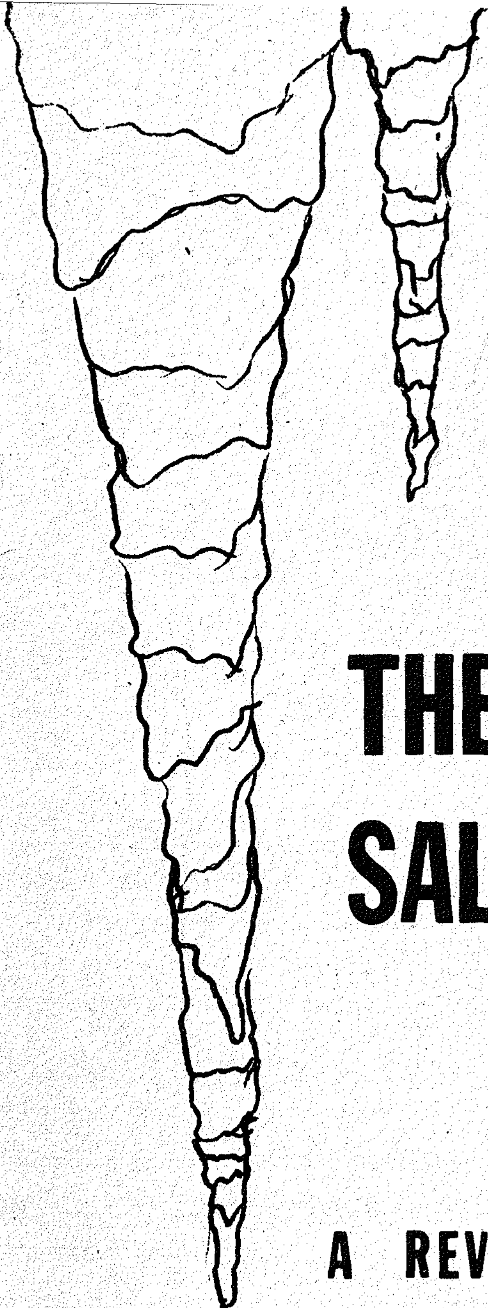

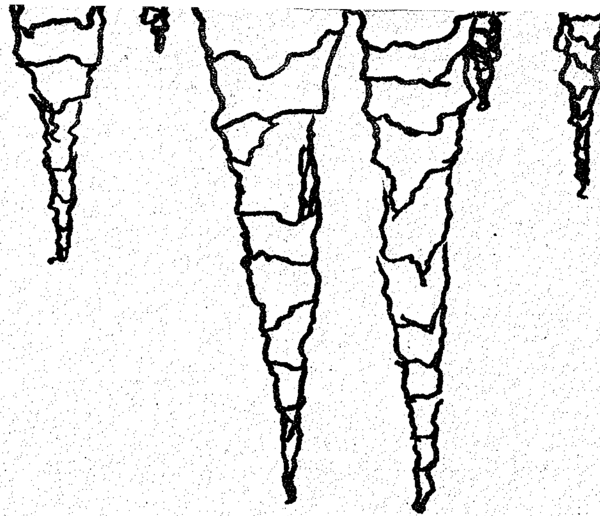

THE USE OF DEICING SALTS IN MINNESOTA

A REVIEW OF SNOW AND ICE REMOVAL MANAGEMENT PRACTICES, SALT USE EFFECTS, AND ALTERNATIVES

ERRATA SHEET

Page

20. Paragraph 3, line 8: The equation should read "$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$."

29. Paragraph 1, line 10: "was" should read "is."
line 12: "was" should read "is."

64 and 66. The horizontal axis labeled "MILES DRIVEN PER YEAR" should have the following scale: 0 to 5,000 | 5,000 to 10,000 | 10,000 to 20,000 | 20,000 to 30,000 | over 30,000

99. Paragraph 2, line 5: "was" should read "is."

103. Paragraph 3, line 4: Delete "ground-speed control on applicating trucks."

111. The total estimated savings for all items together without including slag:

Maintenance Areas	Tons of Salt Used	Tons of Salt Saved	Percent Reduction	Dollars Saved	1/2 Estimate (Tons)	1/2 Estimate (Dollars)
STATE	100,430	79,390	79.1	793,900	39,695	396,950
COUNTY	39,630	33,120	83.6	331,200	16,560	165,600
MUNICIPAL	84,360	50,775	60.2	507,750	25,387	253,870
TOTAL	224,420	163,285	72.8	1,632,850	81,642	816,420

136. Number 5.: Add to the recommendation after the word "WEATHER" the words "AND ROAD CONDITION" . . .

139. Number 4.: Substitute for "ENVIRONMENTAL IMPACT STATEMENT" the words "PROGRAM REVIEW."

153. Delete footnotes 104 through 113.

HOUSE
COMMITTEE ON
TRANSPORTATION

SCIENCE
AND TECHNOLOGY
PROJECT

THE USE OF DEICING SALTS IN MINNESOTA: A REVIEW OF SNOW AND ICE REMOVAL MANAGEMENT PRACTICES, SALT USE EFFECTS, AND ALTERNATIVES

By

Patrick Lee Reagan

April, 1978

This report was funded by the House Committee on Transportation, the Science and Technology Project. (The S and T Project is partially funded by the National Science Foundation Contract No. ISP 76-02379).

This study, in reponse to House Advisory No. 4, was jointly funded by the House Transportation Committee and the Science and Technology Project.

The assistance of Jan Carpenter, Mary Reagan, the Science and Technology staff, the numerous reviewers of this report, and all the engineers on the state, county and municipal levels who reponded to the survey is greatly appreciated.

HOUSE COMMITTEE ON TRANSPORTATION

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EXECUTIVE SUMMARY

I. Background

The use of deicing compounds such as road salt (sodium choride) and calcium choride on streets and highways in Minnesota has generated substantial controversy over the relative benefits of their use in snow and ice removal practices and their adverse effects. Minnesota has reacted to this controversy by enacting legislation which regulates the use of deicing salt on streets and highways in 1971. In January, 1977 Representatives Mann, Fudro and Lemke introduced House Advisory No. 4. This advisory proposed that a study be undertaken by the House Committee on Transportation with the objective of replacing or significantly reducing the negative effects of salt on vehicles and the environment.

As the American public increasingly relies on the automobile and truck for personal transportation and the movement of goods intra- and inter-city, the maintenance of open roads becomes increasingly important. A policy now exists, whether consciously or unconsciously, to provide bare roads for high speed traffic under potentially hazardous road conditions. Because of this policy, a need arose for a fast, low cost, and efficient means of eliminating snow and ice. The use of deicing salt in conjunction with other snow and ice removal practices successfully accomplishes this "bare road" policy.

Deicing compounds are used to augment other snow and ice removal practices for three reasons. First, salt is applied to melt ice on the pavement (deicing). Second, salt is applied to prevent the formation of pack ice (anti-icing). Finally, salt is applied to prevent the build-up of "pack" snow, which is formed by traffic and adheres the snow to the pavement as tightly as ice, but in a thicker and more irregular fashion. Because salt supplies little in the way of traction, sand is added for this purpose.

Two major benefits are derived from snow and ice removal practices. First, the road system is maintained with a minimal decrease in the level of traffice speed, comfort or convenience within a short period of time. This results in a minimal disruption of economic and social activity. In addition, the use of deicing salts provides the cheapest and easiest way of maintaining open roads.

Snow and ice removal practices can provide four specific types of benefits:

1. Open roads can decrease the response time in emergencies. This can result in the saving of lives;
2. Bare roads decrease sliding thereby reducing fuel consumption over a given distance;
3. Open roads provide an economic savings due to reduced travel time and, hence, tardiness or absenteeism, thereby maintaining a near steady level of productivity; and
4. Snow and ice removal practices can provide a possible safety benefit. Unfortunately, the data is unclear and inconclusive at this point. Further research is necessary in order to elucidate the role snow and ice removal, particularly deicing compounds, play in accident prevention.

Among the many negative impacts that use of deicing salts may have, none are greater than the corrosive and deteriorating effects on autos and roads. Deicing salt is a major contributor to rust formation on autos and bridges. Studies have indicated that as much as 50% of automobile rust may be traced to deicing salt. The best methods for reducing corrosion can be undertaken by the auto companies. Design practices, anti-corrosive compounds, undercoating and many other techniques can be employed by the companies to help mitigate the corrosive process. Additional undercoating and regular car washing can be undertaken by the consumer to minimize rust formation.

The role of deicing salts in the deterioration of concrete is quite clear. The impact in terms of dollars is estimated to be from $70 to $500 million annually. Efforts that can minimize the use of deicing salts on roadways will be the most successful in prolonging the life of the roads. The problem is especially acute on bridge decks. Any efforts to reduce or minimize the use of deicing salts will help to prolong the life of roads and bridges.

Deicing salts also have a negative impact on the environment. Studies conducted by MinnDOT, the University of Minnesota and others have shown that deicing salt can severely affect the environment by attacking sensitive plant species, contaminating water, increasing the levels of sodium and chloride in drinking water and contributing to the failure of power line transmission systems. Reducing salt use and improving salt storage practices can help to mitigate these effects.

In order to evaluate snow and ice removal practices on the state, county and municipal levels, a survey was sent to all 16 state maintenance areas, the 87 counties within the state and 101 municipalities of population 5,000 or more.

Based on an overall return of 70%, it was found that management practices for snow and ice removal were lax in most instances. If the following eight management practices were uniformly implemented, then salt use could be reduced considerably. Parenthetically, implementing these management practices elsewhere have successfully reduced salt use levels.

7. Require maintenance crews to start snow removal operations early in the storm.

8. Provide funding to the Minnesota Department of Transportation and/or the University of Minnesota to do research on alternative deicing agents and technologies.

II.2 Salt Management and Control Practices

There are six salt management and control practices recommendations that could substantially reduce salt use and which would go a long way towards mitigating the negative impacts of salt use. These are:

1. Require the periodic calibration of salt application machinery to insure that the proper level of salt is being deposited onto the road.

2. Mandate the use of ground-oriented spreaders that are speed controlled to insure that salt is applied uniformly and at the proper rate.

3. Mandate that salt be stored in enclosed structures, using bituminous pads with brine-catching facilities for salt-sand mixtures, and that no salt-sand mixture be stored outside over the summer.

4. Require driver and supervisor training and education on salt use and its effects.

5. Require recordkeeping practices to be uniformly implemented for salt applications and that weather data also be included.

6. Provide funding to MinnDOT or the University to develop a benchmark to analyze salt applications to compare salt use from storm to storm and year to year and to provide feedback to super-

visors and drivers on their salt application procedures.

II.3 Environment

Since the environmental impacts from deicing salt use are large, state agencies which use salt and others who are responsible for protecting the environment should undertake studies to determine the specific impacts of salt use and other remedial measures. They are:

1. The Minnesota Pollution Control Agency in cooperation with MinnDOT and county and municipal governments should monitor the water quality near all salt storage sites, and water bodies and groundwater near highways to determine if sodium, calcium, chlorides, chromates or cyanides have affected water quality in this state.

2. The Minnesota Department of Health in cooperation with the MPCA should undertake a study to determine if sodium levels in drinking water pose a hazard to human health, particularly for those individuals who must restrict their sodium intake.

3. The Minnesota Department of Natural Resources in cooperation with salt-using agencies and political subdivisions should study the impact of salt use on sensitive areas such as parks, preserves, and boulevards, and ways of mitigating these effects.

4. The Minnesota Department of Transportation should undertake an EIS on the environmental impacts of deicing salt use and its alternatives.

5. Mandate that agencies in charge of highway maintenance be informed and required to plant salt resistant plant species near roadsides.

6. Require that auto companies, by 1985, have a corrosion-proof car which lasts at least 10 years in order to sell their vehicles in Minnesota.

7. MinnDOT should undertake a study to determine the economic feasibility of heating bridges electrically or by some other method as a substitute for salt use.

8. MinnDOT should undertake a cost-benefit analysis to determine whether establishing a test track would improve road construction and reduce accidents.

II.4 Accident Prevention

There are four techniques, which, if implemented, would help prevent accidents due to wet weather. These are:

1. Provide authority to the Minnesota Department of Public Safety (MDPS), to develop a wet weather speed zoning plan which would require reduced speeds during rain or snow on known accident-prone segments of roadways.

2. The Minnesota Department of Public Safety should develop a system of accident reporting by police and sheriff departments and the Highway Patrol in order to assess the impact of road conditions on any accidents.

3. Require grooved pavements on road segments where large numbers of accidents occur due to wet weather.

4. Require that skid resistant surfaces be given high priority as a parameter in highway design and construction.

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CHAPTER ONE

DEICING SALT AND DEICING SALT POLICY IN MINNESOTA

The use of deicing compounds such as road salt (sodium chloride) and calcium chloride on streets and highways in Minnesota has generated substantial controversy over the relative benefits of their use in snow and ice removal practices and their adverse effects. Minnesota has reacted to this controversy by enacting legislation which regulates the use of deicing salt on streets and highways in 1971. In January 1977, Representatives Mann, Fudro and Lemke introduced House Advisory No. 4. This advisory proposed that a study be undertaken by the House Committees on Transportation and Environment and Natural Resources with the objective of replacing or significantly reducing the negative effects of salt on vehicles and the environment.

House Advisory No. 4 specifically states:[1]

> It is proposed that the Committees on Transportation and Environment and Natural Resources establish a special subcommittee to examine the feasibility of the Department of Transportation's, and other road authorities' throughout the state, use of salt (sodium chloride and calcium chloride) for the purpose of snow and ice control on roads and streets.
>
> Millions of dollars of damage are caused to vehicles each year because of the corrosive effects of such chemicals. The use of such salts cause environmental pollution to vegetation along roadways and to surface water and groundwater resources.
>
> It is recognized that some means of snow and ice control must be applied to roads and streets as a means of reducing the hazards of winter driving.
>
> The joint subcommittee shall undertake a study with the objective of finding substitute deicing materials that would replace or significantly reduce the deleterious

> effects of salts on vehicles and the environment, the results, together with the appropriate recommendations for any further research work, to be reported in writing to the Legislature. The subcommittee may draw upon the resources of research personnel of the Commissioner of the Department of Transportation staff.

On September 13, 1977, the House Committee on Transportation and the Science and Technology Project held a legislative workshop on snow and ice control.[2] The workshop proceedings were used as a basis to comply with House Advisory No. 4. This report, then, is in response to House Advisory No. 4.

Some background information is necessary in order to evaluate the impact and control of road salt. This chapter reviews: the road salt controversy; the factors which affect the application of road salt; salt application technologies; and salt use policy in Minnesota and elsewhere.

1.1 The Deicing Salt Controversy

Deicing compounds such as road salt (NaCl) and calcium chloride ($CaCl_2$) are applied to pavement for three reasons. First, salt is applied to melt ice on the pavement (deicing). Second, salt is applied to prevent the formation of ice (anti-icing). Finally, salt is applied to prevent the build-up of "pack" snow, which is formed by traffic and adheres the snow to the pavement as tightly as ice, but in a thicker and more irregular fashion.[3]

Since the end of the Second World War, the American public and American business has relied primarily on the automobile for personal transportation and the truck for movement of goods intra- and inter-city. Because of this a policy has existed, whether consciously or unconsciously, to provide for high-speed traffic under hazardous conditions. As a result, a need arose for a fast, low cost, efficient means of eliminating snow and ice from the roads in order to provide high-speed mobility under safe conditions. As has been stated so often: "If a chemical did not exist which would eliminate snow and ice on the road, then it would have to be invented." Fortunately, salt (NaCl and $CaCl_2$) does accomplish this. Salt, when applied to roads covered with snow or ice, maintains a "coefficient of friction between snow or ice covered pavement and tires adequate for safety and mobility.[4,5] In addition, it is easily obtainable in large quantities under natural conditions at a low cost. Consequently, salt use increased dramatically as greater reliance was placed on the automobile and truck.

Slipperyness between the pavement and tires under hazardous conditions can be compared on the basis of their coefficients of friction. Friction is that force which keeps an object from sliding on a slippery surface. Table 1-1 compares some coefficients of friction. For example, a 3000-lb. car on ice will theoretically require only 150 lbs. of unbalancing force (3000 lbs. x 0.05 = 150 lbs.) on a level surface to commence sliding.[6] Ice and snow act as lubricants because the energy created in the friction process appears almost entirely in the form of heat, which melts the ice or snow.[7] In sum, ice and snow act as lubricants by introducing a layer of low shear stress (friction) at the interface between the tire and the road, which lowers the friction coefficient (increased slipperyness) and promotes accidents.

TABLE 1-1

COEFFICIENTS OF FRICTION UNDER SLIPPERY ROAD CONDITIONS

Road Condition	Coefficient of Friction
Snow	0.05
Ice	0.05
Wet Pavement	0.55
Dry Pavement	0.90

Source: Minsk, David L., "Optimum Chemical Application Rates, Chemical, Physical, and Selective Maintenance Alternatives," Road Salt Use in Minnesota, S & T Project, 1977.

Sand is sometimes used as an alternative to road salt or in combination with it. Sand has the advantage of increasing traction on snow and ice. However, it does not remove snow and ice like salt, and on compacted snow it is readily removed by traffic or wind. In some instances sand can inhibit the melting of ice or snow by decreasing the amount of radiation reaching the ice or snow.[8]

Two major benefits are derived from snow and ice removal practices. First, the road system is maintained with a minimal decrease in the level of traffic speed, comfort or convenience within a short period of time. This results in a minimal disruption of economic and social activity. In addition, the use of deicing salts provides the cheapest and easiest way of maintaining open roads.[9]

Snow and ice removal practices can provide four specific types of benefits:

1. Open roads can decrease the response time in emergencies. This can result in the saving of lives;
2. Bare roads decrease sliding, thereby reducing fuel consumption over a given distance;
3. Open roads provide an economic savings due to reduced travel time and, hence, tardiness or absenteeism, thereby maintaining a near steady level of productivity; and
4. Snow and ice removal practices can provide a possible safety benefit. Unfortunately, the data is unclear and inconclusive at this point. Further research is necessary in order to elucidate the role snow and ice removal, and particularly deicing compounds, play in accident prevention.

As the Salt Institute, a trade association of salt suppliers, has often pointed out, snow or ice impeded highways threaten the capability of emergency vehicles to respond to calls for help. Response time is critical to respond to many medical emergencies such as heart attacks, burns, acute poisoning, and accidents.[10] Snow and ice control practices facilitate the survival possibilities of these individuals.

A study by the Transportation Research Board showed that the roughness of road ice and the slippage of the wheels can result in an average 1/3 more fuel consumption and as much as 1/2 more fuel consumption on two inches of snow.[11] In this time of high energy costs with the potential of shortages, snow and ice removal practices can provide for increased efficiency of vehicles than would otherwise be the case.

