Benefit-Cost Comparison of Salt-Only Versus Salt-Abrasive Mixtures Used in Winter Highway Maintenance in the United States

David A. Kuemmel and Quazi Bari, *Marquette University*

A study at Marquette University examined accident rates and benefit-cost estimates of winter maintenance operations by state agencies that use primarily salt-abrasive mixtures as deicers. The study methodology was patterned after a prior study at Marquette with state agencies that used primarily salt alone as a deicer. The recent study included 788.8 km of two-lane highway and 92.8 km of freeway in five maintenance districts in four states. The study was conducted during the winters of 1992–1993 and 1993–1994. Field data, which were collected by the state departments of transportation, included event and weather information and the amount of salt and abrasives used for more than 781 events. Traffic volumes were adjusted for seasonal, daily, hourly, and snow-reduction variations. Before and after accident rates were calculated, and benefit-cost estimations were made for both two-lane highways and freeways. Accident rate reductions were calculated and benefits were measured. Standard benefit analysis was performed for increased fuel savings and reduced travel time. Accident reductions for two-lane highways on which salt-abrasive mixtures were used were less than those of the prior study of salt-only use. Accident reductions for freeways were much less and took much longer to occur when salt-abrasive mixtures were used, compared with the reductions with salt only. Benefit-cost calculations showed that the application of salt-abrasive mixtures did not recover winter maintenance costs on two-lane highways during the 12-hr analysis period. This finding is affected by the low number of accidents. Benefit-cost calculations showed that freeway operations recovered costs in 6 hr, substantially longer than with salt only. Comparisons are made between the results of accidents and benefit-cost data between the two studies (salt-only and salt-abrasive mixtures).

The benefits of winter maintenance can be categorized as direct and indirect. Direct benefits include improved travel time, reduced travel costs, and reduced accidents and can be estimated or are measurable (*1*). Indirect benefits are those on a socio-economic level and include reduction in lost wages, maintenance of business opportunities and social activities, and provision of close-to-normal fire, police, ambulance, and paramedic services.

The costs of winter maintenance can likewise be categorized as direct and indirect (*1*). Direct costs are agency costs to perform winter maintenance activities. They include the costs of labor, material, and equipment to plow snow and apply ice control chemicals, as well as the costs of equipment repair, snow fence installation, abrasive cleanup, and supervision (*1*). Indirect costs include environmental costs associated with the use of ice control chemicals and abrasives and those related to corrosion of highway components and vehicles. The most complete study of indirect costs of deicing is one by the Transportation Research Board (TRB) in 1991 (*2*). Also, a 1991 study by the Denver Council of Regional Government reported the problems with air quality following heavy use of abrasives (*3*). This study deals with rural highways and direct benefits and costs.

The Marquette University study goals were to compare winter maintenance results achieved by agencies that generally use salt only to reach bare pavement as quickly as is practical, with results achieved by agencies that generally use salt-abrasive mixtures to produce a given level of service. Specifically, the study measured:

- Differences in accident rates before and after treatment,
- Differences in benefit-cost ratios of operations, and
- Differences in accident rates as the percent of salt varied from minimal (5 to 10 percent) up to 50 percent.

METHODOLOGY

Data Gathering

Highway Selection

The research was conducted between 1992 and 1995 by personnel at Marquette University. The states involved in the study were Iowa, Minnesota, New York, and Pennsylvania. Only highways under the states' jurisdiction were included. Within five maintenance districts in the four states, highways were selected jointly by the states and the research team without regard to geometry or their accident potential. The goal was to pick lengths of highway similar to those in the earlier Marquette University salt-only study. The following lengths of highway were used as test sections:

State	*Two-Lane Highways (km)*	*Freeways (km)*
Iowa (Mason City)	160	17.6
Minnesota (Rochester, Owatonna)	318.4	44.8
New York	144	30.4
Pennsylvania	166.4	0.0
Total length	788.8	92.8

General geometric characteristics of the two-lane test sections were 3.33-m or 3.63-m lanes and 0.91-m to 3.03-m paved or gravel shoulders. Divided highways had four 3.63-m-wide lanes and 3.03-m paved shoulders.

State Winter Maintenance Policies

Iowa generally uses 50 percent rock salt (hereafter referred to as salt) and 50 percent abrasives (*4*). On lower-volume highways Iowa uses minimal salt but any blend may be used, depending on conditions.

In Minnesota, the percent of salt in the salt-abrasive mixture is varied depending on storm conditions but generally falls in the 5 to 60 percent range on rural highways and can be 100 percent if dictated by winter conditions (*5*).

In New York, the policy is to discourage general abrasive use, and most of the state uses 100 percent salt only (*6*). The Watertown district policy is to use an approximately 25 percent salt-abrasive mixture because of the district's location at the end of Lake Ontario and adjacent to the St. Lawrence River.

In Pennsylvania's policy (*7*), priority, classification, time of day, and snow accumulation determine the amount of salt. On freeways, which have the highest priority, 100 percent salt is used. On second-priority highways, either salt only or salt-antiskid (abrasive) material is used, depending on temperature. On third-priority highways, a salt-abrasive mixture from minimal to 25 percent salt is generally used, depending on temperature.

