement conditions at a desired level. In Part 2, priority scores were assigned to different pavements of various highway classes by road distress severity level according to the relative urgency of the need for maintenance work.

To aid raters in arriving at priority scores more quickly and efficiently, the following measures were taken:

1. A two-stage rating procedure was adopted. Raters were first asked to rank the entries with all potential ties considered. Keeping the order of the ranks, the raters were next asked to assign a priority score to each on a 10-point scale.
2. Instead of using tables or forms, a set of cards with a different maintenance activity written on each was given to each rater. By allowing each rater to place the cards in rank order and then move them into relative positions above or below each other along the 10-point scale, realistic priority scores could be assigned fairly quickly.

The experience of the survey indicated that this rating procedure was well received by raters, and satisfactory results were obtained in an unambiguous manner. Figure 3 shows the priority rating scale along with rater instructions used for Part 1 of the survey. An identical scale and similar rater instructions were used for Part 2 of the survey.

An alternative procedure would have been to adopt a tree-like survey structure, as shown in Figure 4. The raters would first rate all maintenance activities as in Part 1 of the survey in Figure 2, then proceed to repeat N_1 number of times the Part 2 rating process in Figure 2. However, this procedure is highly time consuming. Consequently, the survey procedure in Figure 2 was used in this study. The computational and analytic techniques discussed in the subsequent sections of this paper are, however, applicable to both procedures.

ANALYSIS OF SURVEY DATA

This section presents the results and computes the final priority ratings of routine maintenance activities by highway class and road condition severity level. In addition, this section shows that the data gathered in this form of study can be analyzed further to provide other useful information on routine maintenance practice. As an illustration, an analysis is presented which compares the maintenance practice of the north and south regions of Indiana.

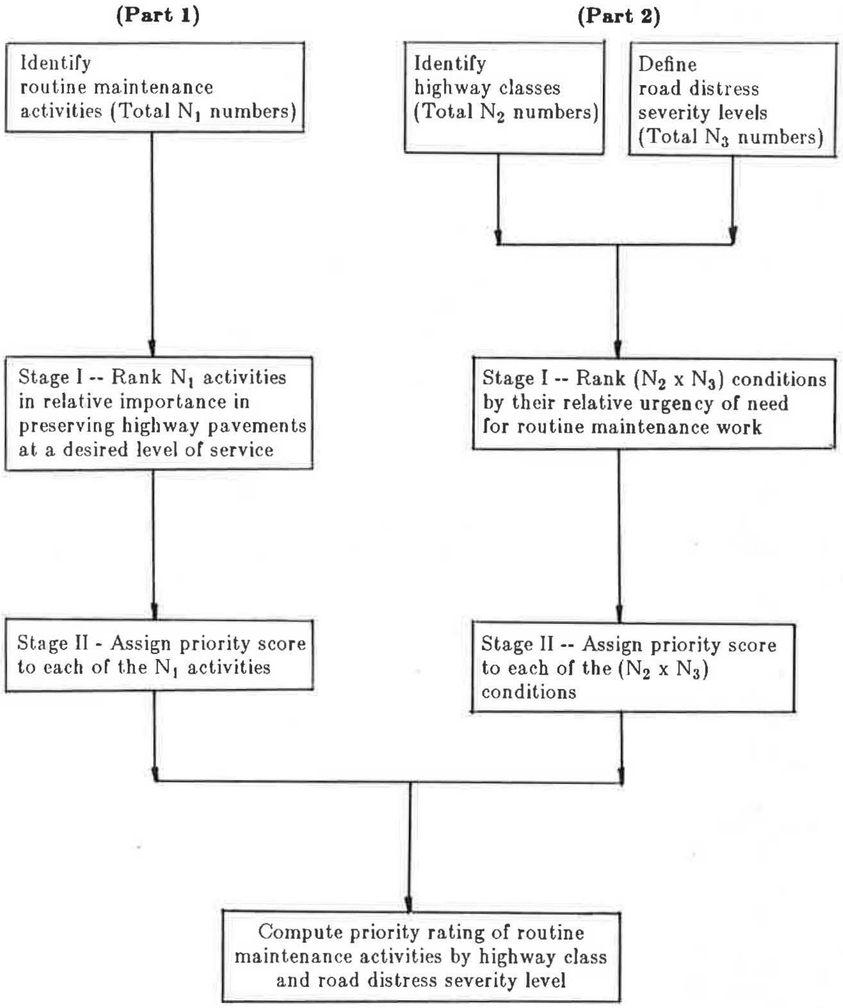


FIGURE 2 Activity flow chart for the partitioned two-stage survey procedure.