The estimated economic savings of snow and ice removal practices can be considerable.[12-14] The Institute for Safety Analysis (TISA) of the Salt Institute has estimated that snow and ice storms cost hundreds of millions of dollars every year in lost productivity. Table 1-2 shows the economic impact in snow belt states (defined as using 3,000 tons or more of salt each year) on commuter travel in time delay and wage loss. Table 1-3 summarizes the economic impact of snow storms in snow belt states. Assuming that only 1% of the snow belt states were affected, 20 lost days due to storms would have an economic impact of $180 million; if 25% of the snow belt states were affected for 20 days per year, then the cost would approach $4.6 billion.[15]

A benefit which has generally been taken for granted from the use of road salt as a deicing compound is that of greater safety. However, the evidence for this is contradictory and inconclusive. The first problem is that the recordkeeping agencies must distinguish between fatalities and casualties, minor property damage, and the specific cause(s) of the accident itself. In addition, the issue of safety is closely related to other aspects of public policy and the behavior of the driving public. The most important of these safety issues are the public's expectations and driving habits.

The importance of safety with regard to the road salt issue cannot be understated. Winter maintenance of roads becomes a

TABLE 1-2

IMPACT OF ONE SNOWSTORM IN SNOW BELT STATES ON COMMUTER TRAVEL
IN TIME DELAY AND WAGE LOSS a/

Some Examples Based on 1974 Travel

	If Snowstorm Affected: 1% of Snow Belt	5% of Snow Belt	10% of Snow Belt	25% of Snow Belt	50% of Snow Belt
Passenger hours of delay (in millions) if delay affected all commuters an average of:					
1 hour	0.4	2.1	4.2	10.5	21.0
2 hours	0.8	4.2	8.4	21.0	42.0
3 hours	1.2	6.3	12.6	31.5	63.0
4 hours	1.6	8.4	16.8	42.0	84.0
Dollar wage loss (in millions) associated with average delays of: b/					
1 hour	1.8	9.5	19.1	47.7	95.3
2 hours	3.6	19.1	38.1	95.3	190.7
3 hours	5.4	28.6	57.2	143.0	286.0
4 hours	7.3	38.1	76.3	190.7	381.4

a/ Snow belt states defined as those that utilize more than 3,000 tons of salt annually for snow removal.
b/ Based on average annual wage in U.S. in 1975 of $4.54 for production employees of manufacturing establishments (excludes wages of supervisors and professional wage earners). Source: Bureau of Labor Statistics

Source: Traffic Institute for Safety Analysis

TABLE 1-3

SUMMARY ECONOMIC IMPACT OF SNOWSTORMS IN SNOW BELT STATES
IN MILLIONS OF DOLLARS

Some Examples Based on 1974 Travel

	If Snowstorm Affected: 1% of Snow Belt	5% of Snow Belt	10% of Snow Belt	25% of Snow Belt	50% of Snow Belt
Dollar wage loss due to lateness of workers who commute by automobile if average delay were 2 hours	3.6	19.1	38.1	95.3	190.7
Dollar wage loss of absent workers who commute by automobile if percentage of absences were 10%	1.5	7.6	15.3	38.2	76.4
Loss to manufacturer in value added due to 2-hour delay of workers	2.5	12.50	25.0	62.6	125.1
Loss to manufacturer in value added due to absent workers, if absenteeism among automobile commuters were 10%	1.0	5.0	10.0	25.0	50.0
Loss of revenue due to 2-hour delay to inter-city combination truck travel on rural roads	0.1	0.3	1.8	1.6	3.1
Loss of revenue due to 2-hour delay to single unit local pick up and delivery truck travel	0.3	1.4	2.9	7.2	14.3
TOTAL LOSS, ONE DAY	9.0	45.9	93.1	229.9	459.6
Annual loss if 10 storm days per winter	90	459	931	2,229	4,596
Annual loss if 20 storm days per winter	180	918	1,862	4,598	9,192
Annual loss if 30 storm days per winter	270	1,277	2,793	6,897	13,788

Source: Traffic Institute for Safety Analysis

Note: Relationship between lines may be slightly distorted by rounded data.

major issue since 82% of all commuting workers use the automobile to get to their jobs, and 92% of travel between cities is by automobile.[16] In addition, nearly 15 million trucks haul 52% of all manufactured products that travel between cities, while school buses carry 39% of public school students to their classrooms.[17] Consequently, safe roads are essential for the maintenance of life, limb, and property.

Numerous studies have examined snow and ice related traffic accidents. One study indicated that an inch of snowfall in Chicago causes between 142 and 200 accidents, and that the range of traffic accidents per inch of snow is from 66 to 875 accidents.[18] In another study it was shown in an analysis of 200,000 accidents that snow and ice were directly a factor in traffic accidents.[19] The Ohio Department of Highways indicated that their snow removal program eliminated 22,700 accidents per year in rural areas.[20] In addition, an estimated 1,265 accidents are prevented by snow removal practices in Rochester, New York each year.[21]

One question that arises is to what extent road salt contributes, independent of other snow removal practices, to accident prevention. One study showed that with increased use of salt to enhance snow and ice removal the percentage of accidents occurring under icy conditions decreased. However, National Safety Council data indicate that there are generally fewer accidents in winter than in summer. After obtaining additional data the study concluded: "Salt apparently does reduce the number of accidents which occur on ice, but the overall accident rate seems to increase with the use of salt...."[22] The study went on: "Because many factors have been eliminated from consideration,...it is impossible to draw conclusions from the above results," and "...no method can conclusively evaluate the effectiveness of using salt to make winter travel safer...."[23] Another study concluded:[24]

> We have shown that at the current levels of salt usage for highway deicing, the gains to society appear to be far less than the costs. In a study of this nature one should examine the time profile of benefits and costs; benefits or costs that will accrue in the future are worth less than the same items today. In this study we found that most if not all of the benefits are immediate, while costs such as the pollution of water supplies and damage to vegetation and highway structures may accrue over relatively long periods of time. Since good estimates of the time profile of these costs have not been made, no attempt was made to discount them to present values. Rather, we included in our cost estimate only a rough approximation of the current costs and omitted any future costs.
>
> Although it was shown that the cost in terms of automobile depreciation alone exceeds the benefits due to reduced travel costs, this does not necessarily imply that all salting should be discontinued. Rather, one is interested in applying salt until the gains from the last ton applied are just balanced by the additional costs incurred. Presumably at some level less than current application rates this relationship might hold. It is impossible, given the quality of the available data, to determine how much salt would then be used.
>
> Given the findings in this study, it appears that the use of salt for deicing should be curtailed. The extent of the reduction can be determined only through a more detailed and comprehensive analysis of the various benefits and costs.

There are a number of costs associated with the use of road salt as well.[25]

> The major costs of the salt-maintained high level of service policy are based on the damage to the environment and indirect economic costs caused by the use of salt on such a large scale. The significant negative environmental impacts include: cases of: contamination of public and private water supplies affecting human health and industrial

uses of water; contamination of lakes and ponds affecting their physical characteristics and aquatic life; contamination of other potential surface and groundwater supplies; and damage to roadside soil and vegetation.

Indirect economic costs to man-made systems include: corrosion to automobiles and utility systems; damage to bridge structures and concrete pavements. These costs can occur in several ways: replacement costs after the damage is done; added costs to reduce or prevent damage; and research and development costs for methods to reduce or prevent damage.

1.2 Factors Affecting Salt Application

There are a multiplicity of factors most of which are unpredictable that comprise a winter storm. These factors include the time of day and day of week that the storm strikes; the deicing compound applied; the meteorological conditions during and after the storm; the type of precipitation; and the nature of the road itself.

A storm that strikes on a weekend would have little effect on the public, except for shopping and some social activities. In most instances the road could be cleared by Monday with salt being applied to slippery spots. However, a storm that strikes in the predawn hours of a weekday needs to be removed immediately to minimize its impact on commerce and people. Consequently, salt will be applied during and after a storm to keep the roads open.[26]

The quantity of deicing compound is an extremely important factor in snow and ice removal. Generally, when more of the chemical is applied, the faster or more extensive is the resulting melting action. However, this does not mean that if one pound is good, ten pounds will be better. As the salt concentration increases, the amount of ice melted per quantity of chemical decreases.

(See Figures 1-1 and 1-2). A more rapidly dissolving chemical or chemical mix will achieve higher coefficients of friction than a slower dissolving chemical. In addition, as concentrations of salt increase (the salt water solution approaches the saturation point) the amount of ice melted decreases regardless of the time. Moreover, the form of the chemical will determine the rate at which it goes into solution. Fine-crushed material goes into solution rapidly and forms a brine on the surface of the ice or snow. Coarse material will go through the snow or ice and will go into solution between the pavement and snow or ice where it will do the most good. In addition, the coarser material will not be blown off by the wind.[27]

Meteorological conditions can be a major factor in the use of a deicing compound. The relationship between air and pavement temperature will influence the effectiveness of the chemical. The chemical will go into solution faster at a higher temperature. As the temperature drops, the chemical reaction will slow down and may stop. The amount of solar radiation striking the road will affect the speed of the chemical reaction as energy is absorbed and warms the road. Humidity and wind speed play a minor role in affecting the chemical reactions of deicing compounds.[28]

The type of precipitation such as wet or dry snow, freezing rain or rime (ice particles formed by the rapid freezing of super-cooled water droplets) will influence the type of bond that will develop between the precipitation and the pavement. Snow with a water content of greater than 15% will become highly compacted. These grains of snow bond together very well. A water content

FIGURE 1-1

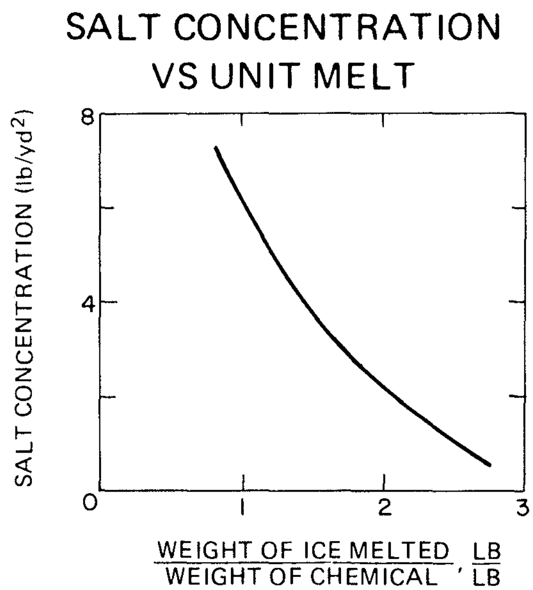
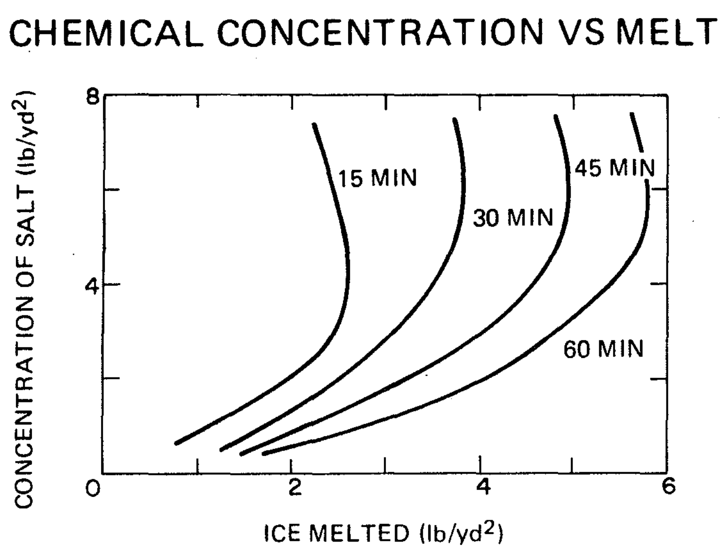


FIGURE 1-2



Source (Figure 1-1 and 1-2): U. S. Army Cold Regions Research and Engineering Laboratory.

of greater than 30% results in a water film surrounding every grain, resulting in little cohesion and slush. A water content of less than 15% will result in little compaction. In addition, the depth of precipitation will have some bearing on the amount of material that must be applied.[29]

There are a number of road parameters that can influence the amount of salt to be applied. The number of wheel passes and the speed of the vehicles will influence the number of load applications of salt that need to be applied. The pavement surface and type will affect the degree of energy absorption and the kind of bond (between the pavement and precipitation) that will develop. It takes longer to melt ice on a bituminous (asphalt) pavement than on concrete, though this situation can be reversed at certain times of year according to laboratory tests.[30]

1.3 Salt Application Technology

Sodium chloride is the chemical most frequently used in snow removal operations. It is effective in eliminating snow or ice in moderately low temperature ranges and it commences the deicing process immediately upon contact with snow or ice. Each year state, county and municipal road departments and other organizations such as shopping centers, hospitals and schools purchase approximately 9 million tons of salt at a cost of about 140 million dollars throughout the United States.[31] Records indicate that only 500,000 tons were sold 25 years ago.[32]

Why is salt so effective as a deicing compound? In either of its commonly used forms (sodium chloride, calcium chloride) salt water has a freezing point in solution below that of pure water.

Sodium chloride has a freezing point of -6° F. and calcium chloride has a freezing point of -67° F. As salt dissolves and goes into solution with water, it gives off heat. Sodium chloride emits 44 Btu's per pound and calcium chloride emits 292 Btu's per pound. A pound of rock salt (sodium chloride) can melt 46.3 pounds of ice at an ambient temperature of 30° F. and 8.6 pounds of ice at 20° F.[33] Vehicle traffic will remove about 90% of the ice cover.[34] The remaining 10% can be removed with salt. A one-mile stretch of road with a 1/4 inch sheet of ice weighs 70 tons. If road salt were required to remove all 70 tons at 20° F it would take 17 tons of salt. With 90% removal by vehicle splash, only 1.7 tons of salt per mile would be needed.

The availability of appropriate and functioning equipment and experienced personnel to operate the equipment is the most important element in having a successful snow and ice removal program. Although no two maintenance departments are likely to have the same equipment, program or approach, there are a number of similarities in the equipment they use. A snow and ice control program requires a unique mixture of personnel and equipment for each section of the road. The equipment and personnel must be suited to the weather, to the traffic conditions and to the level of service to be maintained for that section of road. The equipment and manpower requirements are established over several years based upon the weather, service level and experience in providing the service. Table 1-4 shows equipment guidelines as developed by the Environmental Protection Agency (EPA) based upon survey of maintenance departments.[35]

TABLE 1-4

EQUIPMENT GUIDELINES

Equipment Description	Lane Miles Per Unit of Equipment		
	City and Urban	Major Interstate	Rural
Heavy Duty Truck[1] with Spreader[2]	30	20-40	40-60
Heavy Duty Truck with Plow(s)	30	20-25	25-30
Light Duty Truck with Plow[3]	15	50-100	---
Heavy Duty Front-End Loader (greater than 1 cu. yd.)	100	100	200
Light Duty Front-End Loader (up to 1 cu. yd.)	100	200	400
Road Graders	200-400	100-400	100-400
Heavy Duty Snow Blowers[4]	---	300-1000	300-1000
Light Duty Snow Blowers	200-400	---	---

1. Includes large 4-wheel vehicles.
2. May be a combined spreader and plow.
3. May include loaders or sanitation vehicles or other plow-equipped multi-purpose vehicles.
4. May be mounted on heavy duty front end loader.

Source: Environmental Protection Agency

Another important item in a successful snow and ice control program is the ability to apply chemicals accurately and in the right amounts. Ground-speed-control spreaders are important items of equipment in applying chemicals accurately. These spreaders allow dispensing only when the truck is in motion and in proportion to its speed, thereby eliminating uncontrolled application of chemical. The calibration of the spreaders is important as well. Techniques have been devised to calibrate the spreaders (regulating the amount released on a per unit basis in close compliance with performance objectives) both in the shop and on the road. Calibration allows accurate measurement of not only the amount dispensed, but the pattern and extent of the spread.

1.4 Deicing Salt Policy in Minnesota

In 1971 the Minnesota Legislature passed enabling legislation restricting the use of salt or chemicals for snow and ice removal. The Minnesota Statute 160.215 specifically states:[36]

> In order to:
>
> (1) Minimize the harmful or corrosive effects of salt or other chemicals upon vehicles, roadways, and vegetation;
>
> (2) Reduce the pollution of waters; and
>
> (3) Reduce the driving hazards resulting from chemicals on windshields;
>
> road authorities, including road authorities of cities responsible for the maintenance of highways or streets during periods when snow and ice are prevalent, shall utilize such salt or other chemicals only at such places as upon hills, at intersections, or upon high speed or arterial roadways where vehicle traction is particularly critical, and only if, in the opinion of the road authorities, removal of snow and ice or reduction of hazardous conditions by blading, plowing, sanding, including chemicals needed

for free flow of sand, or natural elements cannot be accomplished within a reasonable time.

Since 1971, several states have introduced legislation to restrict the use of deicing salts.[37,38] In 1977, eight states have introduced legislation regarding salt use. Table 1-5 summarizes state deicing salt legislation introduced in 1977.[39]

TABLE 1-5

STATE DEICING SALT LEGISLATION IN 1977

Connecticut - H6952 - Establishes a commission on salt contamination of water supplies. The Commission is to determine the effects of deicing chemicals on ground and surface waters, develop standards for storage and application, examine alternatives, and gather data on use, methods and location of storage.

Illinois - S709 - Proposes banning the use of salt on highways and streets in the state.

Maryland - JR 68 - Requires the state roads commissioner to study the effects of salt and alternatives.

Michigan - HB 4434 - Excludes funds for the purchase or placement of sodium chloride on any roads, streets or highways in the state.

Minnesota - H Advisory 4 - Directs the Committee on Transportation, Environment and Natural Resources to study the use of sodium chloride and calcium chloride for snow and ice removal.

New Hampshire - HB 2022 - Requires the House Committee on Science and Technology to study the effect of salt on vehicles, roadways, vegetation, water and driving hazards. The economic implications of salt and alternatives are also to be examined.

Ohio - H654 - Requires the covering of salt stockpiles and provides for penalties.

Pennsylvania - H1455 - Bans the use of calcium chloride on roads in the state.

West Virginia - H1334 - Gives authority to the Commissioner of Highways to prohibit the use of calcium or chloride products or derivations on state highways. Substitutes are provided for.

Source: Jackson, K. E., Technical, Environmental and Economic Aspects of Highway Deicing Salts, National Conference of State Legislatures, Office of Science and Technology, Model Interstate Scientific and Technical Information Clearinghouse, January, 1978.