Winter Event Data

Data collection occurred in the winters of 1992–1993 and 1993–1994. Because the winter maintenance policies varied, and because each storm had the potential to change the amount of salt used, an event reporting form was designed to provide the information required in each district. A key data gathering point, stressed in on-site meetings with the supervisors involved in each district, was to accurately determine the quantity of salt and abrasives in each application.

Traffic Volumes

All states provided average annual daily traffic (AADT) for the test sections.They also provided factors (or information) to adjust AADT for seasonal, daily, and hourly variations. Automatic traffic recorder (ATR) stations were used to develop an additional factor, known as the snow reduction factor. This is described in the data analysis section and is based on previous work by Marquette University (*8–10*).

When traffic volumes along a given test section (snow maintenance route) varied and were separately counted, these sections were broken into subsections and volume adjustments were calculated separately to derive million kilometers of travel (MKT).

Direct Benefit Data

Fuel savings related to winter maintenance were based on work by Claffey (*11*). Actual operating costs were not gathered, but the procedures from Claffey's work were used. The differences between gasoline consumed on snow covered or icy pavement and bare pavement in gallons per kilometer traveled, adjusted for travel speed and multiplied by MKT, were used to calculate excess fuel savings through winter maintenance. By using Claffey's methodology, the excess fuel for two-lane roads was determined to be 20 percent and the excess fuel consumed for freeways was 10 percent. The value of fuel savings for all events was then multiplied by the current price of gasoline in that region during the months of testing and averaged over all regions for the benefit calculation. It should be noted that the assumption in Claffey's work calls for bare pavements, and not all events resulted in bare pavement because service standards varied. This assumption tends to overstate any benefits from using salt-abrasive mixtures.

The American Association of State Highway Officials user benefit analysis methodology (*12*) was followed for savings in travel time. A 16-kph reduction in normal average travel speed of 64 kph (25 percent reduction) on two-lane highways and a 16-kph reduction of normal average travel speed of 96 kph (17 percent reduction) on freeways were assumed. These are more conservative than speed reductions reported in other work (*13*). The value of travel time of $3/hr was updated by using the implicit price deflator for the gross national product index (more conservative than the consumer price index), to $7.68 per travel hour in 1993 dollars.

In all states, the researchers worked with staffs to determine references for locating accidents by section and subsection to ensure that accidents were logged in the appropriate hour before or after the hour when the level of service was achieved with a final application (zero hour).

Accident cost data were reviewed from a variety of sources, including the National Safety Council (*14*) and a 1991 Federal Highway Administration report (*15*). The latter was used because it is more appropriate for benefit-cost calculations. The following values [adjusted to 1994 as recommended (*15*)] were used for the cost of each broad category of accidents: fatal accident, $2,722,548; injury accident, $69,592; and property damage only, $4,489. (Injury Categories A, B, and C were disregarded for uniformity purposes.)

Winter Maintenance Direct Costs

The winter maintenance costs for the entire season for each maintenance district were obtained following the close of the season for the second year of data gathering. These included labor, material, equipment, and supervision where applicable. Some states included substantial administrative costs and others included none. This does not significantly affect results, however, because the same procedure was followed in the salt-only study. Unit costs per event were averaged for the entire season by dividing the season's costs by the estimated number of events, and costs per event were averaged for all agencies.

Data Analysis

Winter Events

For purposes of this research, a winter event is described as the occurrence of winter maintenance on an entire length of test section because of freezing rain, formation of ice, or accumulation of snow. The section may have been treated with a mixture with or without plowing.

When an event form was received, it was reviewed by the researchers for completeness and to determine if it was a usable event, depending on the number of applications. Because multiple applications closely spaced in time could actually result in applying more salt to the roadway than salt-only treatment, it was agreed initially to limit selection of events to those with no more than three applications and not more than 50 percent salt mixed with abrasives per application. This was done to allow comparison with 100 percent salt applications.

When forms were reviewed, a zero hour was selected to be most representative of the middle of the last hour of application before achievement of level of service.

As data began to arrive, the researchers realized that many events had more applications, particularly in New York, where the area on the east end of Lake Ontario could have an event that lasted 4 days and could have 35 applications of a 25 percent salt mixture. To expand the database, it was decided to classify the events into regular and special events. The limit for the number of applications for regular events was raised to four in New York only and remained at three in the other states. Events with four or more applications in other states and five or more in New York were identified as special events for separate analysis. They are addressed in another report (*16*).

This change increased the number of included events, but the change was not tested for statistical significance. It also lessened the difference between agencies using salt only and those using multiple applications of salt-abrasive mixtures. This meant that differences in accidents would be potentially more conclusive.

If a section of highway for which an event occurred had a variation in traffic volumes, a subsection of highway was created in the database and an event became a subevent. There were 551 regular events in the 1992–1993 winter, and 230 regular events in the winter of 1993–1994. A total of 3,045 regular subevents for both winters was analyzed.