Computation of Final Priority Ratings

The data collected from Parts 1 and 2 of the survey (see Figure 2) are presented in Tables 2 and 3. Let f_1 and f_2 represent the priority scores obtained from the two parts. The final priority ratings of all routine maintenance activities can be computed as follows:

$$F_{ijk} = (f_1)_i \times (f_2)_{jk} \qquad i = 1, 2, \ldots, N_1,$$
$$j = 1, 2, \ldots, N_2,\ k = 1, 2, \ldots, N_3 \qquad (1)$$

where

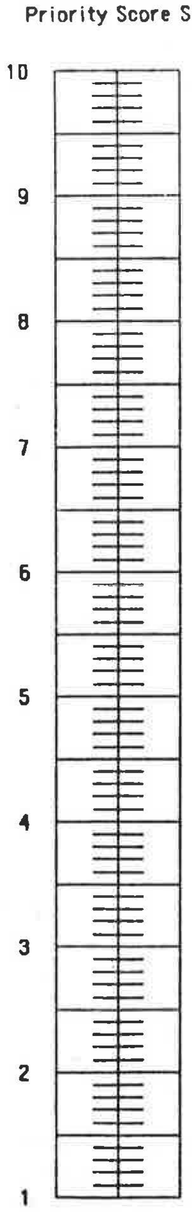
F_{ijk} = priority rating for routine maintenance activity i on highway class j with distress severity level k, $1 \leq F_{ijk} \leq 100$,
$(f_1)_i$ = priority score for routine maintenance activity type i in relation to all other routine maintenance activity types, $1 \leq (f_1)_i \leq 10$,
$(f_2)_{jk}$ = priority score for combination of highway class j and distress severity level k in relation to all other combinations of the two factors, $1 \leq (f_2)_{jk} \leq 10$,
N_1 = total number of routine maintenance activity types,
N_2 = total number of highway classes, and
N_3 = total number of distress severity levels.

In Equation 1, the rating score $(f_2)_{jk}$ can be considered to be a weighting factor applied to each maintenance activity. The priority ratings thus computed are recorded in Table 4. Priority scores for both the north and south regions are presented in the same table. These priority ratings provide the necessary information on the relative importance of various maintenance activities by highway class and distress severity level.

It should be mentioned that, instead of taking the product of f_1 and f_2, a slightly different set of priority ratings, F'_{ijk}, may be computed by adding f_1 and f_2 in the following manner:

$$F'_{ijk} = \frac{10}{(W_1 + W_2)}[W_1(f_1)_i + W_2(f_2)_{jk}]$$
$$i = 1,2,\ldots,N_1,\ j = 1,2,\ldots,N_2,\ k = 1,2,\ldots,N_3 \qquad (2)$$

where W_1 and W_2 are numeric weighting factors and all other symbols are as defined in Equation 1. The factor 10 is included



Instructions for Rater

Step 1. You are given 14 routine maintenance activity types, each written on a small card. Go through and read the activity types carefully.

Step 2. (Ranking Assignment) Rank the cards on your desk in accordance with the importance of each activity type in preserving pavement condition at a desired level. Put the most important activity at the top, followed by other activities in the order of decreasing importance. Ties are allowed.

Step 3. Carefully review the ranking in Step 2. Make changes if necessary.

Step 4. Move the top priority card to the top (i.e. a score of 10) of the scale on this instruction sheet. Next, move one card at a time, in sequence of decreasing importance, to the score and assign a score to each by comparing with the activity immediately above it. Continue until all the cards are placed on the scale.

Step 5. If the last card does not have a score of 1, adjust the scores (except the top score) so that the lowest priority activity has a score of 1.

Step 6. Carefully review the priority scores assigned. Make changes if necessary.

FIGURE 3 Priority rating scale and rater instructions.

so that F'_{ijk} will have the same range as F_{ijk} (i.e., $1 \leq F'_{ijk} \leq 100$).

In comparing the multiplication model of Equation 1 and the addition model of Equation 2, the absolute values of individual priority ratings do not carry much physical meaning. It is their relative magnitudes in the entire set of priority rating scores that makes the difference in routine maintenance programming and scheduling analysis. It is therefore of interest to examine the ability of the two models to differentiate relative priorities of routine maintenance activities.

Consider two maintenance activity–highway class–distress severity combinations, A and B. Let f_{a1} and f_{a2} be the priority scores of A from Parts 1 and 2 of the survey, respectively, f_{b1} and f_{b2} the corresponding priority scores of B, and F_A, F_B, F'_A, and F'_B be the respective final priority ratings for A and B computed from the two models. The following relationships can be shown (*15*):

Case 1. $\min(f_{a1}, f_{a2}) \geq \max(f_{b1}, f_{b2})$, $f_{a1} \neq f_{a2}$ or $f_{b1} \neq f_{b2}$ or both. We have $F_A > F_B$ and $F'_A > F'_B$. The two models agree.