CHAPTER TWO

SALT CORROSION AND DETERIORATION

Among the many negative impacts of the use of salt, few are greater than the corrosive and deteriorating effects on bridges and automobiles. This chapter reviews the corrosive and deteriorating mechanisms; their impact on bridges and autos; and the economic impact of salt use on bridges.

2.1 Corrosive Effect of Salt

The fact that deicing salts are present does not automatically insure that corrosion will occur. A number of factors can affect the corrosion process. These factors include pH, dissolved oxygen, temperature, humidity, and atmospheric pollutants. Rust is the result of the corrosion of iron. Rusting occurs as a two-step process. The first is electrochemical and occurs in aqueous conditions. The second step is a direct chemical process in which iron is converted into rust. This section reviews the corrosion process and the factors that can affect it.

The electrochemical process occurs when iron (Fe) is immersed in an aqueous solution. At some points on the metal there is a tendency for iron ions (Fe^{++}) to be formed from metal iron (anode).

$$Fe \rightarrow Fe^{++} + 2e^-$$

The iron itself is the conductor for the electrons (e^-). Oxygen (O_2) dissolved in the aqueous solution reacts with water (H_2O) and the available electrons to form hydroxyl ions (OH^-)(cathode).

$$H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

The electrochemical process at the cathode (electron receiver) equals the reaction at the anode (electron emitter).[1]

The electrochemical process is basically a small battery. The entire surface is made up of these small batteries that are extremely small in nature. As the process continues, the iron ion (Fe^{++}) concentration increases at the anode locations and the hydroxyl ions (OH^-) increase at the cathode locations. Because these ions are close to each other, they tend to move from their locations and to combine to form ferrous hydroxide ($Fe(OH)_2$).

$$Fe^{++} + 2OH^- \rightarrow Fe(OH)_2$$

The ferrous hydroxide later reacts with the excess oxygen to form ferric hydroxide ($Fe(OH)_3$).

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

Finally, ferric hydroxide converts to a more stable compound--a hydrated iron oxide ($Fe_2O_3 \cdot H_2O$). This is a reddish compound commonly called rust.

$$2Fe(OH)_3 \rightarrow Fe_2O_3 \cdot H_2O \text{ (RUST)} + 2H_2O$$

This compound loosely adheres to the metal surface. Consequently, it does not offer any protection against further rusting.[2]

Chloride contamination, whether from salt or elsewhere, can greatly influence this process. The two common forms of deicing compounds--sodium chloride (NaCl) and calcium chloride ($CaCl_2$)--contain chloride. Chloride speeds up the dissolution rate of iron by ten fold. Further, chloride has a direct chemical reaction as well. The iron ion reacts with the chlorine ion to form ferrous chloride ($FeCl_2$).

$$Fe^{++} + 2Cl^- \rightarrow FeCl_2$$

This reacts with an additional chloride ion to form ferric chloride ($FeCl_3$).

$$FeCl_2 + Cl^- \rightarrow FeCl_3 \text{ (when } O_2 \text{ is present)}$$

Finally, ferric chloride reacts with water to form rust.

$$2FeCl_3 + 4H_2O \rightarrow Fe_2O_3 \cdot H_2O + 6H^+ + 6Cl^-$$

This reaction produces hydrogen and chloride ions. The presence of the hydrogen ions increases the dissolution rate of iron. The chloride ions that were initially consumed in the production of ferrous and ferric chloride are regenerated. Since they continue to exert their influence by increasing the dissolution of iron without being consumed in the chemical process, deicing salts that contain chloride ions accelerate rusting.[3]

The chloride ions have a physical effect as well. The presence of salt in dirt attached to metal extends the time for water to evaporate. The longer the water remains, the greater the period in which rusting can occur. The corrosion process cannot occur without water. As a result, corrosion can occur long after exposure to deicing salt unless the salt is removed. In addition, rust containing chloride is more permeable by water than chloride-free rust. Consequently, whatever protection rust offers in slowing down the corrosion process by keeping out water is further reduced when chloride ions are present.[4]

In sum, the chloride ion: (1) increases the dissolution of iron; (2) promotes rust formation; (3) accelerates the rate of dissolution of iron by producing hydrogen ions; and (4) keeps rust and underbody dirt wet thereby extending the corrosion process.

A number of factors can affect corrosion. The pH or hydrogen ion concentration of the solution can have a bearing on the corrosion rate. Iron is a metal which oxidizes or rusts more rapidly the more acidic the solution. Because the presence of chloride produces hydrogen ions, it lowers the pH of the solution (makes it more acidic). The more acidic it is the greater the dissolution of iron.[5]

Dissolved oxygen in water is another important factor in the corrosion of iron. The greater the dissolved oxygen, the greater the corrosion rate.[6] However, temperature can have a tremendous impact on the amount of dissolved oxygen. Normally, as the temperature increases so does the corrosion rate. Yet, the quantity of dissolved oxygen decreases as the temperature increases. While diffusion rates increase as temperature rises, thereby compensating for the loss of oxygen, the net effect on corrosion rates could be significant.[7]

Humidity is another factor which can have a major effect on the corrosion of metals. Hygroscopic (moisture attracting) impurities in the atmosphere or on the metal can cause condensation at levels below 100% humidity. Iron has a critical level of humidity between 50% and 70%. The greater the level of humidity, the greater the corrosion rate.[8]

Many atmospheric contaminants can absorb gases and moisture. As these contaminants precipitate out on metal they can increase the moisture content and accelerate corrosion. Some contaminants react with water to form acids which can pit the metal and accelerate the corrosion rate.[9,10]

What does all this mean? The corrosion of metal on cars or bridges can be influenced by the activities of man. Table 2-1 describes these activities.

TABLE 2-1

EXAMPLES OF HUMAN ACTIVITIES THAT AFFECT CORROSION OF METAL

Activity	Substance	Effect
Snow and ice removal practices	NaCl and $CaCl_2$	- Speeds up dissolution rate of iron - Makes existing rust more permeable by water
Air pollution	SO_2, H_2SO_3 H_2SO_4	- Pits the metal, allowing greater surface exposure to moisture - Increases moisture content on metal - Increases acidity of solution
Not removing dirt or rust from metal	Cl Hygroscopic compounds	- Traps moisture, extending corrosion period - Attracts moisture from air

2.2 Salt Induced Deterioration of Concrete

A number of parameters affect and influence corrosion and deterioration of concrete. These include the nature of the reinforcing steel, the quality of the concrete, the placement of steel and concrete, and the exposure loading and corrosion factors. These parameters are outlined in Figure 2-1.

Corrosion in reinforced concrete can be studied under two general groups: cracked and uncracked concrete.

Fresh uncracked concrete normally has ample resistance to corrosive attack. The concrete cover over the bar is very effective in inhibiting the penetration of corrosive agents to the level of the steel. The thicker and denser the concrete cover, the more effective it becomes in resisting corrosion. In addition, fresh concrete has a very high pH value which usually inhibits corrosion reactions. Fresh concrete has a high calcium hydroxide ($Ca(OH)_2$) content which gives it a pH of about 13.[11]

The last defense against corrosion is offered by the oxide film (mill scale) around the bar surface. This oxide film prevents corrosive agents from coming into direct contact with the bare metal. Thus mill scale provides localized corrosion protection.

However, as time passes the above conditions tend to alter. Water, salt, oxygen, carbon dioxide, and industrial gases (if present) slowly begin penetrating the concrete, the rate of which depends upon the permeability of the concrete cover. Carbon dioxide (CO_2), which penetrates into concrete through pores and cracks, reacts with calcium hydroxide and produces calcium carbonate ($CaCO_3$).

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O$$

FIGURE 2-1

SUMMARY OF THE VARIOUS PARAMETERS FOUND TO INFLUENCE THE CORROSION OF STEEL IN CONCRETE

REINFORCING STEEL

1. Metallurgy
2. Prerusting
3. Bar size and steel arrangement

QUALITY OF CONCRETE

1. Type of cement
2. Cement factor
3. Water-cement ratio
4. Air content
5. Aggregates (type and grading)
6. Permeability

PLACEMENT OF STEEL AND CONCRETE

1. Cover (amount and uniformity)
2. Bar spacing
3. Slump
4. Consolidation
5. Finishing
6. Curing

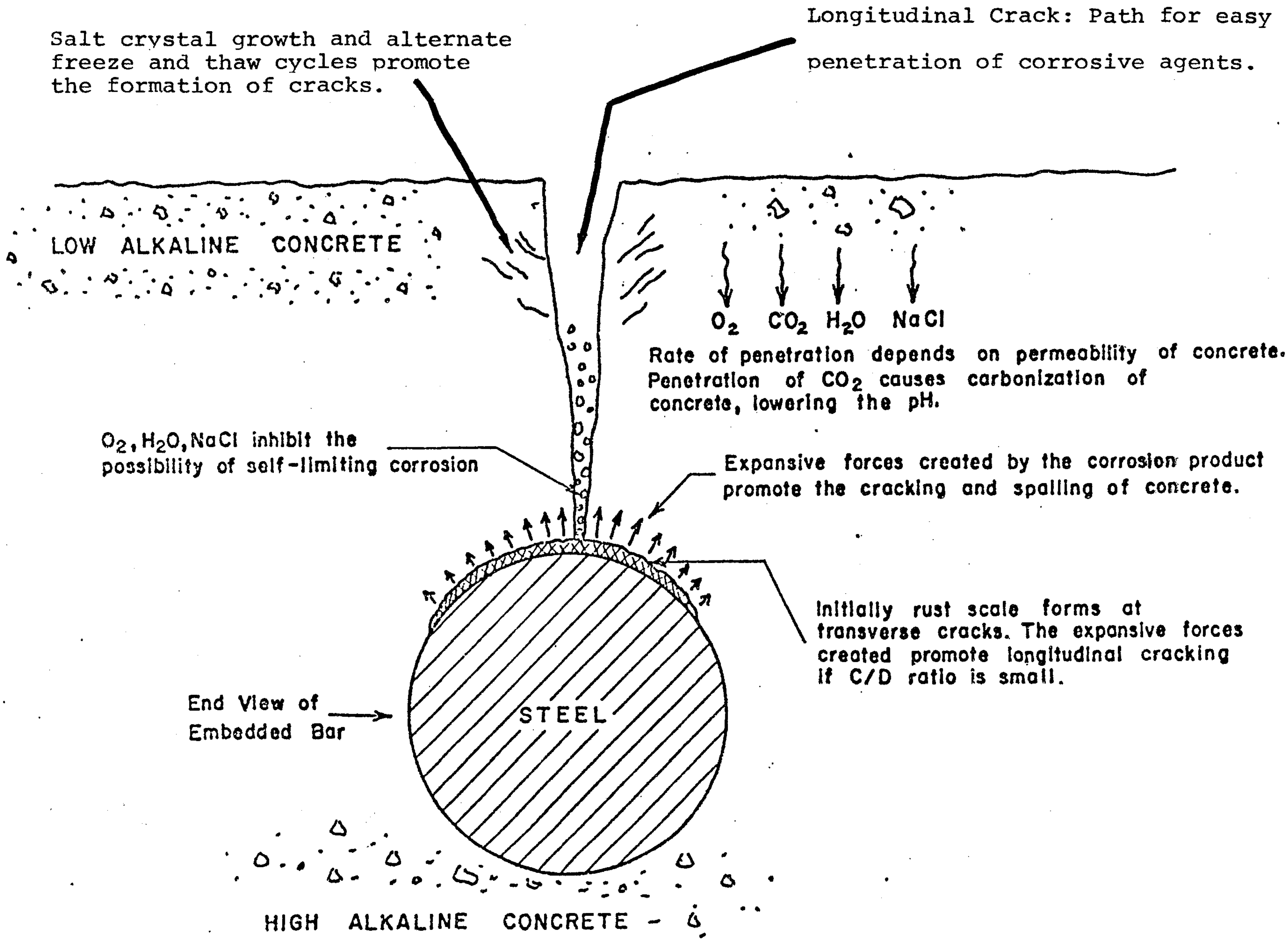
EXPOSURE, LOADING, AND CORROSION

1. Moisture
2. Temperature
3. Effect of pH
4. Chlorides
5. Oxygen
6. Carbonation
7. Concrete cracks
8. Steel stress
9. Type of loading

Source: Houston, J. T., et al., Corrosion of Reinforcing Steel Embedded in Structural Concrete, Research Report No. 112-1F, Center for Highway Research, University of Texas at Austin, Texas Highway Department, March, 1972.

FIGURE 2-2

GENERAL MECHANISM FOR THE CORROSION OF REINFORCING STEEL IN CONCRETE.



Thus, the pH value and consequently the protective quality of concrete are reduced. The general mechanism by which corrosion occurs in concrete is indicated in the drawing of Figure 2-2.

If the pH of concrete falls as low as 8, the probability of corrosion is high. Crystallizing salt and freeze-thaw effects set up internal forces that adversely affect the durability of the concrete cover. As a corrosive medium reaches the steel, it concentrates its attack at the flaws in the oxide film. More importantly, if salt is present, it will destroy the passivity of the oxide film on the steel and corrosion is thus promoted. At large cracks in the concrete, the penetration phase of the above sequence will be shorter and corrosion will rapidly begin on the steel below the cracks. In uncracked regions of the concrete the same sequence will take place at a much reduced rate.

The presence of salt is an important factor in the corrosion process. Salt ions destroy the passivity of steel, set up corrosion cells, and increase the conductivity of the concrete. Without salt ions, corrosion of steel in concrete may be inhibited for a long period of time. In that case, the corrosion rate is generally controlled by the processes of carbonation. If the concrete cover is relatively impermeable and thick, corrosion may not occur at all in uncracked areas. However, cracks do not lose their importance in this case because localized corrosion can occur under them.[13]

The corrosion products formed tend to have an inhibiting effect upon continued corrosive reactions. These products may seal off the base metal from hydrogen and oxygen diffusion and thus terminate the corrosion reactions. This process is known as selflimiting corrosion. The longitudinal splitting is mainly due to the tensile forces created by the corrosion products which occupy about three times greater volume than the metal from which they are formed. If the concrete cover is not sufficient to resist such forces, longitudinal cracks develop through which oxygen and other external agents gain access to the steel. At this point, it is only a matter of time until the structure reaches a hazardous state of corrosion and must be repaired or replaced. Repeated loadings may also play a role in breaking the protective effect of the rust scale, but more research is needed to establish its importance.[14]

In sum, the ability of concrete to inhibit corrosion of reinforcing steel is essentially determined by its watertightness or permeability. The relative permeability of concrete is generally found to be reduced as the water-cement ratios of the various concretes were reduced, and this in turn produced more corrosion-resistant structural members. The watertightness of the concrete was also shown to be significantly dependent upon the type of coarse aggregates used with the more permeable concretes being produced by use of selected crushed limestone and lightweight aggregate.[15] Although corrosion protection was directly related to depth of cover over reinforcement, a more meaningful parameter in this regard was the ratio of the clear cover to bar diameter (C/D). Greater corrosion protection is provided by beams and slabs having high values of C/D with good protection resulting for C/D values greater than about 3.0. This finding is of importance since normal design practice calls for specific minimum concrete cover regardless of bar size whereas it has been shown that a given cover may provide adequate protection for a small bar but may be totally inadequate for a relatively large bar. In addition to C/D effects, it was determined that the initial rate of corrosion of reinforcement was very dependent upon concrete cover. For example, the decrease of a cover from 2 inches to 1 inch resulted in a fourfold increase in the initial rate of corrosion.[16]

Although flexural cracking of concrete is found to promote corrosion of the reinforcement at the crack location, the severity of the long term corrosion damage to the bars is primarily dependent on the depth of concrete cover. Large cracks usually found in conjunction with large cover promoted early corrosion at the crack locations, but further development of the corrosion as well as longitudinal cracking of the cover over the bars were inhibited for the larger covers. Narrower cracks generally associated with shallow covers had little influence on the overall corrosion. In that instance the bars are rather uniformly rusted with extensive longitudinal splitting of the concrete cover over the bars. Only a slight increase in corrosion results as a consequence of stressing the beam reinforcement through flexural loading. These observations indicate that the existence of stresses in the reinforcing bars and the flexural cracks produced by these stresses are of less importance as corrosion-accelerating hazards.[17, 18]

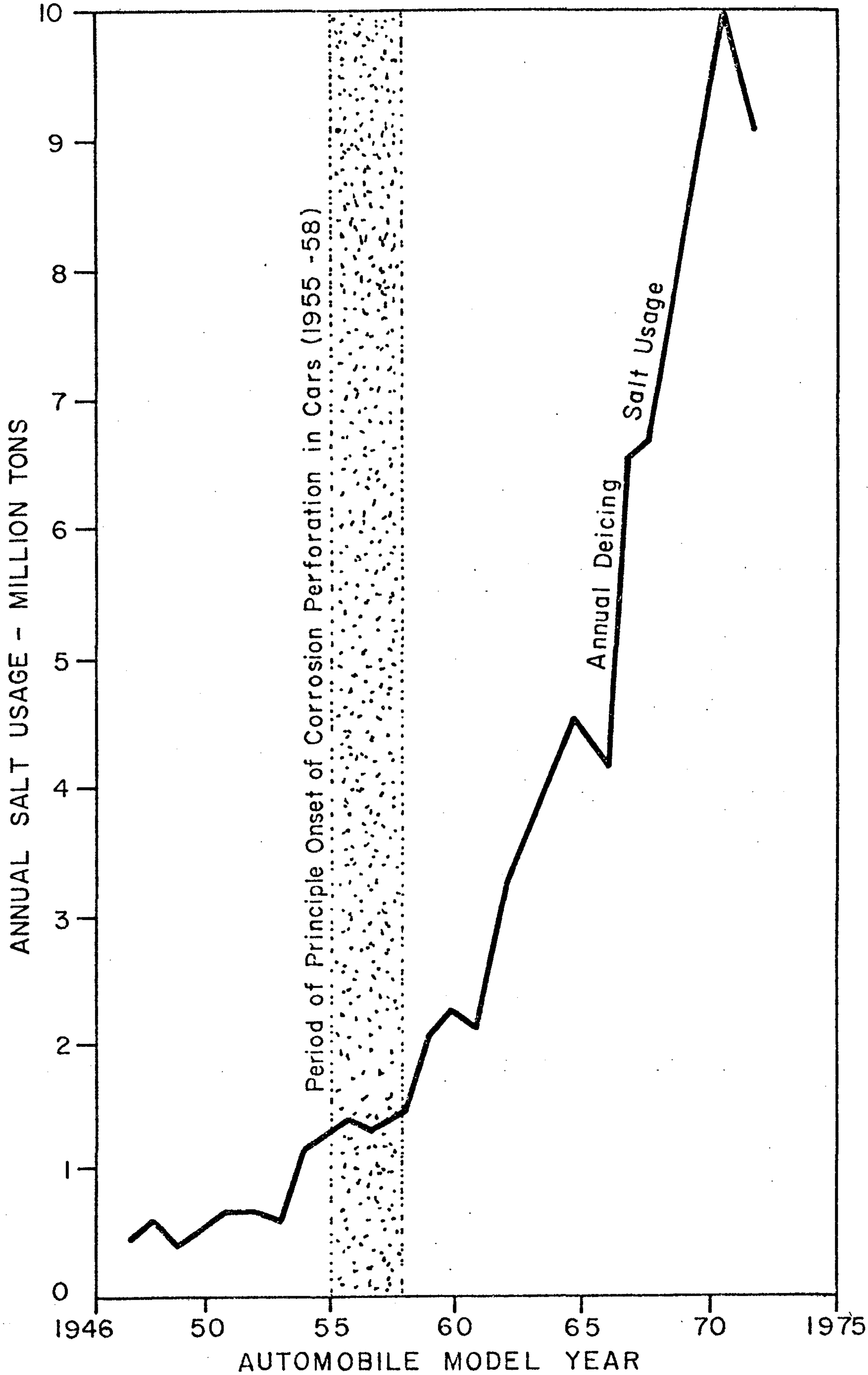
2.3 Impact of Road Salt on Autos

It is fairly well known to people who own autos that within a couple of years of regular use they will start to corrode. Much of the blame for this is given to deicing salts. This section will review the history of the corrosion problem in autos, the role salt plays in auto corrosion, the use of anti-corrosive agents, methods of preventing corrosion, and the cost of corrosion.