Traffic Volume Analysis

For purposes of a before-and-after accident analysis for each of the 12 hr before and after the zero hour, it was necessary to select the proper hourly traffic count for each of the appropriate 24 hr for each subevent to calculate MKT. The following formula was used for this conversion:

$$HTV_{nH} = AADT \times MF_M \times DF_D \times HF_H \quad (1)$$

where

HTV_{nH} = hourly traffic volume, normal day, for hour H,
MF_M = monthly factor for month M,
DF_D = day of week factor for day D, and
HF_H = hourly factor for hour H of the day.

MKT was then calculated by using the length of the subsection multiplied by HTV_{nH}.

A detailed description of the databases and the calculations is provided elsewhere (*16,17*). The methodology was also described elsewhere (*8–10*).

Daily Traffic Adjustment Factor

An analysis of daily factors was made by using the actual days and times of each event to determine if a daily factor was needed. The four scenarios from the earlier study were used to determine the impact on results if a day-of-the-week factor were not used. There are 198 events with underestimation of accidents and 194 with overestimation. Therefore, as in the earlier study, a day-of-the-week factor was not used.

Snow Reduction Adjustment Factor

It is conceivable that when it snows, traffic volumes may change by hour or by day. How much they can change was explained in work performed by Hanbali and Kuemmel (*9*). That approach was used in this study, and data from nearby ATR stations were used to adjust volumes on the basis of variations from a normal traffic day to arrive at the factors for either reduction of or increases in traffic during an event (*16,17*). Adjustments to reduce or increase volumes were applied to all hours to avoid any use of assumptions.

Accident Analysis

Each accident was identified to determine a match between the date and hour of the accident and the 24 hr surrounding the zero hour of any event. Accidents were tabulated in accidents per MKT, as used in similar studies in Europe (*18*) and the United States (*1,8–10*) for each test section and subsection. MKT also was accumulated for all subevents, for each of the 12 hr before and after zero hour, by using databases described previously. Separate tabulations were made for two-lane highways and freeways for regular events. The computerized database performed approximately 75,000 calculations of MKT. After MKT was established, accident rates were calculated by hand for each hour.

Accident rate reductions (or increases) were calculated for each cumulative hour following zero hour for both two-lane highways and freeways, for both injury and property-damage-only accident rates (there were no fatalities). These rate reductions were multiplied by the appropriate cost and type of accident to arrive at total savings due to reduction in accidents.

Treatment of Variables

In a study of this type, many variables were not accounted for simply because they are nearly impossible to account for. Human factors, roadway geometry, maintenance policies, and weather all varied. The use of control sections was not possible. More than 1,000 events with a variety of traffic, geometry, and weather conditions were analyzed, and it was believed that these events would be representative of a cross section of possibilities that would reduce the impact of any one variable.

Statistical Analyses of Accident Data

Following calculation of the accident rates for each of the 12 hr before and after the zero hour, the percent rate of change in accident rates was calculated for each of the cumulative pair of hours (conjugate hours). For example, in a comparison of the 4 hr before and after the zero hour, the percent rate of change was the difference between the cumulative accident rates for the 4 hr before (Hours −3 to 0) and the 4 hr after (hours 1 to 5) divided by 100.

Three separate statistical analyses were applied to the differences in these changes in accidents for each conjugate pair of hours. The Poisson and revised decision criteria were applied to the change in accident frequencies, and the paired *t*-test was applied to the percent rate of change of accident rates. The revised decision criterion test was developed by Weed (*19*) to meet some of the disadvantages of the Poisson test.

Finally, the paired *t*-test was used to draw inference of parameters between two populations. The data from this study use two dependent variables in the conjugate hours before and after zero hour. This will constitute two dependent samples from two populations (before and after accident rates), and in this case is the most appropriate test.

Research Results

Accident Results

Accident rates before and after (B/A) zero hour are shown in Figure 1 for two-lane highways and Figure 2