Case 2. $\max(f_{a1}, f_{a2}) \leq \min(f_{b1}, f_{b2})$, $f_{a1} \neq f_{a2}$ or $f_{b1} \neq f_{b2}$ or both. We have $F_A < F_B$ and $F'_A < F'_B$. The two models agree.

Case 3. $f_{a1} = f_{a2} = f_{b1} = f_{b2}$. We have $F_A = F_B$ and $F'_A = F'_B$. The two models agree.

Case 4. $\max(f_{a1}, f_{a2}) \geq \max(f_{b1}, f_{b2}) \geq \min(f_{a1}, f_{a2}) \geq \min(f_{b1}, f_{b2})$. We have $F_A \geq F_B$ and $F'_A \geq F'_B$ The two models agree.

Case 5. $\max(f_{b1}, f_{b2}) \geq \max(f_{a1}, f_{a2}) \geq \min(f_{b1}, f_{b2}) \geq \min(f_{a1}, f_{a2})$. We have $F_A \leq F_B$ and $F'_A \leq F'_B$ The two models agree.

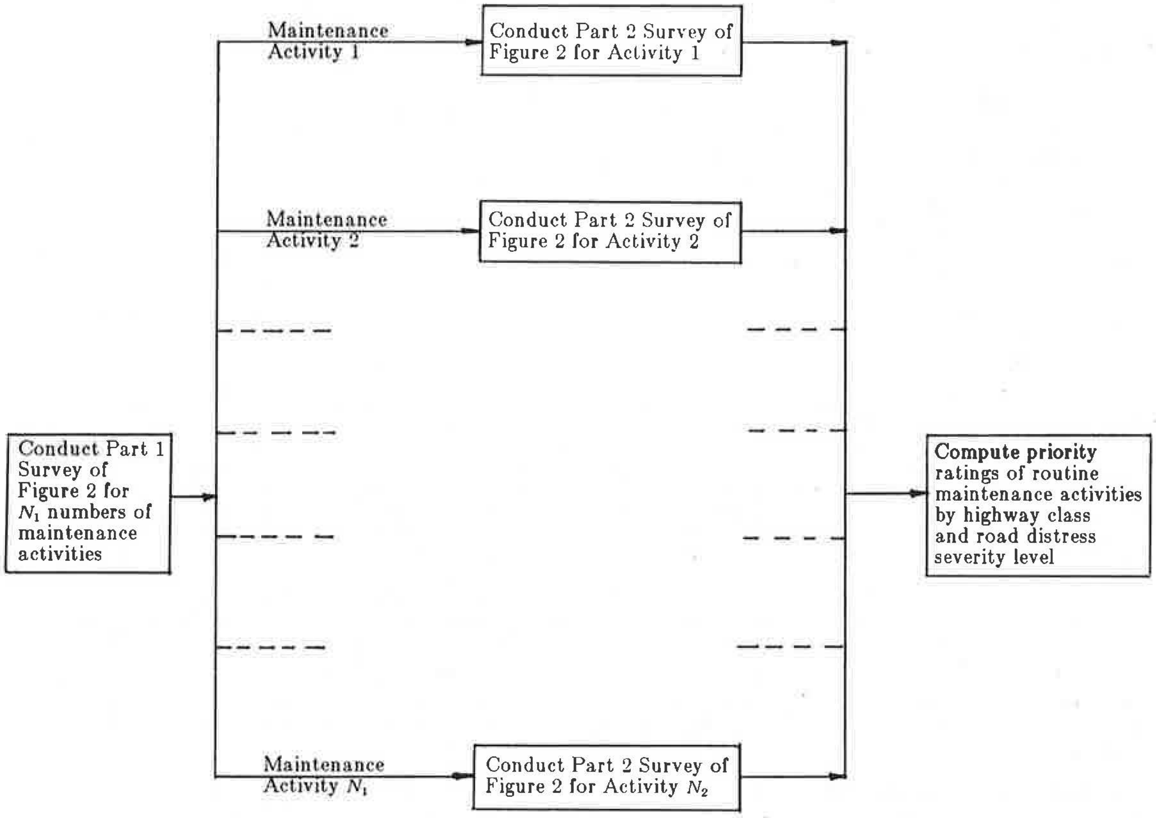


FIGURE 4 Activity flow chart for alternative survey procedure.