The early perforation corrosion of American autos prior to 1955 was a limited and localized phenomenon. By 1955 the American auto companies had altered their design in several important respects. The auto companies altered the geometry of the auto by modifying support structures and by reducing the number of cross members and the thickness of the sheet metal. In addition, little if any anti-corrosion measures were taken in the design or manufacture of the autos.[19-24] While auto companies were switching to unibody construction and sculptured styling, U.S. salt use on roadways doubled between 1953 and 1956, from 500,000 to 700,000 tons to 1 to 1.4 million tons.[25] This doubling was used to implicate salt as the causative agent for the high incidence of corrosion between 1955 to 1958 models. By 1965 U.S. salt use had increased nine fold over 1953. This period had not developed any major advances in anti-corrosion technology. Rather, it was a period of trial and error in automobile research. It is argued that if salt was the major culprit for auto corrosion, then the auto would not have been able to withstand the onslaught of salt during this period. In sum, it is more than likely that changes in the design and manufacturing of autos was the principal reason perforation corrosion occurred in American autos (see Figure 2-3).

Since 1958, the corrosion resistance in the American auto has improved. Auto companies have increased the amount of galvanized steel from 6 pounds per auto in 1955 to 160 pounds per auto in 1977.[26] By the late 1950s zinc rich primer was being added. The late 1960s saw the introduction of dip tanks using electro-coating

FIGURE 2-3



Source: Utah Department of Transportation

procedures. A new process called coil coating is being used on 1977 models.[27] Presently, Ford Motor Company offers a three-year guarantee against perforation corrosion on 48% of its autos.

This does not mean that deicing salts are not a significant cause of automobile corrosion. Deicing salts as well as atmospheric pollutants are the principal agents in the corrosive process. The fact that deicing salts can accelerate the corrosion of autos has been well documented.[28-39] A study by Fromm in Canada concluded:[40]

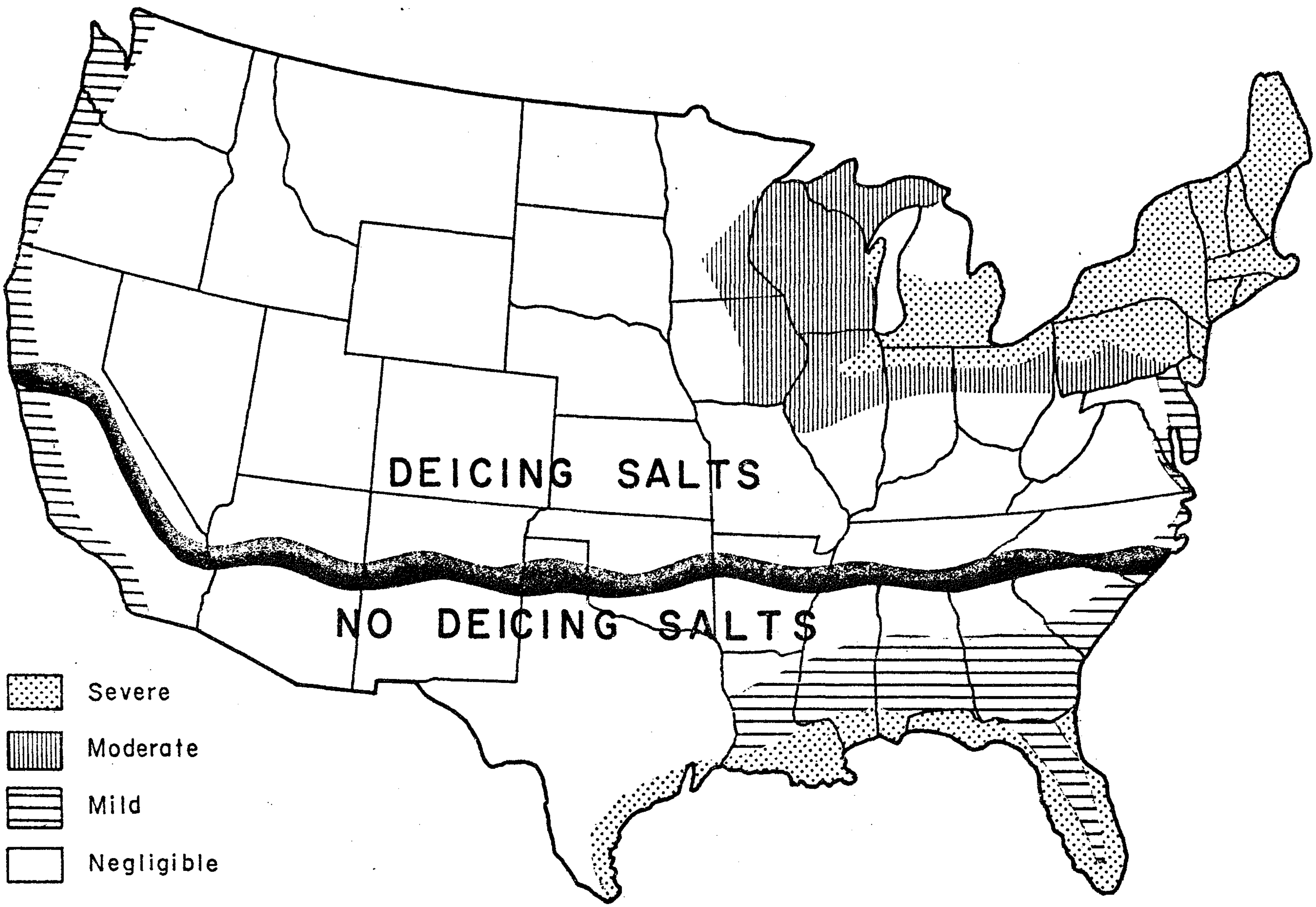
> 1. The atmospheric corrosion rate varies from area to area within a country. It varies with weather conditions and is highest in areas where moderate to warm temperatures and high humidities predominate. It also varies with population concentration and industrial densities; being lower in rural communities and higher in the more industrialized and populated centers. Proximity to a large body of salt water causes a marked increase in the corrosion rate.
> 2. The motor vehicle corrosion rate follows much the same pattern as the atmospheric corrosion rate; however, the use of the regular types of deicing salts causes an increase in the rate which varies directly with the amount of salt used.
> 3. Test coupons installed in traffic simulators corroded at a rate which was very close to that obtained from similar coupons mounted on test vehicles.
> 4. When tested in traffic simulators under natural conditions (no deicing salts used) the corrosion rate of unprotected auto-body steel is approximately one-half of the atmospheric corrosion rate.
> 5. The corrosion rate of auto-body steel under the conditions prevailing in the Toronto area (deicing salt used during winter) is little greater than the atmospheric corrosion rate.
> 6. The corrosion of a bare, unprotected piece of auto-body steel is not as severe or as damaging as the pitting corrosion which can occur under a protective lacquer film. This type of corrosion can occur wherever a break occurs in the film and an oxygen concentration cell is set up. Perforation of 20-gage steel was observed from this type of corrosion in a 19-month period.

Another study by the American Public Works Association in Minneapolis concluded that about "50% of the corrosion of some parts of automobiles can be attributed to the regular use of deicing salts."[41] It is estimated that non-salt environmental factors account for the other 50%. Deicing salts produce the most severe effect on the corrosion of autos in areas where road splash, dirt, leaves, and other debris can collect with little chance of being washed away. According to the unified theory of crevice corrosion, acids can be formed in crevices under deaerated conditions in the presence of deicing salts.[42,43] Consequently, deicing salts and atmospheric pollutants are the principal causes of corrosion, but the design and manufacture of the auto itself are the principal methods of inhibiting the corrosive process.

The corrosive environment is described in Figures 2-4 and 2-5. Figure 2-4 represents a conservative estimate of the corrosive environment in the United States. This estimate affects 46 million autos of the 102 million registered in 1973.[44-46] Figure 2-5 represents a more liberal view of the corrosive environment. This estimate affects 74 million autos of the 102 million.[47] These two figures represent the range of opinion of the extent of the corrosive environment in the United States.

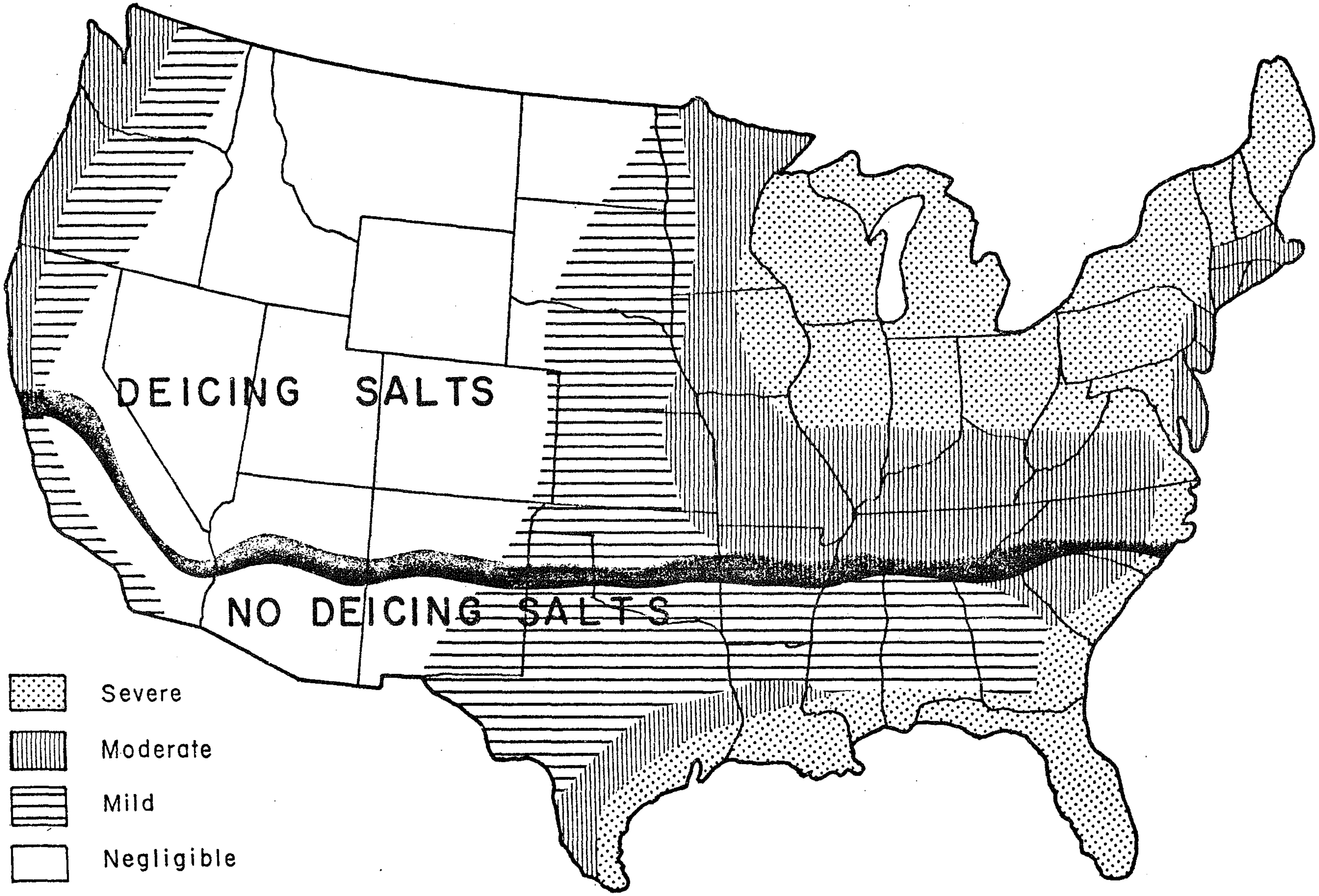
The treatment of deicing salts with corrosion inhibitors has been experimented with for 25 years.[48-61] While some inhibitors have looked promising the general consensus is that corrosion accelerated by the use of deicing salts will not be solved by the use of inhibited salt. The Technical Practices Committee of the National Association of Corrosion Engineers has stated: "There appears to be no easy and effective way to inhibit the corrosion of autobody steel by adding chemicals to deicing salts or to the streets directly."[62]

FIGURE 2-4



Source: Utah Department of Transportation.

FIGURE 2-5



Source: Utah Department of Transportation

Corrosion can be prevented or reduced by designing and manufacturing autos that are resistant to corrosion and by using preventive measures after the purchase of the auto. The design principals that need to be implemented are as follows:[63]

1. Keep underbody surface dry: avoid ledges, flanges, and pockets where dirt can accumulate and hold moisture.
2. Where appearance is of primary importance, use solder-filled, double-offset lap joints.
3. Make joints watertight.
4. Seal joints with mastic-type compound and cover entire faying surface in riveted joints.
5. Provide protective flange for lap joint in line with wheel splash to prevent water and road contaminants from being driven into the area of faying surfaces.
6. Avoid the use of dissimilar metals in contact with each other wherever possible to prevent galvanic corrosion.
7. Use open construction wherever possible. Avoid box sections and enclosed areas.
8. Provide adequate drainage in doors and in body areas having movable windows.
9. When box sections or enclosed areas are used, provide sufficient openings for application and drainage of protective coatings.
10. Keep electrical connectors free from moisture.
11. Design fuel tanks and other fluid-containing components to eliminate solder joints requiring the use of corrosive solder flux.

The American Public Works Association recommends the following measures to help prevent corrosion after the purchase of the auto:[64]

> (1) clear drain holes in rocker panels and door bottoms, (2) flush out the rocker panels through the rear access holes, (3) patronize the few car washes that have underbody spray equipment, (4) clean nickel-chromium plated materials with a fairly abrasive cleaner, but use only a mildly abrasive cleaner for stainless, (5) wash and wax metal trim and paint, but not to excess, and (6) touch up stone chips and scratches to minimize undercutting corrosion.

In addition, using heated garages can accelerate corrosion by 300%.[65]

It is difficult if not impossible to place a dollar cost on the impact of deicing salt-induced corrosion on the depreciation of the auto. First, the source of the salt can come from somewhere beside deicing applications. Second, atmospheric pollutants strongly contribute to the corrosive process. The make, model, design, manufacturing practices, location of use, the owner's preventive care and other factors all have to be considered in assessing the role deicing salt plays in the corrosive process. Numbers have been bandied about that range from $4.50 to $100.00 per year per auto.[66-70] This gives a total U.S. auto cost of $207 million ($4.50 times 46 million autos) to $333 million ($4.50 times 74 million autos) as a minimum estimate to $4.6 billion ($100.00 times 46 million autos) to $7.4 billion as a maximum estimate for auto depreciation each year. These numbers were determined by taking the conservative and liberal estimates of the number of autos whose corrosion is affected by deicing salts times the minimum and maximum estimate of depreciation attributed to deicing salts each year. This provides a range of $7.067 billion, which seems a bit questionable. Consequently, deicing salts contribute to the depreciation of the automobile over time, but the cost that can be attributed to deicing salts is impossible to be determined even on a crude basis.

2.4 Impact of Deicing Salts on Roads and Bridges

The question of whether or not to use deicing salts is becoming a rare decision in reference to structural deterioration. Most structures that were built without protection against salt and that are going to be salted have been salted. In addition, those structures that have been built with protection against chlorides have been salted. Moreover, that protection has failed or is failing. Consequently, any efforts that are to be made to inhibit structural deterioration must be remedial rather than preventative in nature. This section reviews the impact of water and chlorides on structural deterioration.

Winter maintenance activities, particularly the use of deicing compounds, are continuing to have a major impact on structural deterioration.[71-78] Salt, while heavily impacting the decks of bridges, is also affecting the supporting elements.[79-84] Estimates of structural deterioration costs due to deicing chlorides alone range from $70 million to $500 million annually.[85,86] The minimum estimate is expected to rise to $200 million annually. If these estimates are legitimate in determining the magnitude of the costs associated with the use of deicing salts, then the validity of the "bare road" policies should be questioned. Estimates of this magnitude would indicate that the use of deicing salts may NOT be cost effective.

A complete account for the contributions that all deterioration mechanisms and their effects must be made in creating a base upon which to develop estimates of damage costs by deicing salts or any other chloride source. Table 2-2 lists the factors that are related to deterioration. Of these factors the freeze-thaw cycle is the most important in determining the impact of water and deicing agents (chlorides) in structural deterioration.

Water is the most pervasive factor affecting structural deterioration.[87-89] Water is essential to concrete construction and curing. Yet, when in excess, both during the construction and for the life of the structure, it becomes the principal aggressor on reinforced concrete especially in areas subject to freeze-thaw conditions.[90] Without water in sufficient quantities, neither

TABLE 2-2

FACTORS RELATED TO DETERIORATION

Design

a. Superstructure type
b. Beam type
c. Span length
d. Beam spacing
e. Skew angle
f. Connection
g. Live-load deflection
h. Concrete cover over steel

Environment

a. Deck age (year of construction)
b. Traffic volume
c. Freeze-thaw cycle

Material

a. Air content (entrained air)
b. Aggregate source
c. Cement content
d. Water content

Construction*

a. Mixing method
b. Placement method
c. Placement temperature
d. Placement humidity
e. Curing method

*Some of these construction variables are available through record for only the newer projects.