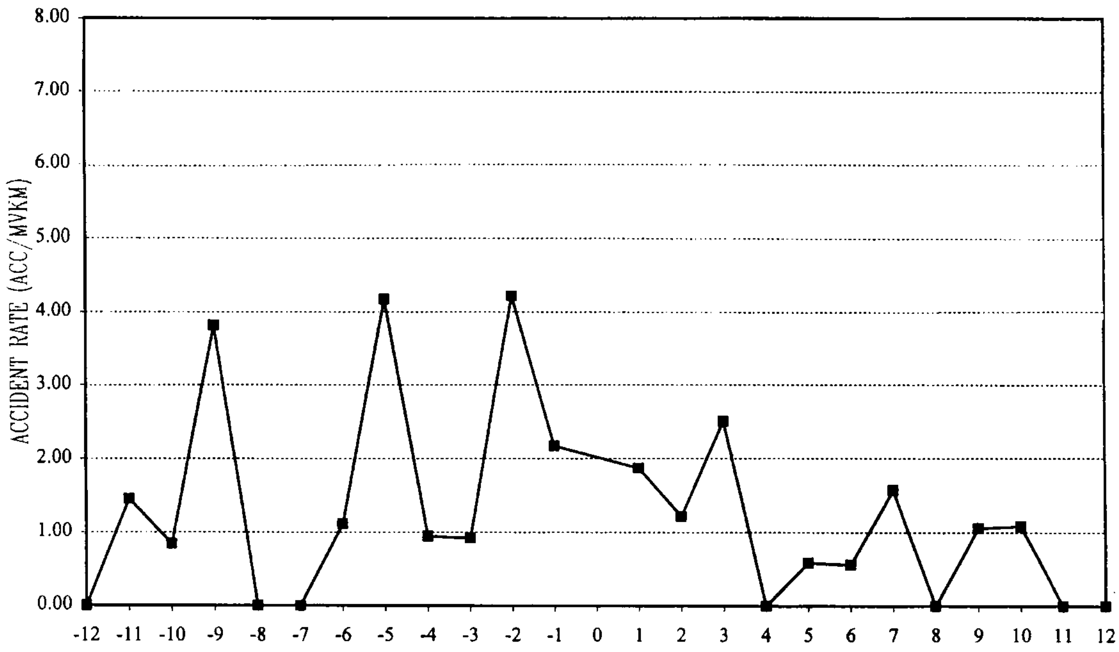

FIGURE 1 Accident rates for regular events, two-lane highways.

for freeways for all regular events in all states. Accidents and MKT were combined for two-lane and freeway test sections and the B/A accident rates were calculated for various groupings of percent salt in the salt-abrasive mixture. The results were inconclusive because of the insufficient accident data. A full discussion and results are presented elsewhere (*15,16*).

Results of Benefit-Cost Analysis

Winter Maintenance Costs

The direct costs of winter maintenance in each of the maintenance districts ranged from \$9 to \$63/lane-km/event. The average cost for all agencies was approximately

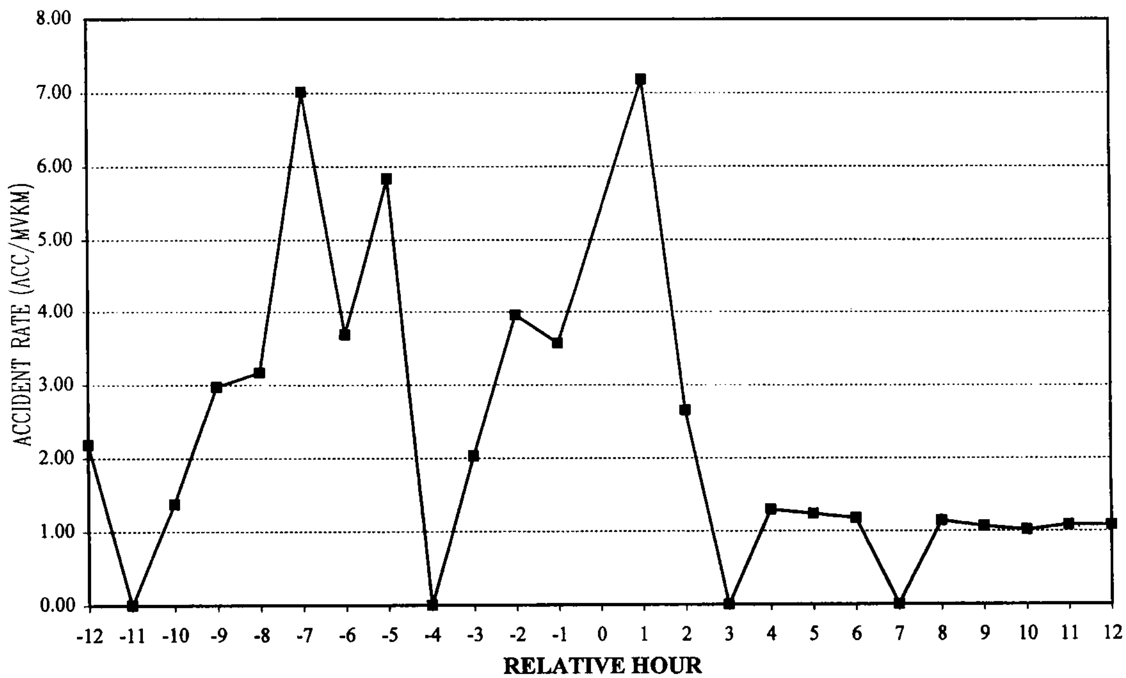

FIGURE 2 Accident rates for regular events, freeways.