TABLE 2 RESULTS FROM PART 1 OF PRIORITY RATING SURVEY

Maintenance	North Region			South Region		
Activity	Average	Priority Score		Average	Priority Score	
Code	Rank	Average	95% Conf. Interval	Rank	Average	95% Conf. Interval
201	1	9.9	9.8 - 10.0	2	9.4	8.8 - 10.1
202	2	9.6	9.2 - 10.0	1	9.6	9.1 - 10.0
203	6	7.2	5.5 - 8.9	8	5.4	2.9 - 7.9
204	10	4.9	3.2 - 6.6	12	3.5	2.1 - 5.0
205	8	6.4	5.4 - 7.3	11	4.4	2.8 - 6.0
206	7	6.7	5.3 - 8.1	8	5.7	4.1 - 7.3
207	7	6.8	5.3 - 8.4	7	6.5	4.6 - 8.4
208	9	5.6	3.8 - 7.3	12	2.9	1.7 - 4.2
210	5	7.8	6.1 - 9.6	7	7.1	5.8 - 8.4
211	6	7.0	5.1 - 8.8	9	5.9	4.2 - 7.5
212	10	4.6	2.8 - 6.4	8	5.8	4.2 - 7.4
213	11	4.2	2.7 - 5.6	7	6.5	4.4 - 8.6
231	10	3.7	1.6 - 5.9	5	7.8	6.7 - 8.8
234	3	1.9	0.3 - 3.5	7	6.6	4.9 - 8.4

TABLE 3 RESULTS FROM PART 2 OF PRIORITY RATING SURVEY

Highway Class	Distress Severity Level	North Region			South Region		
		Average Rank	Priority Score		Average Rank	Priority Score	
			Average	95% Conf. Interval		Average	95% Conf. Interval
Interstate	Severe	1	10.0	10.0 - 10.0	1	10.0	10.0 - 10.0
	Moderate	3	8.7	8.2 - 9.2	4	8.1	7.3 - 8.6
	Slight	6	6.3	4.7 - 7.8	7	4.1	2.8 - 5.4
High Volume OSH	Severe	2	9.4	8.9 - 9.9	2	9.6	9.5 - 9.7
	Moderate	5	7.8	7.2 - 8.3	5	7.3	6.8 - 7.9
	Slight	8	4.3	3.0 - 5.6	7	3.7	2.2 - 5.1
Low Volume OSH	Severe	5	7.4	6.4 - 8.3	4	7.6	6.0 - 9.3
	Moderate	7	4.9	3.6 - 6.4	7	3.8	2.2 - 5.5
	Slight	9	1.0	1.0 - 1.0	9	1.0	1.0 - 1.0

TABLE 4 PRIORITY RATINGS OF ROUTINE MAINTENANCE ACTIVITIES BY HIGHWAY CLASS AND DISTRESS SEVERITY LEVEL

Routine Maintenance Activity Code	Interstate			High Volume OSH			Low Volume OSH		
	Distress Severity Lev.			Distress Severity Lev.			Distress Severity Lev.		
	Severe	Moderate	Slight	Severe	Moderate	Slight	Severe	Moderate	Slight
201	99 (N) 94 (S)	86 (N) 76 (S)	62 (N) 39 (S)	93 (N) 90 (S)	77 (N) 70 (S)	43 (N) 35 (S)	73 (N) 71 (S)	49 (N) 36 (S)	10 (N) 9 (S)
202	96 (N) 96 (S)	84 (N) 78 (S)	60 (N) 40 (S)	90 (N) 92 (S)	75 (N) 70 (S)	41 (N) 36 (S)	71 (N) 73 (S)	47 (N) 35 (S)	10 (N) 10 (S)
203	72 (N) 54 (S)	63 (N) 44 (S)	45 (N) 22 (S)	68 (N) 52 (S)	56 (N) 39 (S)	31 (N) 20 (S)	53 (N) 38 (S)	35 (N) 21 (S)	7 (N) 5 (S)
204	49 (N) 35 (S)	43 (N) 28 (S)	31 (N) 14 (S)	46 (N) 34 (S)	38 (N) 26 (S)	21 (N) 13 (S)	36 (N) 27 (S)	24 (N) 13 (S)	5 (N) 4 (S)
205	64 (N) 44 (S)	56 (N) 36 (S)	40 (N) 18 (S)	60 (N) 42 (S)	50 (N) 32 (S)	28 (N) 16 (S)	47 (N) 33 (S)	31 (N) 16 (S)	6 (N) 4 (S)
206	67 (N) 57 (S)	58 (N) 46 (S)	42 (N) 23 (S)	63 (N) 55 (S)	52 (N) 42 (S)	29 (N) 21 (S)	50 (N) 43 (S)	33 (N) 22 (S)	7 (N) 6 (S)
207	68 (N) 65 (S)	59 (N) 53 (S)	43 (N) 27 (S)	64 (N) 62 (S)	53 (N) 47 (S)	29 (N) 24 (S)	50 (N) 50 (S)	33 (N) 25 (S)	7 (N) 7 (S)
208	56 (N) 29 (S)	49 (N) 23 (S)	35 (N) 12 (S)	53 (N) 28 (S)	44 (N) 21 (S)	24 (N) 11 (S)	41 (N) 22 (S)	27 (N) 11 (S)	6 (N) 3 (S)
210	78 (N) 71 (S)	68 (N) 58 (S)	49 (N) 29 (S)	73 (N) 68 (S)	61 (N) 52 (S)	34 (N) 26 (S)	58 (N) 54 (S)	38 (N) 27 (S)	8 (N) 7 (S)
211	70 (N) 59 (S)	61 (N) 48 (S)	44 (N) 24 (S)	67 (N) 57 (S)	55 (N) 43 (S)	30 (N) 22 (S)	52 (N) 46 (S)	34 (N) 12 (S)	7 (N) 6 (S)
212	46 (N) 58 (S)	40 (N) 46 (S)	29 (N) 23 (S)	43 (N) 55 (S)	36 (N) 42 (S)	20 (N) 21 (S)	34 (N) 43 (S)	23 (N) 22 (S)	5 (N) 6 (S)
213	42 (N) 65 (S)	37 (N) 53 (S)	26 (N) 27 (S)	39 (N) 62 (S)	33 (N) 47 (S)	18 (N) 24 (S)	31 (N) 50 (S)	21 (N) 25 (S)	4 (N) 7 (S)
231	37 (N) 78 (S)	32 (N) 63 (S)	23 (N) 32 (S)	35 (N) 75 (S)	29 (N) 57 (S)	16 (N) 29 (S)	27 (N) 59 (S)	18 (N) 30 (S)	4 (N) 8 (S)
234	19 (N) 66 (S)	17 (N) 53 (S)	12 (N) 27 (S)	18 (N) 63 (S)	15 (N) 48 (S)	8 (N) 24 (S)	14 (N) 50 (S)	9 (N) 32 (S)	2 (N) 7 (S)