Source: Nevels, James B., A Study to Determine the Causes of Bridge Deck Deterioration, State of Oklahoma Department of Highways, 1973.

corrosion of steel nor deterioration due to freeze-thaw are possible. The control of water in mixing, construction or curing is essential. Improper control results in numerous deficiencies which weaken the structure's ability to withstand deterioration forces.[91] The inability of a structure to remove water from its surface, to stop its permeation into the concrete, and to prevent its contact with the steel will result in early deterioration of the structure.[92] Nearly all deterioration mechanisms are controlled or affected by water.[93] Therefore, any factor which reduces a structure's ability to regulate water will harm the structure.[94,95]

Deicing salts that contain chloride ions can have effects that are specific to concrete. These aspects are described by the terms <u>scaling</u>, <u>cracking</u>, <u>delamination</u>, <u>spalling</u>, and others. Table 2-3 defines these and other terms. The role that chloride ions have in inducing or promoting these effects are described in detail in Table 2-4.

TABLE 2-3

DEFINITIONS

Scaling

Light Scale - Loss of surface mortar up to ¼ in. in depth, and exposure of surface of coarse aggregate.
Medium Scale - Loss of surface mortar ¼ in. to ½ in. in depth, with some loss of mortar between coarse aggregate.
Heavy Scale - Loss of surface mortar and mortar surrounding aggregate particles ½ in. to 1 in. in depth, so that aggregate is clearly exposed and stands out from the concrete.
Severe Scale - Loss of coarse aggregate particles as well as surface mortar and mortar surrounding aggregate, greater than 1 in. in depth.

Cracking

Transverse - Reasonably straight cracks perpendicular to centerline of roadway. Vary in width, length, and spacing. Frequently occur over primary slab reinforcement. Sometimes extend completely through slab. May be visible before bridge is open to traffic or at some later date. On some skewed bridges, the transverse slab steel is placed at an angle other than 90 deg. to the roadway centerline. Cracks parallel to this steel are also defined as transverse cracks.
Longitudinal - Fairly straight cracks, roughly parallel to centerline of roadway. Vary in width, length, and spacing. Sometimes extend completely through slab. May be visible before bridge is open to traffic or at some later date.
Diagonal - Roughly parallel cracks forming an angle other than 90 deg. with the centerline of the roadway, except as noted under Transverse above. Usually shallow in depth. Vary in width, length, and spacing. May be found immediately after completion of construction or may not appear until after bridge is open to traffic.
Pattern or Map - Interconnected cracks forming networks of any size and similar to those seen on dried mud flats. May vary in width from fine and barely visible to well-defined and open. May develop early in the life of the concrete or at some later date.
"D" - Cracks usually defined by dark-colored deposits, generally near joints and edges. The cracks at early stages are not open, but may ultimately develop sufficiently to produce failure of the concrete.
Random - Cracks meandering irregularly on surface of slab, having no particular form and not fitting other classifications.

Surface Spalling

Small - A roughly circular or oval depression, generally not more than 1 in. deep nor more than about 6 in. in any dimension, caused by separation and removal of a portion of the surface concrete, revealing a roughly horizontal or slightly inclined fracture. Generally a portion of the rim is vertical.

Large - May be a roughly circular or oval depression, generally 1 in. or more in depth and 6 in. or more in any dimension, caused by separation and removal of a portion of the surface concrete, revealing a roughly horizontal or inclined fracture. Generally a portion of the rim is vertical. In some cases it may be an elongated depression over a reinforcing bar.

Hollow Area - An area of concrete which, when struck with a hammer or steel rod, gives off a hollow sound, indicating the existence of a fracture plane below the surface.

Other Defects

Joint Spall - An elongated depression along an expansion, contraction, or construction joint.

Popouts - Conical fragments that break out of the surface of concrete leaving holes varying in size from that of a dime to as much as a foot in diameter. Generally, a shattered aggregate particle will be found at the bottom of the hole, with part of the particle still adhering to the small end of the popout cone.

Mudballs - Small holes in the surface left by dissolution of clay balls or soft shale particles.

Other Definitions

Bleeding Channels - Essentially vertical, localized open channels, caused by heavy bleeding.

Water-Gain Voids - Voids formed during the bleeding period along the underside of aggregate particles or reinforcing steel. Usually, initially filled with bleeding water that subsequently evaporated or was absorbed.

Specific Surface - The surface area of the air voids in hardened concrete, expressed as square inches per cubic inch of air void volume.

"L" - Spacing factor. The average maximum distance in inches from a point in the cement paste to the periphery of the nearest air void. Useful as an index of the maximum distance water has to travel during freezing to reach a protective air void.

Source: Durability of Concrete Bridge Decks, State Highway Commission of Kansas, 1965.

TABLE 2-4

IMPACT OF CHLORIDES ON REINFORCED CONCRETE

Chlorides - Scaling[95-103]

As concentrations of salt in the surface wearing layer begin to build, the freezing point of the surface drops. The result is an intermittant surface layer which fails to freeze or freezes after the layer below it. The stresses set up in the boundary planes by the differential freezing of the chloride contaminated upper layer, are sufficient to initiate and propagate cracking. The process is accelerated through the infiltration of water into the boundary zone via vertical cracks, capillarities and other discontinuities. The net result of the described processes is binder deterioration, internal cracks, small popouts and a generalized scabbing of the affected wearing surface. This type of surface deterioration is referred to as scaling. Scaling continues at an elevated rate as long as the surface structure, consisting primarily of fines, is intact. However, as the larger subsurface aggregate is exposed, the concrete matrix deterioration process slows and continues at a reduced rate.

At some point in the time frame, during which scaling is active, a second process, delamination, resulting directly from rebar corrosion begins. Depending on which source is referred to, the initiation of the corrosion process leading to delamination can begin at chloride ion concentrations of 1.18 kilograms and between 0.59 of salt per cubic meter (1 to 2 lbs./cu.yd.) of concrete.

Chlorides - Reinforced Steel Corrosion[104-108]

Reinforcing steel completely embedded in an intact concrete matrix can be encased in a highly alkaline (pH + 13.5) environment. Steel immersed in a solution of this alkalinity corrodes at a relatively slow rate. Chloride salts, regardless of source, impact the alkaline-moderated solution of the steel-concrete interface by supplying free-chloride ions which act to partially neutralize the solution. (Free-chloride ions in solution are highly mobile and readily permeate typical structural concretes.) This partial neutralization reaction approximates a threshold reaction in that the electrochemical reaction curve rises rapidly with a slight decrease in pH below the critical pH of the material. This decrease in pH can be initiated by a nominal increase in free-chloride ion over the critical concentration of free-chloride required for depacification. The actual concentration of chloride required varies with the composition of the matrix.

In the typical rebar corrosion reaction one segment of the rebar acts as an anode and another segment acts as the cathode. Both anode and cathode segments must have sufficient free-chloride ion concentrations to be in the depacified state. Chemical modifiers affecting rebar corrosion in concrete have not been extensively

TABLE 2-4 (Cont.)

explored, but based on various reports it would appear that both buffering effects and loosely-bound metallic ions associated with either the aggregate or the mortar constituents could act to increase the concentration of free-chloride ions necessary to produce depacification. Whether or not increasing free-chloride ion concentrations will accelerate the corrosion reaction after the initial sharp rise accompanying depacification has not yet been quantified.

Chlorides - Delamination[109]

Once the corrosion mechanism is active and pressure generated by the corrosion products builds, the concrete, unable to withstand the pressures generated (in excess of 316 kg/cm^2 4500 psi), cracks. (Iron oxide corrosion products produce a volume approximately 2.2 times greater than original steel.) Normally a vertical crack will form above the rebar, while a horizontal crack is initiated in the plane of the rebar. Freeze-thaw in conjunction with surface water entering the crack system plus additional stress from fatigue mechanisms and traffic loading impacts causes rapid expansion of the fracture planes; intersection of the resultant crack systems initiates spalling.

Chlorides - Spalling[110-113]

The spall then is the next major phase of deterioration. "Spalling usually occurs near or over reinforcing steel with portions of concrete removed, revealing roughly horizontal or inclined fractures. Concrete is often gone from areas not directly over bars but associated with them. A vertical crack may be present over the bars." Once delamination has occurred both live loadings and thermal stresses act to develop cracks between the delamination and the surface. These intersection crack planes eventually define the limits of a given spall and act to sever the spalled material from the deck proper.

Source: Sources are listed in the Footnotes under Chapter Two corresponding to the numbers by the categories. The primary source is: Economic Impact of Highway Snow and Ice Control, FHWA, 1977.

CHAPTER THREE

ENVIRONMENTAL EFFECTS OF DEICING SALTS

Numerous studies have been conducted in the past decade on the effects of deicing chemicals on the environment. Other studies have attempted to quantify the environmental degradation associated with the use of deicing chemicals. This chapter reviews the environmental effects of deicing salts on vegetation and soil, water quality, drinking water, and electrical power line transmission.

3.1 Vegetation and Soils

Salt has damaged plants in Minnesota since the early 1950's. A survey of 1914 trees in 1956 indicated that 9.4 percent had discolored leaf margins typical of soil-salt damage.[1] About 1/5 of these 9.4 percent were dead or dying. Surveys in later years have shown that more trees have died.[2,3] The problem is not limited to Minnesota. Many studies have shown that salt has damaged plants in many parts of the country.[4-12]

Deicing salts applied to roads and streets may be carried by surface runoff into streams and waterways, splashed upon roadside vegetation, or they can infiltrate soils near treated highways.[13] A major study conducted by the Minnesota Highway Department and the University of Minnesota confirmed that salt is responsible for damage to woody plants growing along many Minnesota roads.[14] This damage is caused by both salt spray (salt deposited aerially on branches, buds, and leaves of trees) and soil salt (salt deposited in the soil occupied by the roots of plants).

The study concluded that salt spray is the second major cause of twig dieback in deciduous trees (Dutch Elm disease is the major cause). In addition, salt spray is the number one cause of spring-browning of red, white, Scotch and Austrian pines. Generally, salt spray reduces the growth, worsens the appearance, and lowers the economic value of trees. Salt spray has also been shown to kill sensitive species such as white pine, but generally does not kill established trees or shrubs. Moreover, soil salts appear to raise the pH (make more alkaline) to undesirable levels within 45 feet of certain roads. In addition, soil salt causes marginal leaf scorch, leads to branch dieback, and possibly results in plant death along city streets.[15]

The National Cooperative Highway Research Program also conducted a major study of the impact of salt on plant biota and soils.[16] Their findings support the Minnesota study. Both studies evaluated susceptible species of plants. Tables 3-1 and 3-2 show the relative tolerance to damage from deicing salts for species commonly planted along Minnesota highways and city streets. Table 3-3 provides important information to policy makers in locating plants along roadsides. Table 3-3 shows the probable amount of damage that will occur to species of various tolerances to salt as affected by the ADT (average daily traffic) of the road and distance of the plant from the road. Amounts of damage are classified as low, medium, and high.

In short, salt damage can be reduced by: (1) carefully matching salt tolerant species to high salt sites for new plantings; (2) increased rodent protection and control; (3) maintaining the health of existing trees by appropriate techniques; (4) correcting the drainage problems that cause accumulation of salt from road were satisfied with the states sanding policies (see Figure 4-5). The degree of satisfaction also increased with age. The upward trend in satisfaction in both plowing and sanding could be attributed to the impatience of youth, who may want to drive any time of the year, or the older drivers' comparisons of present snow and ice removal techniques with those of the past.

The majority of the drivers by miles driven rated sanding as satisfactory. This satisfactory rating, however, decreased with the increase in miles driven (see Figure 4-6)....

Due to the increased interest in states' salting policies, it was felt that the complete plots of the public ratings should be included instead of summaries as with plowing and sanding....

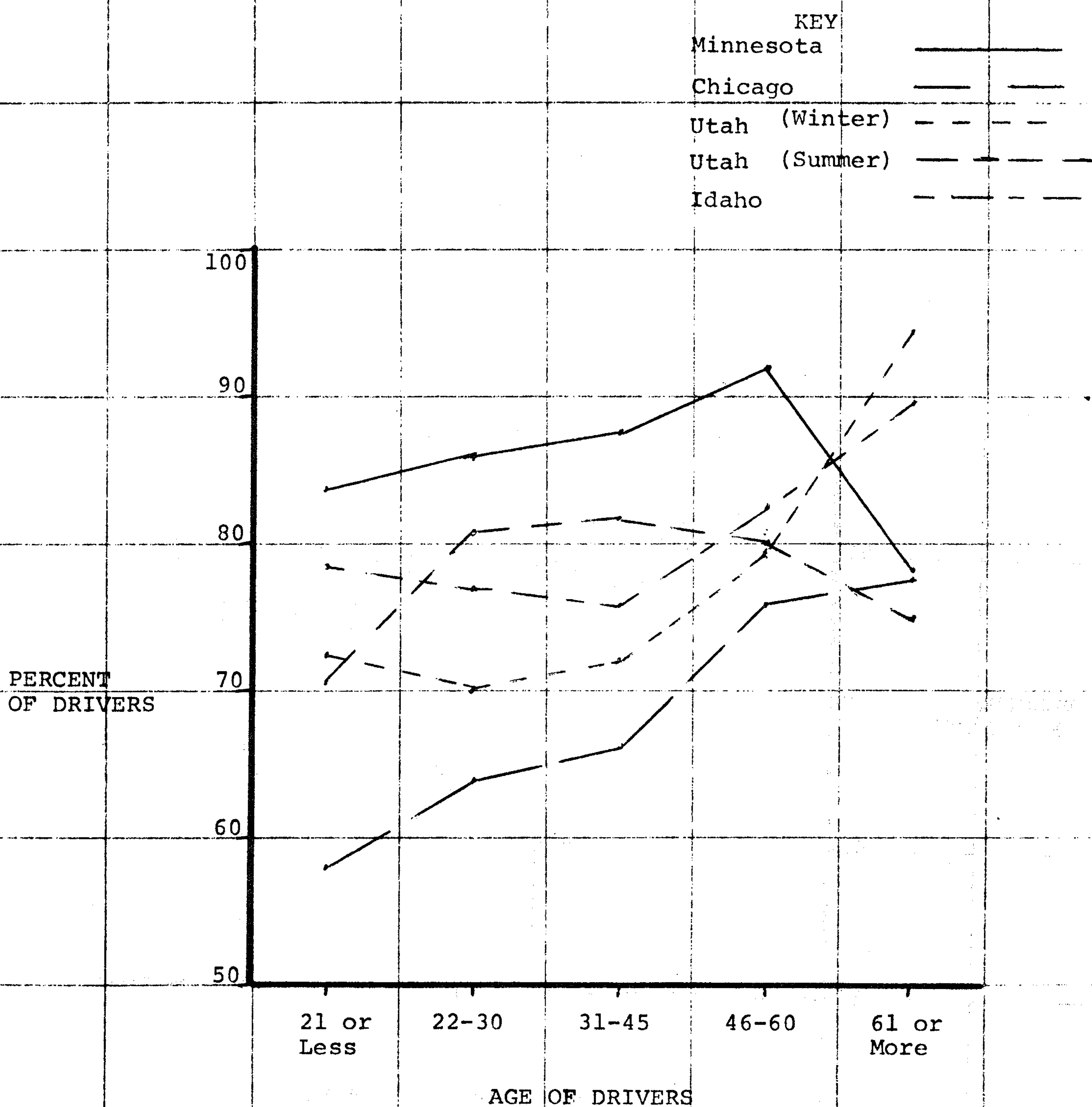
Minnesota drivers were the only ones which rated "too much" salt higher than satisfactory in salt application (see Figures 4-7 and 4-8). These ratings were fairly constant through each category and did not follow the increasing or decreasing trends as in plowing and sanding....

The majority of the drivers were satisfied with the present amount being spent on snow and ice control....In the case of Minnesota ($3.00) and Idaho ($4.50) there was significant decrease in present expenditures as miles driven increased. This decrease was a result of an increase of the next higher cost increment, Minnesota $4.50 and Idaho $6.00, receiving additional support as miles driven increase....