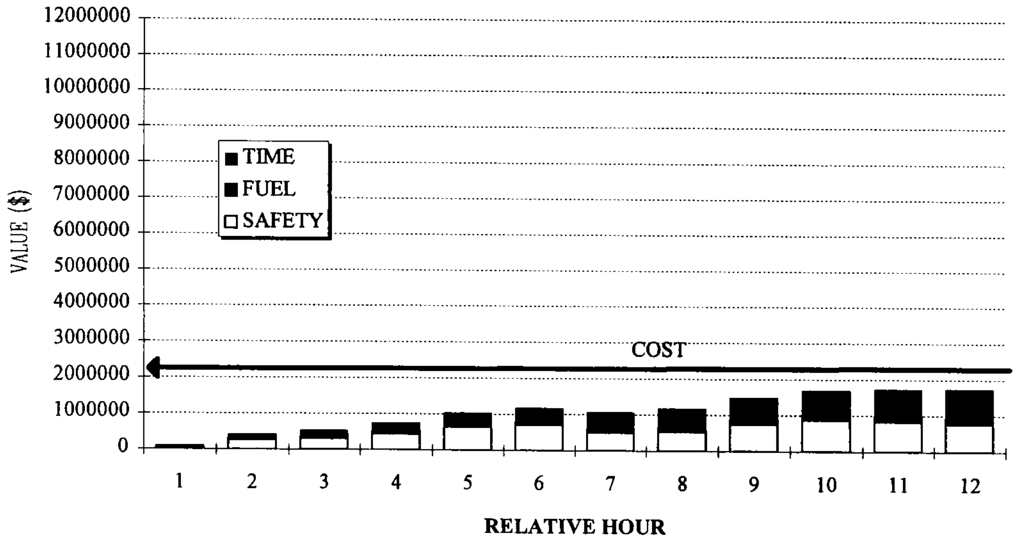

FIGURE 3 Cumulative summary of direct benefits, two-lane highways.

$30/lane-km/event for two-lane highways and $21 for freeways. This cost estimate is conservative because it excludes major storms. (As noted earlier, major storms were not analyzed in this study because of multiple applications.

The total cost of all winter maintenance regular events (3,045 subevents) was approximately $2,106,000 for two-lane highways and $158,000 for freeways. A full discussion of the calculations is presented elsewhere (15).

Winter Maintenance Benefits

The individual components of direct benefits of winter maintenance in the after period are shown as savings in travel time (marked "time"), savings in gasoline consumption (marked "fuel"), and savings in accident reduction (marked "safety") for the cumulative hours after zero hour in Figures 3 and 4 for two-lane highways and freeways, respectively. If accidents increased in the after period, the increased cost is shown as a negative saving.

The results of the cumulative benefits by hour after zero hour (top of the bar graph for each hour) along with the costs (a solid bold line) for all regular events are shown in Figures 3 and 4 for two-lane highways and freeways, respectively.

The total benefits for all regular events was approximately $1,740,000 on two-lane highways and $424,000 on freeways.

For two-lane highways, the regular winter maintenance events did not recover costs at any time during the first 12 hr analyzed. The benefit-cost ratio for these events was approximately 0.6 for the first 6 hr after zero hour and 0.8 for 12 hr after.

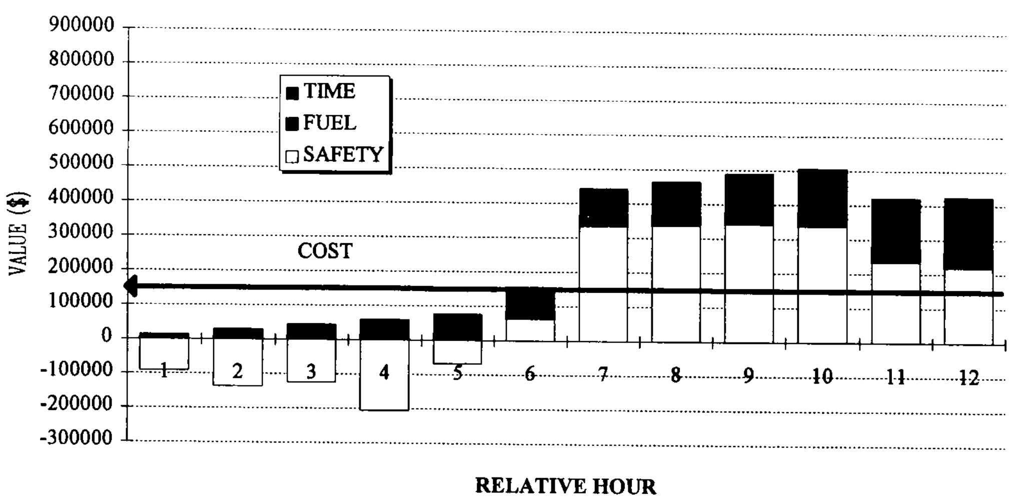

FIGURE 4 Cumulative summary of direct benefits, freeways.

For freeways, the regular winter maintenance events recovered costs after 6 hr. The benefit-cost ratio was 1.0 after the first 6 hr after zero hour and 2.7 after 12 hr. A plot of these cumulative benefit-cost ratios is shown in Figure 5 for both two-lane highways and freeways.

COMPARISON OF STUDY DATA

A final goal of this study was to compare the results of winter maintenance using salt-abrasive mixtures (data labeled "Salt II," and conducted from 1992 to 1994) with a study conducted by Marquette University (*1,8,10*) of agencies that used salt only (data labeled "Salt I", conducted from 1990 to 1991). Appropriate adjustments to both benefit and cost calculations were made to allow economic comparisons.