Note: (N) stands for North Region, and (S) stands for South Region.

Case 6. $\max(f_{a1},f_{a2}) \geq \max(f_{b1},f_{b2}) \geq \min(f_{a1},f_{a2}) \geq \min(f_{b1},f_{b2})$, or $\max(f_{b1},f_{b2}) \geq \max(f_{b1},f_{b2}) \geq \min(f_{a1},f_{a2}) \geq \min(f_{b1},f_{b2})$. The two models may agree or differ, depending on the magnitudes of f_{a1}, f_{a2}, f_{b1}, and f_{b2}, and the relative values of W_1 and W_2 in Equation 2.

The two models produce the same order of relative magnitude in priority ratings for Cases 1 through 5, but discrepancies are found in Case 6. This means that (a) regardless of the computation method used, the top and bottom portions of the priority rating list are likely to stay unchanged; and (b) the discrepancies would lead to some differences in the order of priority ratings in the middle portion of the list. In the context of the present study, the computation selected is unlikely to affect much the relative priority ratings of important maintenance activities on Interstate or high-volume OSH with high distress severity levels. These are the activities that are of major concern in a routine maintenance programming analysis. To quantitatively assess the difference between the models, a statistical correlation analysis was performed *(10)* to compare the set of priority ratings in Table 4 and one computed from Equation 2 with $W_1 = W_2$. The coefficient of correlation found was 0.966, showing an excellent positive association between the priority ratings obtained from the two methods. The impact of the choice of computation method is, therefore, not likely to be great on priority ratings used for routine maintenance planning purposes.

While the multiplication model is used in this study, one should not overlook the potential usefulness of the addition model. A highway agency may to some extent influence the results in favor of certain policy preferences through the use of weighting factors W_1 and W_2. The values of W_1 and W_2 are, however, not expected to be very different from the simple case of $W_1 = W_2$ in normal conditions.

Analysis of Priority Rating Data

An analysis was conducted to compare the maintenance practice of the north and south regions of Indiana. Plotted in Figures 5, 6, and 7 are data obtained from Table 4 for routine maintenance activities on Interstate, high-traffic-volume OSH, and low-traffic-volume OSH, respectively. Because of the large number of data points in the table, three plots instead of one were prepared for clarity of presentation.