One final question to be considered in evaluating the public's attitudes is whether they have indicated their dissatisfaction to

FIGURE 4-3

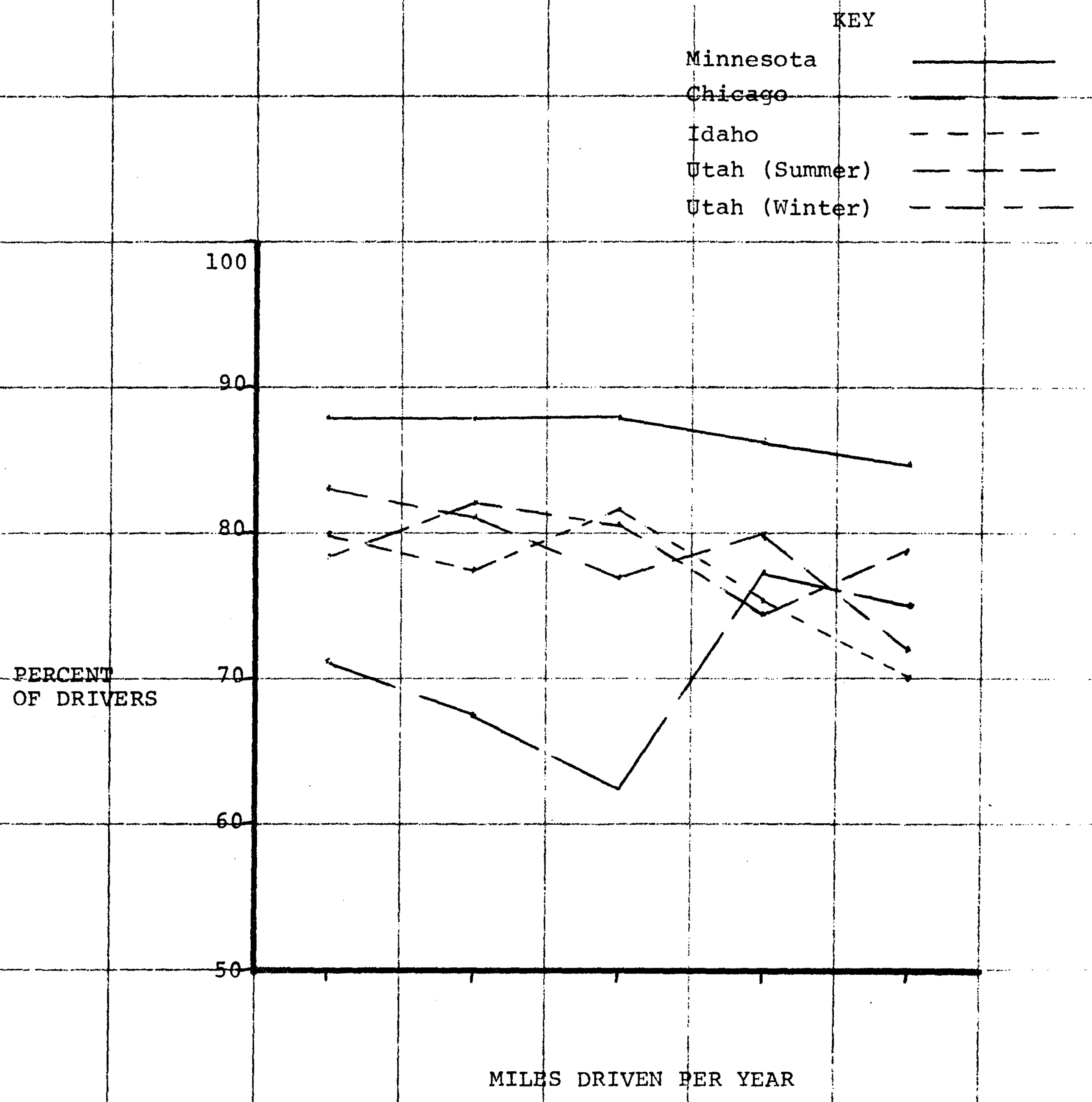
DRIVERS BY AGE WHO FEEL STATE PLOWING POLICIES ARE SATISFACTORY



Source: Utah Department of Transportation

FIGURE 4-4

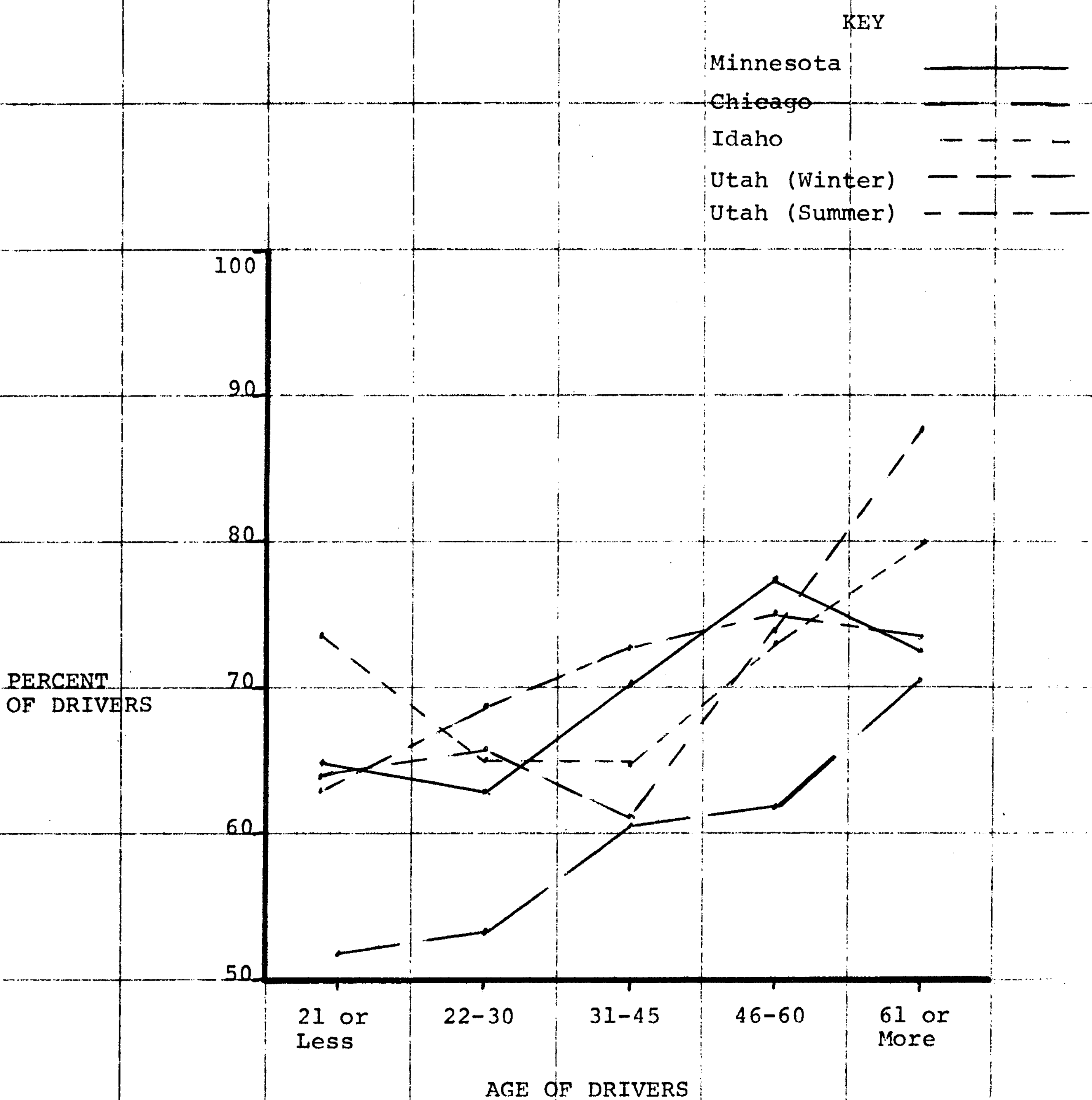
DRIVERS BY MILES DRIVEN WHO FEEL STATE PLOWING POLICIES ARE SATISFACTORY



Source: Utah Department of Transportation

FIGURE 4-5

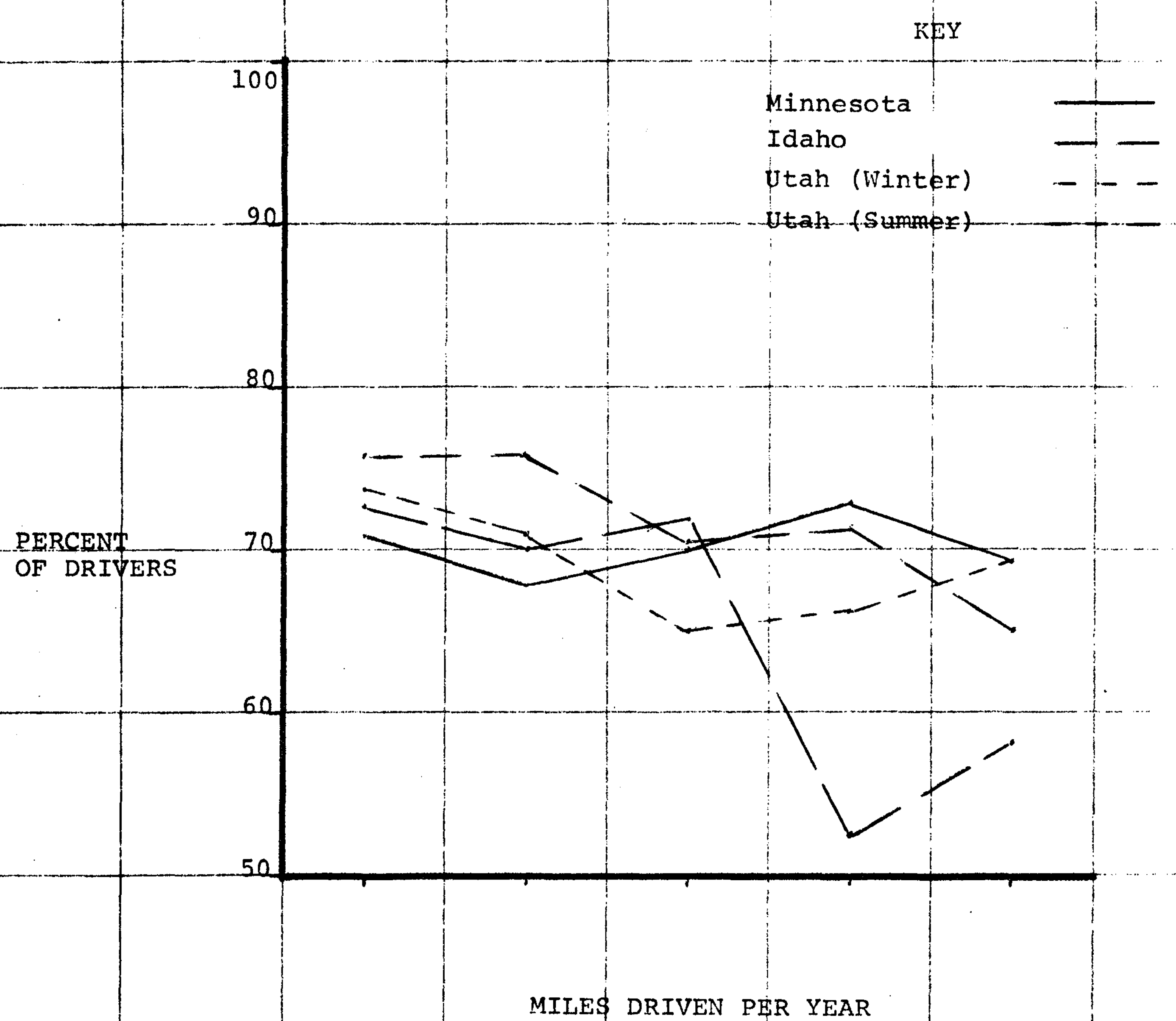
DRIVERS BY AGE WHO FEEL STATE SANDING POLICIES ARE SATISFACTORY



Source: Utah Department of Transportation

FIGURE 4-6

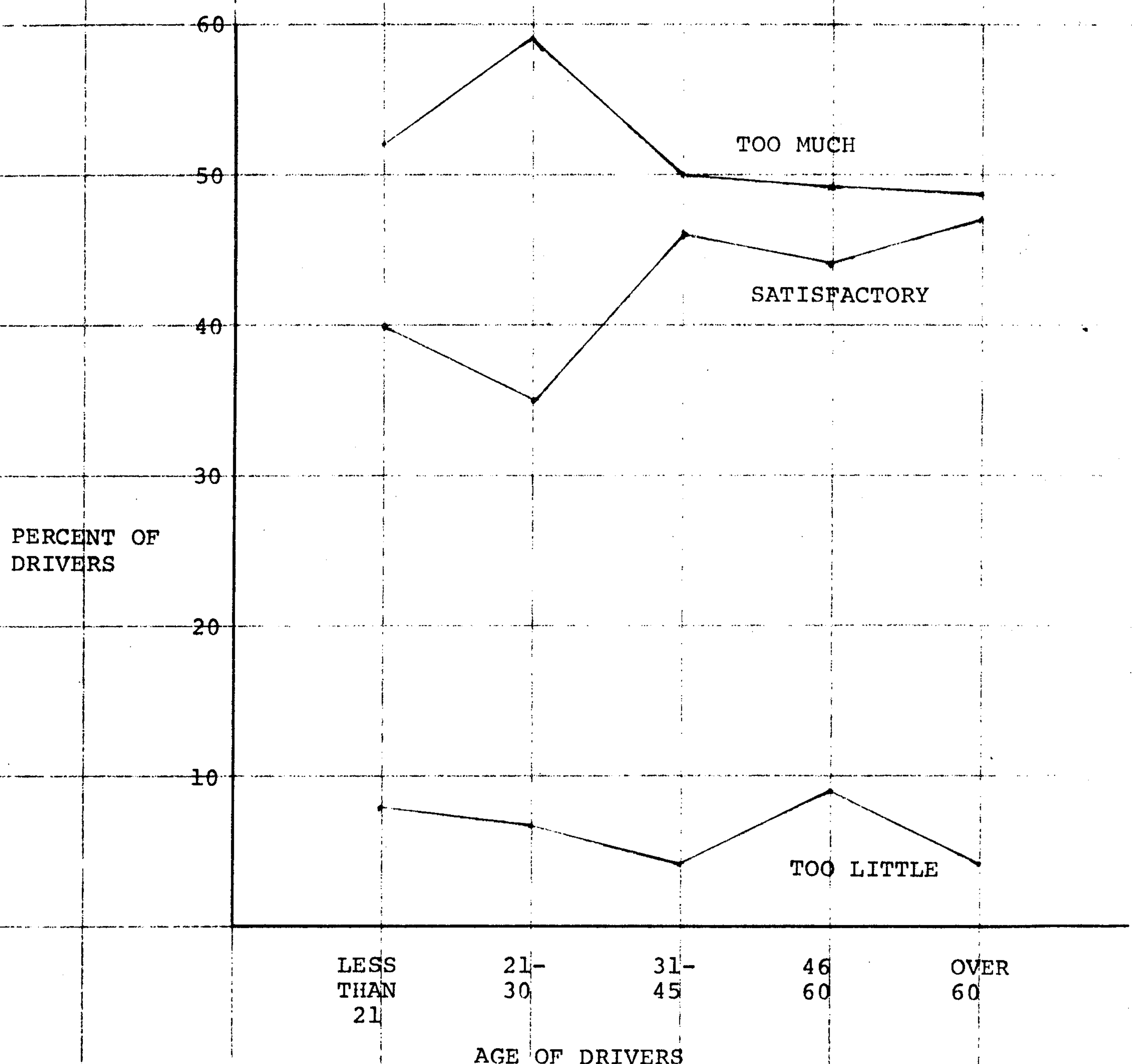
DRIVERS BY MILES DRIVEN WHO FEEL STATE SANDING POLICIES ARE SATISFACTORY



Source: Utah Department of Transportation

FIGURE 4-7

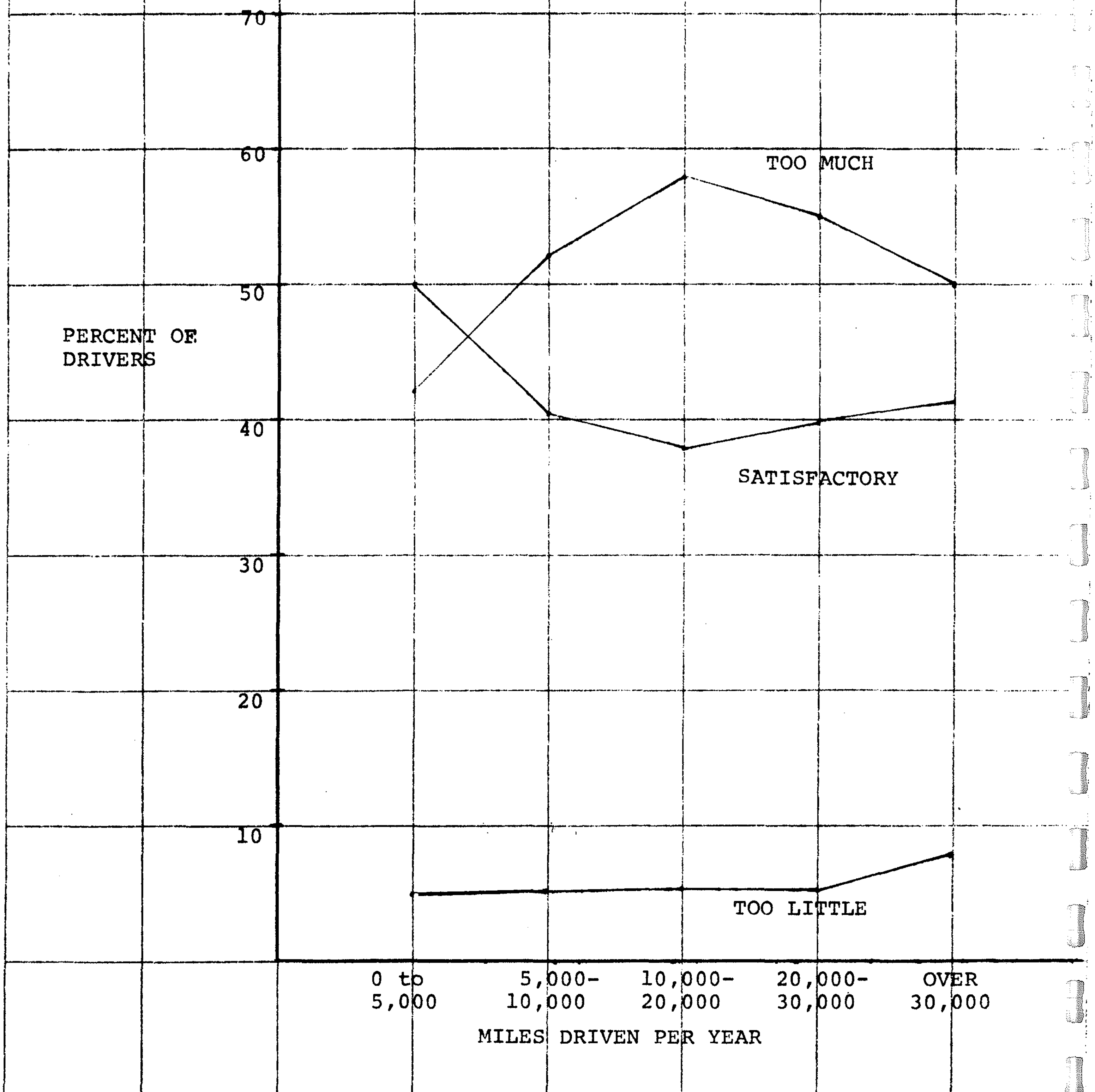
PUBLIC ATTITUDES TOWARD SALTING BY AGE



Source: Utah Department of Transportation

FIGURE 4-8

PUBLIC ATTITUDES TOWARD SALTING BY MILES DRIVEN



Source: Utah Department of Transportation

the maintenance departments. The Utah survey shows generally that the Minnesota public believes that too much salt is being used. The survey undertaken in conjunction with this study shows that many departments have received complaints on excessive salt usage in the last eight years (see Table 4-2). One conclusion that may be drawn from this is that the Minnesota public is generally satisfied with snow and ice removal maintenance, but would rather see this accomplished with less salt.

4.2 Salt Management Practices

There are four fundamental areas in snow and ice removal practices that are related to deicing salts. They include: (1) calibration of equipment; (2) storage of deicing material; (3) training and education of personnel; and (4) the use of ground-speed controls on the spreaders. All of these areas can affect the quantity of salt used, and, hence, the quantity and quality of negative effects that may result from salt use.