Maintenance Policies

In the earlier study of agencies that used salt only, all (Illinois, New York, and Wisconsin) had a bare pavement policy. New York was included in both studies but with different maintenance districts and maintenance policies. In the later study on salt-abrasive mixtures, some highway classifications (freeways) had bare pavement as a goal, but on two-lane highways some states had a lower level of service (one bare wheel path, for example).

Size of Database

Information about test sections is presented in the following table.

Database	*Salt Only*	*Salt-Abrasives*
Kilometers of Test Section	912	881.6
Travel, MKT 24 hr range		
Two-lane (millions)	3.36–4.64 m	0.8–1.76 m
Freeway (millions)	1.28–2.08 m	1.44–2.72 m
Winter Maintenance		
Events	226	781
Subevents	4,600+	3,045
Accidents		
Two-lane, 12 hr before	184	22
Freeways, 12 hr before	13	21

Accident Rate Reduction Before and After

A comparison of cumulative percentage accident reductions is shown for two-lane highways and freeways (Figures 6 and 7). For freeways in Figure 7, the reduction is negative because accidents increased in 3 of the first 4 hr.

Benefit-Cost Ratios and Recovery of Cost Periods

Cumulative benefit-cost ratios are shown for both studies, without the detail of breakdown in benefit component, for two-lane highways in Figure 8 and for freeways in Figure 9. Winter maintenance cost lines are indicated for each study separately.

When salt only was used on two-lane highways, the operation paid for itself in 25 min after zero hour. The

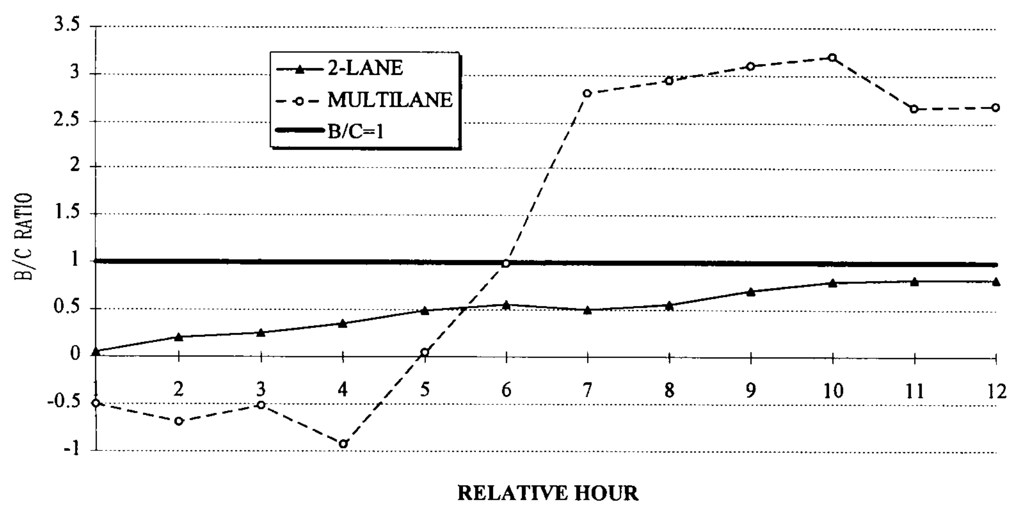

FIGURE 5 Cumulative benefit-cost (B/C) ratios for both highway groups.

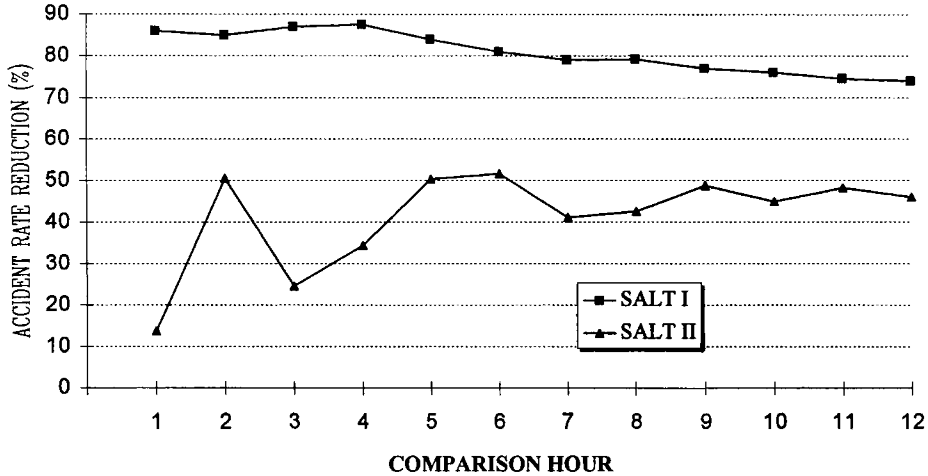

FIGURE 6 Comparison of accident rate reduction, two-lane highways.