In a priority rating comparison analysis, as mentioned in the preceding section, one is interested in the relative magnitudes of priority values within each set of ratings. For instance,

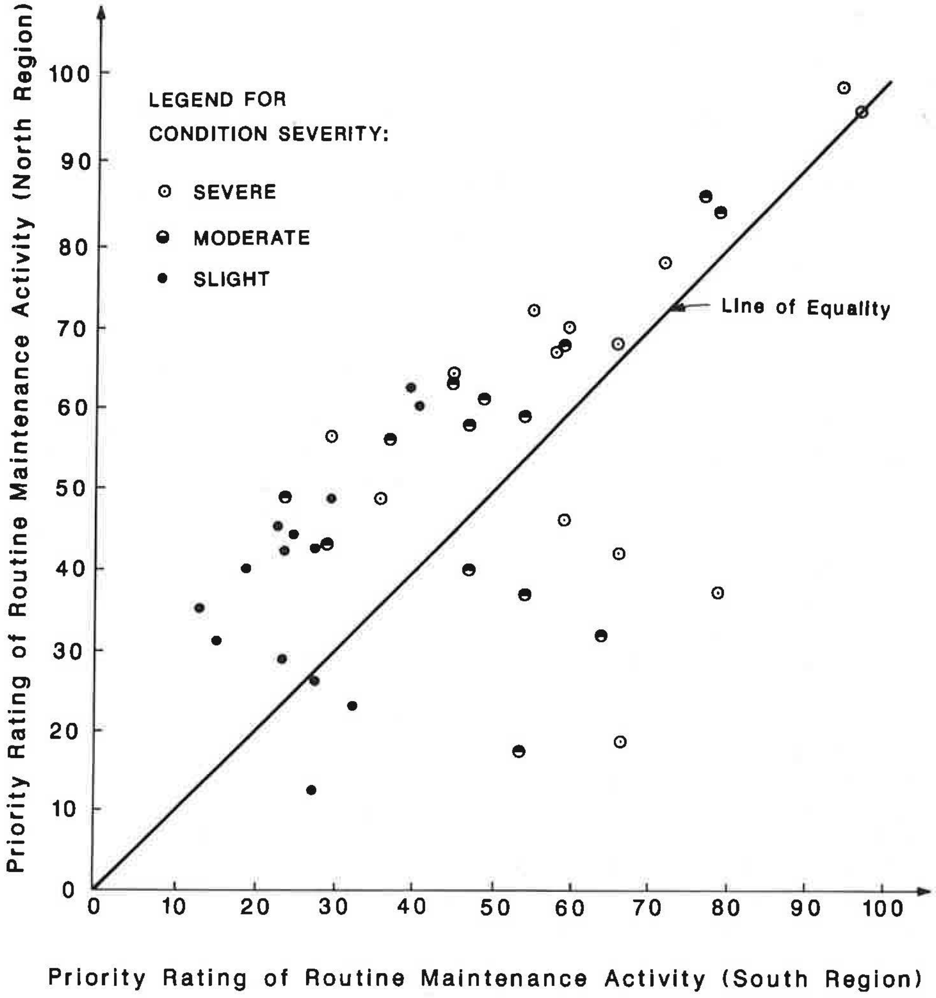


FIGURE 5 Comparison of north and south region priority ratings for maintenance activities on Interstate.