Calibration refers to the techniques that insure the proper application and spreading efficiency of machinery used in deicing application. Proper calibration prevents the over-application of deicing salts where conditions do not warrant and provides proper regulation of spreading equipment so that the deicing material which is distributed does not go beyond the pavement break. There is considerable wasting of salt when it is misdirected or excessively applied.[4-7] Improper calibration and operation of equipment can increase overall costs of snow and ice removal. Ontario has claimed a $1 million saving per year due to better application of deicing salts.[8] The State of Maine has reduced its salt use by 30,000 tons annually by improving its snow and ice removal practices.[9]

TABLE 4-2

Question 23: "Have you received any complaints on salt usage between 1970 and 1977?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	9	56.3
COUNTY	86	66	76.7
MUNICIPAL	98	52	53.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	6	3	66.7	33.3
COUNTY	16	50	24.2	75.8
MUNICIPAL	22	30	43.3	57.7

At $10 per ton, this is a $300,000 savings per year. The city of Madison, Wisconsin reported a 34% reduction in salt use, due primarily to equipment calibration.[10]

The survey sent to state, county and municipal maintenance areas asked whether they calibrated their application equipment. The results are found in Table 4-3. Although 100% of the state maintenance areas calibrate their equipment, only 6.1% of the counties and 10.8% of the municipalities do so. If they calibrated their equipment and achieved only a 20% reduction in salt use (compared with a 34% reduction in Madison, Wisconsin), the counties would save 7,900 tons per year (20% of the 1976-1977 winter salt use). If the municipalities accomplished the same reduction, they would save 16,900 tons per year. At $10 per ton, this is a savings of $79,000 for counties and $169,000 for municipalities each year.

Each year state, county and municipal highway departments and other organizations in the U.S. purchase about 9 million tons of salt and other deicing chemicals for a total value of $140 million.[11] These chemicals undergo several rounds of handling and storage. In recent years many highway departments have taken steps to protect this material. The reasons for this are clear.

At each step of the journey from mine or salt-producing facility to highway, there are numerous opportunities for loss of material. At any of the storage points, salt exposed to weather is dissipated into the immediate environment by rain and wind. Rain will reduce a salt pile at the rate of about 1/4% per annual inch of precipitation.[12] In an area with 40 inches of precipitation each year, a salt pile left exposed for half a year will lose 5% of its volume.

TABLE 4-3

Question 12: "Do you calibrate the spreaders on your application vehicles?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	66	76.7
MUNICIPAL	101	37	37.8

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	14	0	100	0
COUNTY	4	62	6.1	93.9
MUNICIPAL	4	33	10.8	89.2

An exposed salt pile of 500 tons would lose 25 tons under these conditions, not counting losses due to wind.

Enclosed structures are recommended in order to: (1) abate contamination of nearby streams, wells, and groundwater by excess salt runoff; (2) improve aesthetics in the local area; (3) prevent formation of lumps and reduce frozen crust in the salt piles; (4) eliminate heavy, caked salt in the pile thereby facilitating easier handling by mechanical equipment; and (5) enable better control over stored materials and more efficient loading and unloading.[13,14]

Loss of material provides cause for several kinds of concern. Chief among these, from the standpoint of the Environmental Protection Agency, is the concern for environmental damage that may result from water- and wind-borne salt. In Massachusetts, for example, seepage from storage piles has contaminated town water supplies.[15] The 25 tons of salt carried off the 500-ton salt pile cited above is sufficient to pollute almost 15 million gallons of water to the 250 milligrams per liter (mg/l) chloride maximum recommended by the U.S. Public Health Service for drinking water supplies. Water of even lower salinity has been known to cause corrosion problems in industrial plants.[16] That same 25 tons of salt runoff is capable of raising the sodium content in almost 120 million gallons of water to threshold level (20 mg/l) beyond which it becomes dangerous to medical patients restricted to low-sodium diets.

Deicing salts may be stored in unused buildings, garages, covered sheds, elevated storage bins, domed structures, cribs, and upon elevated platforms, or pallets. Stockpiles outdoors are preferably placed on storage pads and should definitely be covered with heavy tarpaulin, canvas or other protective materials. Salt storage sites should permit easy access by trucks, front-end loaders and similar equipment, and be situated so that trucks and salt spreaders do not have to "dead-head" long distances before reloading. The Salt Institute recommends that all storage pads, cribs and similar structures be located at sites completely free of groundwater.[17] They suggest that bituminous pads be placed upon crushed aggregate and salt-stabilized subgrades. Pads should be crowned to enable drainage away from the pile on all four sides. Additionally, drainage ditches, pipes or tiles may be necessary around salt storage areas to prevent contamination of local ground and surface water supplies. In certain instances, impoundment basins may be essential to capture and retain this salt drainage.[18]

The survey sent to state, county and municipal maintenance areas reveals that salt storage practices vary considerably. The survey revealed that 7.1% of the state, 43.9% of the county, and 51.9% of the municipal maintenance areas had one or more "open" salt storage sites (see Table 4-4). The rest of the sites were either under tarps or in buildings. The Minnesota Pollution Control Agency (MPCA) indicates that "easily pollutable drinking water supplies occur over most of the state." The MPCA concludes that there is a "greater opportunity for pollutant runoff from stockpiles in the eastern part of the state."[19] A detailed examination would be necessary to determine the pollution potential of each salt storage site.

A description of MinnDOT salt storage practices is as follows:[20]

Regarding the storage of salt, the Minnesota Department

TABLE 4-4

Question 10: "How do you store your salt (in the open, under tarp, in building, or other)?

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	66	77.6
MUNICIPAL	97	52	53.6

Maintenance Area	No. Open	No. Under Tarp	No. in Bldg.	No. Other	Pct. Open of Sample	Pct. Under Tarp of Sample	Pct. in Bldg. of Sample	Pct. Other of Sample
STATE	1	6	14	0	7.1	42.9	100	0
COUNTY	29	10	40	0	43.9	15.1	60.6	0
MUNICIPAL	27	6	20	6	51.9	11.5	38.5	11.5

of Transportation has 185 truck stations and 85 reloading sites throughout the state. These reloading sites are sites that do not have trucks stationed at them in the wintertime. There are frontend loaders at them along with a stockpile of sand and chemicals. Of these 270 locations, 186 of them have some sort of salt storage shed in various sizes, ranging from 40 to 1200 tons. Most of these resemble an old little coal shed type of building with one side open and constructed of treated timbers. This leaves approximately 80 sites where salt is stored outside. At these sites, there is a bituminous pad on the ground, and the stockpiles are always covered with a plastic material to keep the rain out of them. The bituminous pads are constructed so that there is no water, whether ground or surface, running through the piles.

These sheds are all filled to capacity in the fall of the year. Most of the maintenance areas fill them during the latter part of September and in October. They are refilled during the winter as need dictates, and to the extent necessary to fill the need until spring. As spring approaches, the amounts in the piles are watched very closely since it is not desirable to have surplus salt left over that must be stored over the summer. If by chance there is some salt left over, that salt is not stored outside, but put in one of the salt sheds.

In 1972, the then Minnesota Highway Department conducted an investigation of salt brine runoff control at salt stockpile sites. The investigation concluded:[21]

A. Improperly stored chemicals in stockpile form do cause an environmental problem which deserves the attention of highway officials if they are to prevent pollution, maintain a desirable image, prevent public criticism, and protect their right to use deicing materials for snow and ice control.

B. All of the 260 stockpile sites used by the Minnesota Highway Department contribute to pollution to varying degrees. Taking corrective action to avoid visual pollution will not only eliminate the cause of most of the public criticism but will also minimize, or perhaps even eliminate, the cases where chemical pollution can be scientifically proved to be a significant detriment to society.

C. Since bulk salt piles are covered all year around, the major source of salt brine runoff is from winter sand piles and this problem is greatest during the high precipitation months, March through November. The five most critical months are May through September.

D. There is no one magic solution to problems in all situations; rather a family of solutions, each of which may or may not apply to a given situation.

E. Methods of abating pollution, both visual and chemical, which eliminate the cause of brine formation are cheaper, more easily implemented and more effective than any method of collecting and disposing of the brine after it is formed. If preventive measures will not eliminate all brine from forming, it is believed that the runoff can be minimized and diluted to the point where, in most cases, it will not significantly affect the environment if allowed to flow off the site.

F. Salt will not precipitate or settle out of a normal unsaturated brine solution and, therefore, salt settling basins are ineffective and basically a waste of money as a pollution control measure. Basins of this type are effective only if brine is collected and disposed of either by evaporation or by hauling away. However, because of size requirements, the cost of operating and maintaining them are such that collection type facilities should be considered only as a last resort.

According to the Office of Maintenance of the now Minnesota Department of Transportation, conditions have improved.[22]

> In 1972 only sixty-one percent of our stockpile sites had buildings for the storage of salt. Today seventy percent of our sites have salt storage buildings. This represents the addition of 80 buildings.
>
> Since 1972, many sites have been improved with bituminous pads and curbs to control any potential contaminated runoff. Sand and salt mixtures left in the spring are now covered with Poly or moved into a storage building. If there is still potential for contamination every effort is made to contain it in tanks or holding basins.
>
> Another study similar to the one done in 1972 would be required to answer this question in greater detail. The PCA has indicated a desire to review all stockpile sites sometime in the future. When their review is complete, coordination with them may provide the answers to your question.

Counties and municipalities might save 2% and 3%, respectively, if greater efforts were made to store salt properly, preferably in a building. Such a savings could reduce salt waste by 800 tons for counties and 2,500 tons for municipalities. This is an economic savings of $8,000 for counties and $25,000 for municipalities each year ($10 per ton saved).

Training and education of personnel is another fundamental area that can help maintain open roads in an efficient and effective manner. The Salt Institute believes that proper training for maintenance personnel is vital. They believe that training courses should be conducted to assure:[23]

- That equipment operators fully understand how to operate and maintain plows, spreaders, loaders and other equipment used for winter maintenance.
- That all employees are thoroughly familiar with their responsibilities.
- That all employees receive a full review of snow removal schedules, describing the beginning and end of each section and personnel and equipment assigned.
- That dry runs are made over areas to be covered during actual snow-fighting operations.
- That all employees understand how salt works in snow and ice so they know how, when and in what amounts it should be applied.

The survey sent to all state, county and municipal maintenance areas revealed that training and education courses are sparse on the county and municipal level (see Table 4-5). The survey showed that 79.4% of the counties and 69.1% of the municipalities do NOT have a training course on snow removal for their drivers. Two state maintenance areas indicate that they have no training courses.

It is difficult to quantify the reduction in salt use that can be attributed to having well trained drivers and supervisors. It is logical to assume, however, that training and education could help an employee do the job better. In addition, a trained

TABLE 4-5

Question 14: "Do you have a training course on snow removal for your drivers?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	87	68	78.2
MUNICIPAL	98	55	56.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	12	2	85.7	14.3
COUNTY	14	54	20.6	79.4
MUNICIPAL	17	38	30.9	69.1

employee may be more discriminating when applying deicing salts.

The EPA strongly recommends the use of ground-speed controls on salt application vehicles. In its manual on application practices for deicing chemicals it states:[24]

> A recent addition to the control system for hydraulic chemical spreaders is a control unit, which synchronizes the spreader feed mechanism with the forward motion of the truck. This automatic type of control relieves the driver of the burden of manual control of the application rate of salt and/or sand or other chemicals during a storm; thus he is free to focus his attention on driving, plowing, and other responsibilities.
>
> Ground-speed controllers are a most important piece of equipment for controlling the rate of chemical application. More importantly, they enable spreading of chemicals only when the truck is in motion and go a long way toward eliminating the wasteful spreading of chemicals that inevitably occurs when a vehicle is stopped, for one reason or another, and the spreader continues to operate. Further, these ground-speed controllers are capable of spreading chemicals in proportion to the speed at which the truck is traveling. At slow speeds, a small amount of chemical is spread, whereas, at high speeds, larger quantities are released. The net effect is that a uniform quantity is spread on each mile the truck goes.

Based on the above, ground-speed controls can effectively reduce waste in salt application perhaps as much as 5%. This would reduce salt use for state, counties and municipalities by 5,000, 2,000, and 4,200 tons, respectively, each year.

4.3 Salt Application Guidelines

The basic problem in establishing guidelines for deicing salt applications is in establishing priority or service levels for snow and ice control. The Utah Department of Transportation conducted a multi-state survey of highway service levels in an attempt to solve this problem. From their survey, they concluded:[25]

> Traffic volume and highway types were the two parameters most used in determining level of service. It also appeared

that many states' policies were written around what ideally they would like their service to be and not what actually may happen. For example, one state's policy was simply to maintain a bare pavement on all highways during a storm. This type of policy was too arbitrary and not indicative of the actual maintenance practice. This type of policy would be difficult to defend in a court case if the court held the state exactly to its stated policy. To protect themselves against possible litigation many states such as Illinois have rewritten their maintenance policies for snow and ice control so that they reflect what was actually accomplished during the storm. For the purposes of economic analysis the traffic volume and highway type alone were not enough. Information about the snow accumulation and results of the snow and ice control should be included.

Upon analysis of the state policies, the Utah Department of Transportation combined several state policies and came up with a maintenance model for stated levels of service. There are five levels of service ranging from a "bare road" policy to allowing seasonal closings of highways. A description of each level of service is as follows:[26]

Level of Service 1 - The roadway is plowed, sanded, cleared of frost, snow and ice pack, and widened as quickly as possible even though this may involve working extra hours at night or Sundays or legal holidays. The work is carried out continuously during the storm to keep all lanes open for traffic and provide a good surface on which to operate. Exceptions are when blizzard conditions, poor visibility, avalanche danger or other hazard requires other action be taken.

In general, under normal storm conditions, the plowing frequency should insure an accumulation not to exceed x.xx inches. The estimated time under moderate storm conditions is approximately xxx minutes.

Chemicals, abrasives, or a mixture of the two, applied to roadway surfaces to improve traction and facilitate the removal of snow and ice, as required. First attention is given danger spots such as steep grades, sharp curves, intersections, bridges, and bridge approaches. For the most part, the initial response during a storm and any special attention needed during the storm at these points will be provided for by the Foreman over the area.

Operations will proceed without interruption and continue through and after the storm until the roadway is bare of snow bottom without any restriction on overtime, inasmuch as the equipment, materials, and men assigned to the work will permit.

Level of Service 2 - Snow will be removed continuously during the storm to keep roads open for traffic. After plowing is started, the major effort is keeping the road open with less emphasis on keeping it bare (not to preclude removing loose snow before becoming snow or ice pack). Also provide a reasonable bare portion of sufficient width near the centerline to give traction for traffic in both directions. Completely bare pavement should, however, be provided on hills, curves, and at intersections as soon as possible. On highways with four or more lanes, two lanes in each direction should be kept open during the storm. When this condition is reached and is likely to sustain itself, overtime work will cease.

Estimated time under moderate storm conditions is approximately xxx minutes round trip. In general, under normal storm conditions, the plowing frequency should insure an accumulation not to exceed x.xx inches in plowed lanes.

Chemicals, abrasives, or a mixture of the two, applied to roadway surfaces to reduce slipperiness and facilitate the removal of snow and ice, as required.

Clearing the remaining lanes and shoulders should be done during regularly scheduled shifts after the storm ends.

Level of Service 3 - Snow should be removed during the storm to keep the travel way (one lane each direction) open for traffic. (On divided highways, left lanes should be half bare with sanded curves and hills before termination of snow removal efforts.)

Estimated plowing time for moderate storm conditions is approximately xxx minutes round trip. In general, under normal storm conditions the plowing frequency should provide an accumulation not to exceed x.xx inches.

Where available, traction aid requirements (snowtires, chains, etc.) may be considered for intermittent periods as required.

Apply chemicals, abrasives, or a mixture of the two, to roadway surfaces to reduce slipperiness and facilitate the removal of snow and ice with continued maintenance at hazardous locations.

Overtime restrictions should be observed throughout with shoulder widening and cleanup activities carried out during regularly scheduled shifts after the storm ends.

Level of Service 4 - Snow should be removed only during regular working hours as required to obtain passable conditions--snow pack is acceptable.

When necessary, road can be closed for intermittent periods of time.

Abrasives or chemically treated abrasives may be applied to facilitate the movement of traffic and control hazardous locations as conditions require.

Level of Service 5 - These routes are allowed to be closed during the winter by snow and remain closed (except under unusual conditions). Routes will be reopened in the spring when it is reasonable to assume the storm possibilities are over.

xxx - To be filled in by State.

Some examples of states' maximum snow accumulation and plowing frequencies are shown in Table 4-6.

A major finding in an Environmental Protection Agency (EPA) study on salt application was the discrepancy between the prescribed amounts of deicing agents and the amounts that were actually used on the highway surface. The study states:[27]

> Many maintenance managers were aware of this and readily admitted that they were using more material in their operation than was actually prescribed by their maintenance manuals. Those managers who, for economic or environmental reasons, initiated actions to reduce the amount used to the prescribed levels found to their surprise and satisfaction that there was no reduction in the level of service provided by the lesser amounts of deicing chemicals.

Other problems in establishing guidelines for deicing salt applications involve the use of various techniques to remove snow and ice. The Environmental Protection Agency has identified six techniques for reducing the amount of deicing chemicals needed. These include:[28]

> The use of ground-speed controllers for all spreaders.
>
> Calibration of spreaders to determine how much material is being used. Two techniques are presented: a yard calibration and an in-service calibration. Rule-of-thumb techniques are also presented for checking calibration and determining when spreaders are not operating at their prescribed rates.
>
> Establishment of levels of service. Standards for maintaining roads during the winter should vary according to road types and their average daily winter traffic.
>
> Establishment of a set of application rates for each agency. Guidelines are presented for the amount of chemicals to be applied under varying weather conditions for various classes of roads. Two distinct rates are prescribed: one for the first application and lesser amounts for secondary applications as the storm progresses.
>
> Starting to plow snow early in each storm and emphasis on plowing rather than salting. Underbody scrapers are recom-

TABLE 4-6

EXAMPLES OF LEVELS OF SERVICE, SNOW ACCUMULATION

AND PLOWING FREQUENCY

State	Level of Service	Snow Accumulation	Plowing Frequency
Michigan	1	1/2"	-
	2	1 "	-
	3	2 "	-
	4	-	-
	5	-	-
Minnesota	1	1 "	120 min.
	2	1 1/2"	180 min.
	3	3 "	240 min.
	4	-	-
	5	-	-
New Hampshire	1	1 "	60 min.
	2	1 1/2"	90 min.
	3	3	120 min.
	4	-	180 min.
	5	-	-
Virginia	1	1 "	-
	2	2 "	-
	3	6 "	-
	4	-	-
	5	-	-

Source: McBride, J. L., et al., Economic Impact of Highway Snow and Ice Control: Final Report, National Pooled Fund Study, August 1977.

mended for keeping snow-pack from forming.

Accounting for the amount of salt used on each section of highway or city street. A daily report filled out by each operator--summarizing the amounts of chemical used, the lane miles upon which it is used, and the results obtained--is essential for accurate accounting for chemical usage.