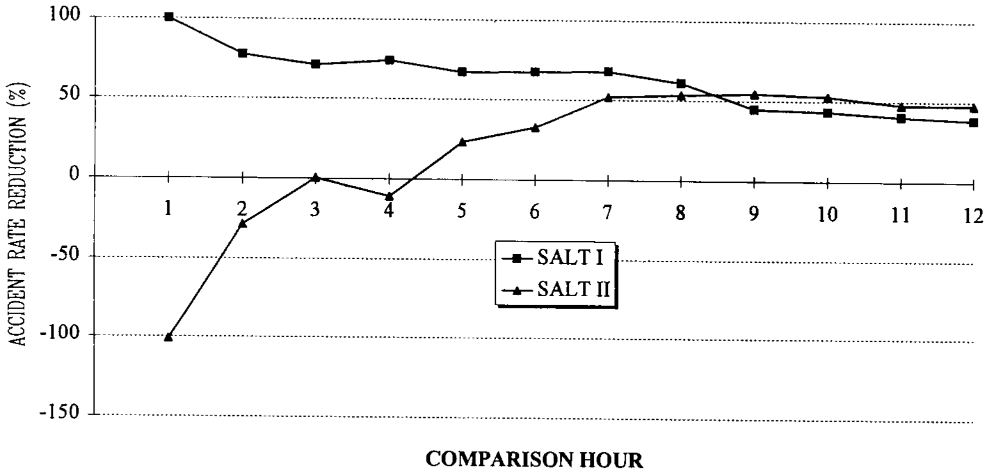

FIGURE 7 Comparison of accident rate reduction, multilane highways.

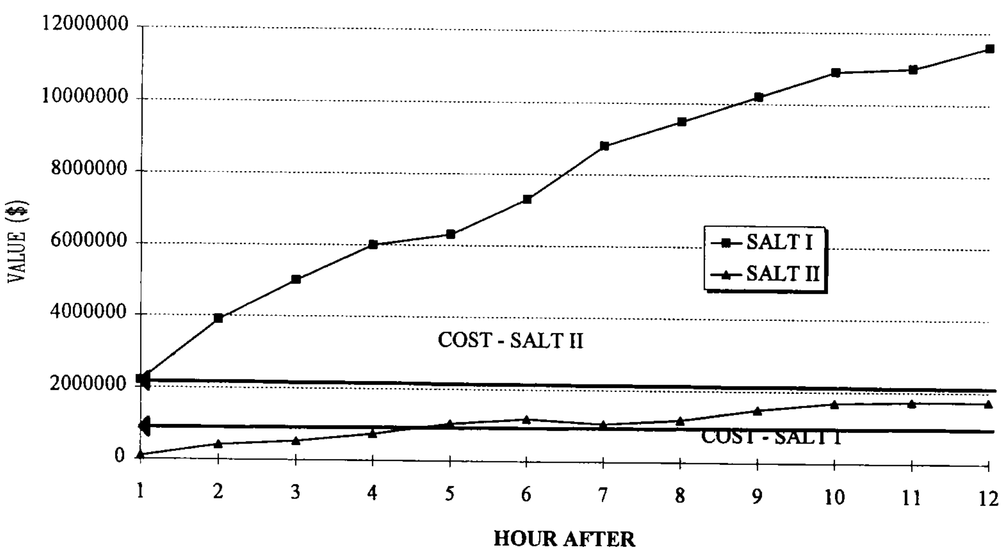

FIGURE 8 Comparison of cumulative benefits, two-lane highways.

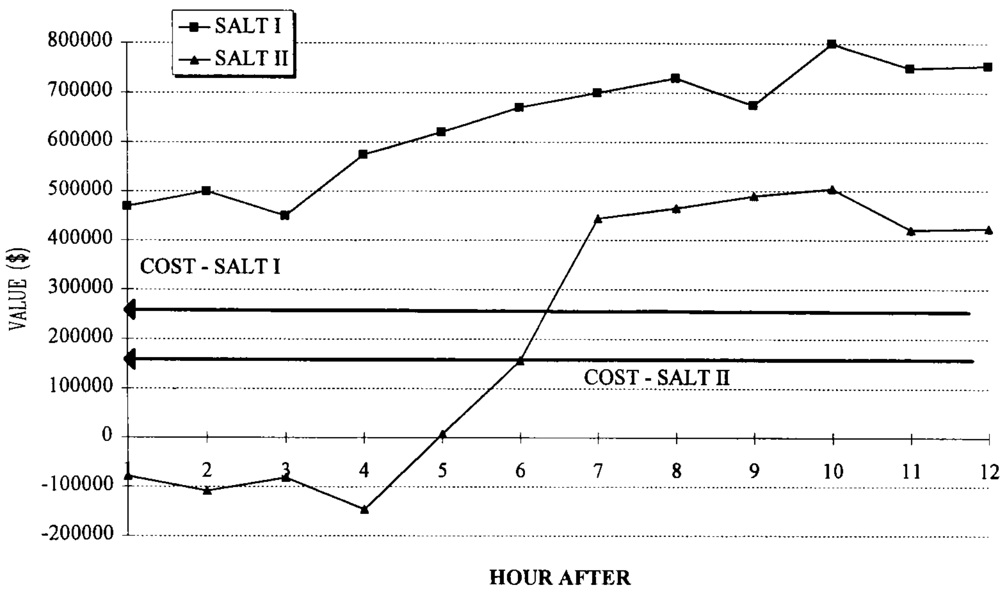

FIGURE 9 **Comparison of cumulative benefits, multilane highways.**

cumulative benefit-cost ratio for 12 hr after was approximately 12:1. When salt-abrasive mixtures were used, the operation did not pay for itself in 12 hr, with a benefit-cost ratio of less than 1.0.