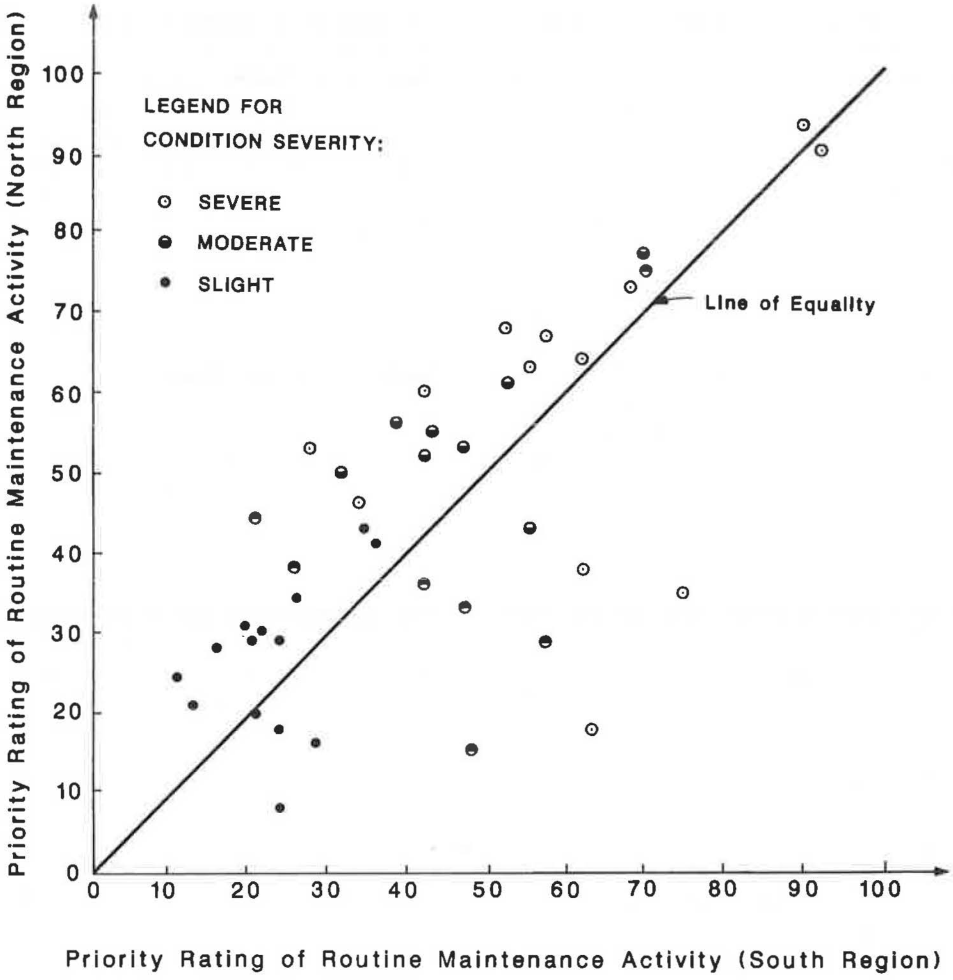


FIGURE 6 Comparison of north and south region priority ratings for maintenance activities on high-volume OSH.

Rating Panel A may award priority values of 20, 30, 40, and 50 to four different maintenance activities, while Rating Panel B awards 40, 50, 60, and 70, and Panel C awards 30, 20, 50, and 40 to the same activities. It is clear that there is no difference between the Panel A and B scores for the purpose of routine maintenance programming, but that the Panel C scores are quite different from those of the other two. The statistical coefficient of correlation, *r*, would again be an appropriate parameter to measure this difference (*10*). Panels A and B would give a *r* value of 1.0, which means a perfect linear association between the two sets of priority scores. Panels A and C or B and C produce a much lower *r* value of 0.60, indicating a relatively poor association between the two sets compared.

Using all the 126 pairs of priority scores in Table 4, computation gives a value of *r* equal to 0.74. This shows that the agreement between the priority ratings of the north and south regions was only fair. However, a closer examination of the plots in Figures 5, 6, and 7 shows that (a) all the points that lie below the line of equality belong to four maintenance activities (212, 213, 231, and 234) and (b) all other data points tend to cluster relatively closely within a straight band.

A revised computation confirms the above observation. The results are indicated in Table 5. Considering only the first 10 maintenance activities in Table 4, a *r* value of 0.95 was obtained. For the last four maintenance activities (i.e., Activities 212, 213, 231, and 234) the *r* value computed was 0.69. These results reveal that the north and south maintenance personnel were in excellent agreement over the priority ratings of most maintenance activities, except for the four activities mentioned above. These four activities are mainly drainage-related maintenance work. The south region personnel placed more priority on these activities compared with their counterpart in the north region. This is possibly due to climatic and topographical differences between the two regions. The south has steeper and more rolling to hilly terrain. It also has more rainfall, with an annual average of more than 40 in. compared with about 35 in. in the north.

A study of the priority rankings in Table 2 indicates that both the north and south region maintenance personnel gave highest priorities to pavement-related activities such as shallow and deep patching, premix leveling, and crack sealing. The main discrepancy arose when the south region maintenance personnel assigned appreciably higher priorities to the last four drainage-related activities. If these four activities are set aside, the two groups of maintenance personnel agreed closely on the relative priority rankings of the remaining activities. These observations concur with comments made in the preceding paragraph.

The pattern of the comparison plot seen in Figure 5 for Interstate is repeated very closely in the plot in Figure 6 for high-volume OSH and again in Figure 7 for low-volume OSH.

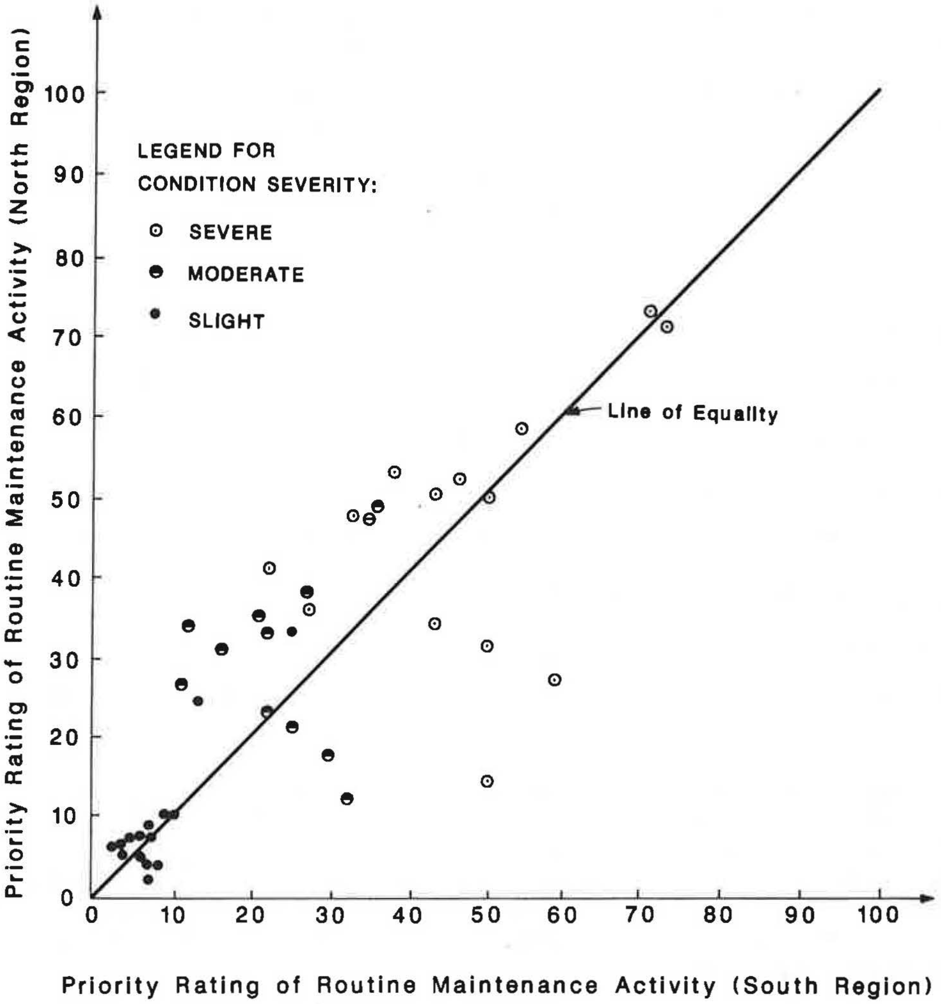


FIGURE 7 Comparison of north and south region priority ratings for maintenance activities on low-volume OSH.

This reflects indirectly a measure of consistency in the rating results. The partitioning technique and the two-stage procedure used in the survey process appeared to have produced logical, realistic ratings from the raters. The three plots also show a progressive shift in the position of general data points toward the low-priority area (at the lower left-hand corner of the plots) as one moves from Interstate to high-volume OSH and then to low-volume OSH. This roughly reflects the priority rankings of various highway classes depicted in Table 3.

Summary of Findings

The main findings of the Indiana study are summarized below:

1. The partitioned two-stage survey procedure was well received by raters. The process was found to be quick, easily understood, and easily implemented by maintenance personnel with different levels of knowledge and experience. Analyses of the data showed that logical realistic ratings were obtained from raters. The results provided a consensus view of the unwritten but important daily decision-making process governing routine maintenance practices of the highway maintenance agencies in Indiana.

2. The priority ratings from the north and south regions of Indiana showed, overall, a fair degree of agreement, although the south region maintenance personnel placed significantly higher priorities on drainage-related activities compared with their north region counterparts. The two groups showed excellent agreement on the relative priorities of other routine maintenance activities. Both assigned highest priorities to pavement-related activities on Interstate and high-volume OSH, and lowest priorities to activities on low-volume OSH with moderate and low distress severity levels.

3. The difference in the priority ratings between the two regions is believed to be related to the differences in their climatic and topographical conditions. One would therefore expect variations in priority ratings of maintenance activities among regions with different climatic and environmental conditions.

CONCLUSION

A partitioned two-stage survey scheme was implemented and found to be effective in assessing priority ratings of routine maintenance activities by highway class and road distress severity. The maintenance-activity-specific priority data were

TABLE 5 COEFFICIENTS OF CORRELATION BETWEEN PRIORITY SCORES OF ROUTINE MAINTENANCE ACTIVITIES OBTAINED FOR THE NORTH AND SOUTH REGIONS OF INDIANA

Group of Maintenance Activities	Interstate	OSH with High Traffic Volume	OSH with Low Traffic Volume	All Highways Combined
First 10 Activities in Table 4	0.97	0.96	0.94	0.95
Activities 212, 213, 231 and 234	0.44	0.61	0.78	0.69
All 14 Activities in Table 4	0.60	0.69	0.80	0.74

informative and useful in providing meaningful insight into the routine maintenance practices of highway agencies.

Since the priority ratings are influenced by seasonal factors, climatic and environmental conditions, highway maintenance policy emphasis, and pavement maintenance and repair technology, there is a need for each highway agency to develop its own set of routine maintenance priority ratings and to periodically update these ratings as a part of the continuing process of highway pavement maintenance management.

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