When salt only was used on freeways, the operation paid for itself in the first 35 min after zero hour. The benefit-cost ratio for 12 hr after was approximately 3:1. When abrasive salt mixtures were used, the operation paid for itself after the first 6 hr. The benefit-cost ratio for 12 hr after was approximately 2.4:1. Note that it was negative for the first 5 hr because of the higher accident rates.

Analysis of Comparisons Between Two Studies

Study Databases

Although every effort was made to obtain comparable lengths of highway test sections with similar volume characteristics by using AADT, it is obvious that volume data used to select highway test sections did not result in the same winter traffic volumes on highways. This resulted in lower MKT and hence lower number of accidents.

In addition, there was a difference (and change) in accident reporting limits between the states used in the two studies. In the salt-only study, Illinois, Wisconsin, and New York had minimum reporting limits of $250, $500, and $600, respectively. In the salt-abrasive study, Iowa and Minnesota had $500 limits, New York had a $1,000 limit, and Pennsylvania used the injury or tow-away criteria for reporting. To assess the effects of this change, a brief study was made of all reported accidents in New York for 1990 (lower limits) and 1992 (higher limits). In 1992, the first year of increase, there were approximately 63,000 fewer reported property damage accidents, a 40 percent reduction.

Differences in Variables Between Studies

Differences in any other variables that could exist in accident studies were also reviewed. It is believed that because of the large number of events, the other variables of weather, time of day, driver differences, and vehicle differences were likely to exist equally during both studies, so that any conclusions drawn need not be tempered by those differences.

Accident Rates

Differences in accident rates can be only partly hypothesized on two-lane highways by the lower traffic volumes and lower frequency of accidents. The accident database was not sufficient to draw accident conclusions for two-lane highways.

The database for freeways was comparable and conclusions about differences can be made. There was a substantial difference in accident reduction on freeways, even with changes in reporting limits (more accidents under the higher reporting limits).

The low frequency of accidents on two-lane highways resulted in either no significance for the first 4 hr or lower degrees of confidence (95 percent instead of 99 percent) in later hours.

The comparable number of accidents on freeways resulted in substantial significance in the salt-only study for the first 8 hr after zero hour and significance in the last 6 hr for the salt-abrasive study. In effect, it took much longer for the rate reduction on freeways to occur in the salt-abrasive study. This was because of the accident rate increase the first 4 hr after zero hour.

Benefit-Cost Ratios

Because accidents are a major portion of the benefit-cost ratio, the ratio was much less for two-lane highways in the salt-abrasive study than in the salt-only study. On freeways, the ratio was comparable after 12 hr but after 6 hr there was a much greater ratio (2.5:1 versus 1.0:1) on the salt-only study than on the salt-abrasive study.

CONCLUSIONS

Conclusions reached from data gathered in this study (salt-abrasives) and compared to conclusions from an earlier study (salt only) are as follows (the salt-only study is called the first study and the salt-abrasives the second study).

1. The methodology used in each study was comparable. The number of events was larger in the second study. MKT was less in the second study for two-lane highways and comparable for freeways.
2. Accident rate reductions on two-lane highways were less with salt-abrasives than with salt only (Figure 6). Accident rate reductions on freeways were substantially different for the two studies. Accident rates dropped dramatically after achievement of bare pavement with salt only but more slowly with salt-abrasives (Figure 7).
3. Accident rate reductions in the second study were not as significant as those in the first study for two-lane highways. For freeways, rate reductions in both studies were significant. Significance alone, however, does not explain the difference in behavior of the accident rates between the studies. Figures 7 and 8 graphically portray the differences. Clearly, salt-only provided an improved road surface more quickly and controlled accidents sooner than did salt-abrasive mixtures.
4. Benefit-cost ratios in the first study were 12:1 for two-lane highways with the operation paying for itself the first 25 min after zero hour. In the second study, the benefit-cost ratio was 0.8:1, and the operation never paid for itself during the 12 hr of analysis after zero hour (Figures 3, 5, and 8). The use of abrasives and salt-abrasive mixtures was cost ineffective.
5. The benefit-cost ratio in the first study was 3:1 for freeways over the 12 hr of analysis, and the operation paid for itself the first 35 min after zero hour. For the second study, the ratio was 2.8:1 after 12 hr, but it took 6 hr after zero hour for the operation to pay for itself (Figures 4, 5, and 9). It took 6 hr for salt-abrasive mixtures to pay for the operation compared to 35 min for salt-only treatments.
6. The study goal of determining the relative effectiveness by percent of salt in the salt-abrasive mixture was not achieved. Because of insufficient events in the lowest salt percentage and insufficient accident data, the results are inconclusive. A much larger database would be needed for that type of determination.

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