This section will review: (1) data on deicing salt guidelines and techniques for application on a general basis in Minnesota; (2) an examination of Hennepin County, Minnesota, guidelines; (3) an examination of the Minnesota State maintenance area guidelines; (4) an analysis of the State guidelines in terms of Hennepin County's and an examination of the State's salt mixture guidelines; and (6) a look at specific techniques that could reduce salt use in Minnesota.

The first and foremost question in evaluating salt application guidelines is whether any formal or informal guidelines exist. This question was addressed in the survey sent to state, county and municipal maintenance areas. The results are shown in Table 4-7. While all of the state maintenance areas have guidelines, only 37.9% of the counties and 34.8% of the municipalities surveyed had any formal or informal guidelines at all.

Table 4-8 shows the form in which snow and ice removal material is used. It was found that 0.0% of the state, 18.6% of the counties, and 31% of the municipalities use a straight salt mixture. In addition, 35.7% of the state, 62.9% of the counties, and 34.5% of the municipalities use sand with less than 10% salt. Salt is added to sand to keep it from freezing. A salt-sand mixture (salt greater than 10%) is used by all state maintenance areas, 92.9% of the counties, and 81.0% of the municipalities, while 17.1% of the counties and 15.5% of the municipalities use

TABLE 4-7

Question 15: "Do you have any formal or informal criteria to determine whether to apply salt, sand, or a salt/sand mixture?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	66	76.7
MUNICIPAL	98	46	45.9

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	14	0	100	0
COUNTY	25	41	37.9	62.1
MUNICIPAL	16	30	34.8	65.2

TABLE 4-8

Question combination of 6, 7, 15, and 20:
"In what form do you apply your snow and ice removal substances: salt, sand, salt/sand mixture or other?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	70	81.4
MUNICIPAL	98	58	59.2

Maintenance Area	No. Salt	No. Sand	No. Salt and Sand	No. Other	Pct. of Sample Salt	Pct. of Sample Sand	Pct. of Sample Salt/ Sand	Pct. of Sample Other
STATE	0	5	14	0	0	35.7	100	0
COUNTY	13	44	65	12	28.6	62.9	92.9	17.1
MUNICIPAL	18	20	47	9	31	34.5	81	15.5

other materials as well. The state does not use any other material.

While few maintenance areas on the county and municipal level have formal or informal guidelines, some indications of salt application practices can be determined. Table 4-9 indicates that temperature, snowfall, number of vehicles per day, and/or other parameters do affect the time of application for salt, salt-sand mixture, and sand for most maintenance areas on the state, county, and municipal levels. Table 4-10 shows that state and county maintenance areas rely on plowing, blading and a salt-sand mixture (in that order) for snow and ice removal. Municipalities rely on plowing, salt-sand mixture and blading (in that order) for their snow and ice removal. All three levels prefer to start their snow and ice removal operations after the storm is over (see Table 4-11). The second choice is during the storm, then comes "just as it starts". In addition, only a quarter of the counties and a fifth of the municipalities keep records on when, where, and how much salt, salt-sand mixture and sand is applied to the roads (see Table 4-12). All state maintenance areas keep these kinds of records.

Two informal surveys of county salt application guidelines have been conducted. The Minnesota Pollution Control Agency (MPCA) conducted an informal survey in late 1977 of 23 counties outside the metropolitan area. They found:[29]

> County road salting policies in general do not attempt to provide a totally bare pavement throughout the winter. The county survey showed that there is an emphasis on using chemicals in areas that present the greatest traffic hazards (hills, curves, bridges, and intersections). In addition, routes that have high traffic volume generally receive greater applications of salt than roads that are used less.
>
> Specific practices to control traffic hazards vary from county to county. One county may do only "spot" salting on

TABLE 4-9

Question 19: "Does the time of application for salt, sand, salt/sand mixture or other vary with any of the following parameters: temperature, snowfall, number of vehicles per day or other?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	67	77.9
MUNICIPAL	98	50	51

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	13	1	92.9	7.1
COUNTY	53	14	79.1	20.9
MUNICIPAL	38	12	76	24

TABLE 4-10

Question 17: "Which do you rely on most in snow removal maintenance: blading, plowing, sanding, salting, salt/sand mixture, nature, and/or other (rank in order)?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	11	68.8
COUNTY	87	71	81.6
MUNICIPAL	98	54	55.1

Maintenance Area	First Choice	Second Choice	Third Choice
STATE	Plowing (90.9)	Blading (83.1)	Salt/Sand (45.5)
COUNTY	Plowing (77.2)	Blading (54.9)	Salt/Sand (43.7)
MUNICIPAL	Plowing (57.4)	Salt/Sand (50.0)	Blading (38.9)

TABLE 4-11

Question 20: "When do you prefer to apply the following with regard to snow conditions (before storm starts, just as it starts, during storm, and/or after storm)?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	68	79.1
MUNICIPAL	98	54	55.1

Number

Maintenance Area	Before Storm Starts	Just As It Starts	During Storm	After Storm
STATE	0	9	3	2
COUNTY	0	5	7	56
MUNICIPAL	3	7	9	35

Percent of Sample

Maintenance Area	Before Storm Starts	Just As It Starts	During Storm	After Storm
STATE	0	64.3	21.4	14.3
COUNTY	0	7.4	10.3	82.4
MUNICIPAL	5.6	13.0	16.7	64.8

TABLE 4-12

Question 22: "Do you keep records of when, where, and how much sand, salt, or salt/sand or other that you apply in a storm?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	68	79.1
MUNICIPAL	98	55	56.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	14	0	100	0
COUNTY	19	49	27.9	72.1
MUNICIPAL	11	44	20	80

icy stretches of road; another county may apply salt along the center of the road so as to maintain one clear tire track in each lane of traffic.

The survey revealed that there is no single standard for the amount of salt to use under any given set of conditions.

In August, 1977, the Washington County Highway Department conducted an informal survey of 11 counties. Analysis of this survey revealed:[30,31]

> Approximately 50 percent of the counties do not maintain a bare road policy, but rather apply sand and chemicals to hazardous locations such as hills, curves, intersections, and railroad crossings. The remaining 50 percent maintained a bare road policy in varying degrees from the establishment of bare wheel tracks to complete bare pavement within a period of 24 to 48 hours. The establishment of a bare road policy by counties is primarily in the areas where there is a high percentage of commuter traffic living in rural areas commuting to larger cities. Almost without exception, the county engineers are being pressured by the public, law enforcement agencies, school districts, and post offices to increase the levels of service provided in ice control.

These two surveys seem to contradict each other as to whether the counties have a "bare road" policy. A "bare road" policy for 50% of the counties is probably unnecessary and would result in a considerable waste of salt. If service levels were established for salt application, the quantity of salt used would be reduced considerably. Low service levels would not need a "bare road" policy. Hennepin County and MinnDOT have formal guidelines for salt application. The following is a review of their guidelines.

Hennepin County has altered its maintenance procedures to comply with the 1971 Minnesota law (see Section 1.4 of Chapter One for more details). The following operational guidelines have been adopted:[32]

Salt, or other deicing chemicals, will be used to achieve bare pavement only on county arterials which generally exceed average daily traffic volumes of 7,500.

Salt, or other chemicals, will be used in very limited amounts at controlled intersections or intersections which have high-turn movement volumes, and at certain other areas such as hills, curves, railroad crossings, and signed school crossings where traction is critical.

Salt, or other chemicals, may also be used as a last resort to restore reasonable driving conditions if sand and other methods prove ineffective.

Sand, containing only the necessary amounts of salt or other chemicals to prevent freezing, will be applied at such other locations deemed necessary as soon as is reasonable after the end of a storm.

Table 4-13 summarizes this policy.

TABLE 4-13

HENNEPIN COUNTY GUIDELINES

Average Daily Traffic	Level of Service
> 7500	Bare Road Policy-- Salt all roads after the storm starts
< 7500	Bare Road Policy-- Salt only high volume hills, curves, railroad crossings, and school bus crossings; sand remaining.

Minnesota maintenance areas policy is described in Table 4-14.[33]

TABLE 4-14

STATE MAINTENANCE AREA GUIDELINES

Average Daily Traffic	Level of Service
>10,000	Bare Road Policy-- All roads clear in 8 hours
2,000 - 10,000	Bare Road Policy-- Right lane clear, left lane intermittent bare pavement
800 - 2,000	Intermittent bare pavement with clear wheel tracks
< 800	Bare left wheel track, sanded hills and curves, compacted snow on gravel roads

Table 4-15 shows a comparison of additional maintenance practices.

TABLE 4-15

COMPARISON OF HENNEPIN COUNTY AND STATE MAINTENANCE PRACTICES

Maintenance Practice	Hennepin County	State
Form of material	Salt and sand	Salt-sand mixture
Recordkeeping	YES	YES
Calibration	YES	YES
Storage in building	YES	Mostly
Training and education	YES	YES
Reliance on:	Plowing, blading, salting	Plowing, blading, salt-sand mixture
Prefer to start operations:	As the storm starts	After the storm

If the state adopted Hennepin County guidelines an estimated 30% salt reduction could occur. Of the total salt used, 38% is in the 2,000 - 10,000 ADT bracket (see Table 4-16). Perhaps as much as 80% of the salt in this bracket could be eliminated by altering the service level to that of Hennepin County. This would reduce salt usage by 30,000 tons with an estimated savings of $300,000 per year ($10 per ton). If counties adopted this service level, a savings of 11,900 tons could be made. However, insufficient data does not permit a reliable estimate to be made for municipalities.

In addition to the above practices, the state has a five condition program for salt application. Table 4-17 describes these conditions.

Since conditions vary from maintenance area to maintenance area, there is some flexibility. One maintenance engineer described salt use in his district this way:[34]

> "We used 14,906 tons of sand in 1976-77. We mixed 1,269 tons of rock salt in our sand stockpiles for freeze proofing in the fall. This amounts to an 8 1/2% mixture. This mixture was used on hills, curves, intersections and other danger points at temperatures ranging from 25° F. to 32° F. For temperatures from 10° F. to 25° F., we used approximately 1/4 rock salt and 3/4 sand. Temperatures below 10° F. required 50-50 mixtures. Rock salt added for the entire winter amounted to 5,105 tons which gives an average ration of 33% salt. When icing conditions are severe, all trunk highways with speeds over 30 mph are treated with appropriate ratios of salt/sand mixtures based on the temperature ranges above and on specific conditions of wind, sunshine, surface texture and type, volumes and types of traffic, etc."

In order to evaluate the state's conditions for salt application, it is necessary to review some characteristics of snow and ice. Snow and ice properties pertinent to winter highway maintenance have been extensively studied.[35] The stresses

TABLE 4-16

Winter 1976-1977 Sand and Salt Usage by Road Classifications.

Classification	Lane Miles	Amount of Salt (tons)	Amount of Sand (tons)	Total Amount (tons)	% Salt
Urban Commuter	3,455 (11%)	32,418 (35%)	70,843 (31%)	103,261	31.4%
Rural Commuter	12,391 (41%)	34,709 (38%)	98,376 (43%)	133,085	26.1%
Primary	10,089 (33%)	19,159 (21%)	45,883 (20%)	65,042	29.5%
Secondary	4,520 (15%)	5,692 (6%)	13,863 (6%)	19,555	29.1%
TOTALS	30,455 (100%)	91,978 (100%)	228,965 (100%)	320,943	

TABLE 4-17

STATE CONDITIONS FOR SAND AND SALT PROPORTIONS

Condition	Temperature	Type of Precipitation	ADT	Sand/Salt Ratio	Before Rush Hour	After Rush Hour
1	25° F. & rising	Sleet, freezing rain, wet snow	-	Sand: 90-95% Salt: 5-10%	-	-
2	25° F. & falling	Sleet, freezing rain, wet snow	-	Sand: 75% Salt: 25%	-	-
3	10° F. & rising	Dry snow	-	Sand: 75% Salt: 25%	-	-
4	10° F. & falling	Dry snow	High	Sand: 50% Salt: 50%	All roads	Ramps, spots, stop signs
5	10° F. & falling	Dry snow	Low	Sand: 50% Salt: 50%	Ramps, spots, stop signs	Ramps, spots, stop signs

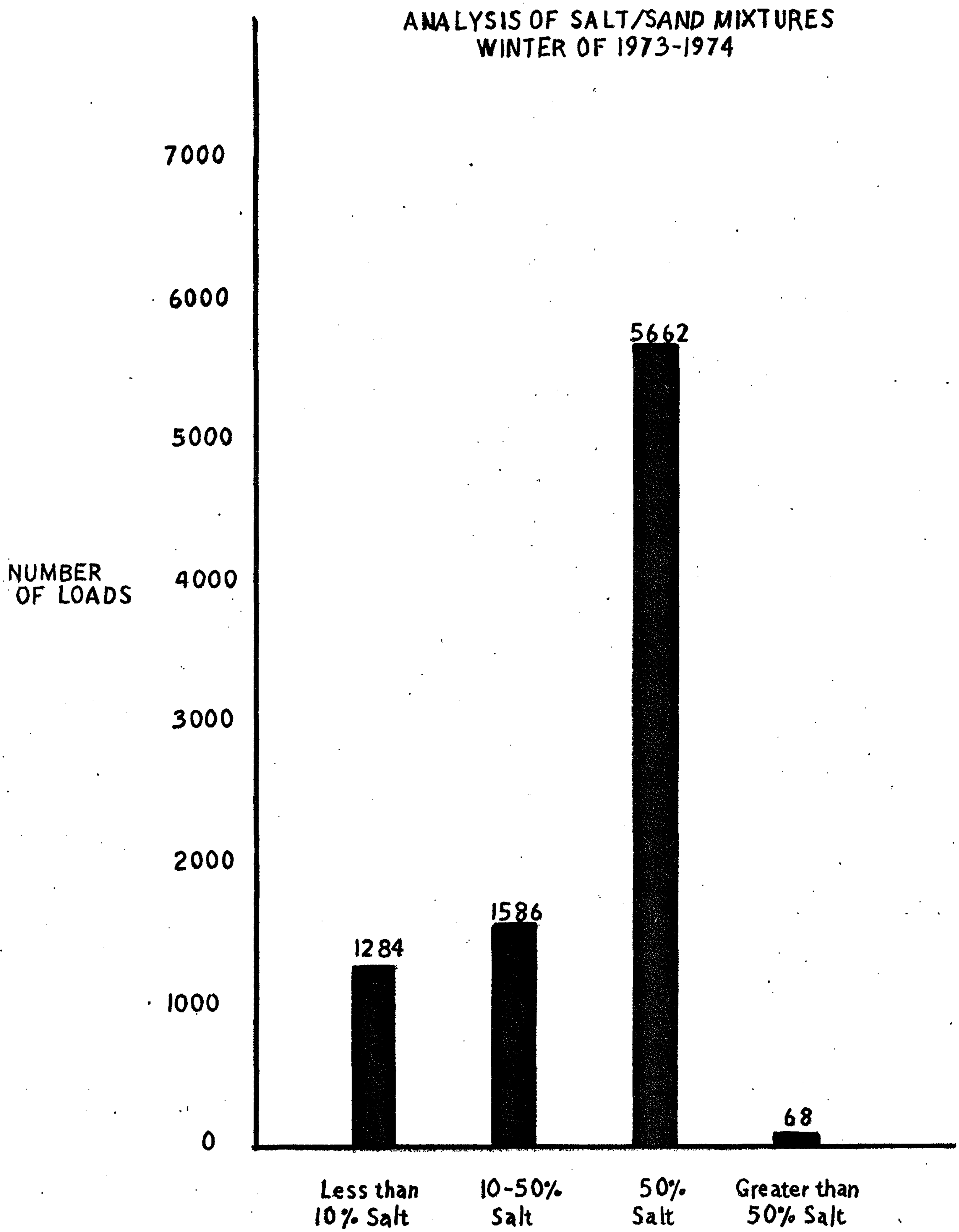
causing structural collapse in snow and ice can result from tension, compression and shear forces. Tensile strength of low density (low moisture) snow is low and shows wide scatter. The crushing strength is about twice that of tensile strength, but is very low in low-density snow. If the snow should be confined during compression it collapses in stages until it reaches a density of 0.5 gm/cm (31.2 pcf) is reached. At this point the snow grains are closely packed and stress then increases very rapidly because any further densification must occur by deformation of an increasing number of snow grains. Shear strength is very similar to tensile strength.

Generally, dry, new snow may be compacted mechanically or by wind up to a density of slightly less than fifty percent. Wet snow can be compacted to higher densities (up to 80%) when moisture content approaches or exceeds 17% (medium-density snow). With 25% or more moisture, the mixture usually becomes slush.[36]

Ice is generally a more serious problem than snow in both its effects and because of its greater adhesion to surfaces, and its influence on traffic movement. The adhesive force of ice, which is much greater than that of snow, is great enough to remove chunks of concrete when an attempt was made to remove it from the road surface. In general, the strength of adhesion of ice is greater than the tensile strength of concrete.[37]

A review of the state's conditions for sand and salt proportions in conjunction with their reply to the survey (in particular, see Table 4-10), indicates that the state uses plowing and blading and extensive use of salt when these two do not do an adequate job. Figure 4-9 shows the number of truck loads used in state

FIGURE 4-9


ANALYSIS OF SALT/SAND MIXTURES
WINTER OF 1973-1974
NUMBER OF LOADS
7000
6000
5000
4000
3000
2000
1000
0
1284
1586
5662
68
Less than 10% Salt
10-50% Salt
50% Salt
Greater than 50% Salt

maintenance area 5A by condition (see Table 4-17, supra, for conditions). The figure reveals the following: 3.8% of the salt used in the winter of 1973-1974 for maintenance area 5A was for sanding operations; 11.7% was for conditions 2 and 3; 83.3% was for conditions 4 and 5; and 1.2% was for conditions that exceeded the salt requirements of conditions 4 and 5 (see Table 4-18).

A report by the Environmental Protection Agency indicates that there exists adequate technology for snow removal involving conditions 3 through 5 without the use of deicing salts. The report reviews the work of Dr. C. J. Posey of the University of Connecticut and his work in developing a snow plow blade that works in conjunction with compressed air.[38,39] The report concludes:[40]

> This device utilizes a conventional plow blade with an attached air pipe that directs a thin sheet of high velocity air onto the pavement at the angle of attack of the blade. This stream of air loosens and lifts the snow so that the plow blade can move it off the road. The advantages of this system are that:
>
> 1) snow in cracks and uneven portions of the pavement can easily be removed, and
>
> 2) the plow does not have to be in contact with the pavement, saving wear on both the road and the blade.
>
> It is thought that with high enough pressure, even dense snow could be lifted from the pavement.
>
> One other mechanical approach which merits further development and testing is a broom and blower system. The broom consists of a rotating drum that contains rows of steel bristles. The broom can be positioned at different angles to change the direction in which the snow is brushed. The blower follows the broom, clearing all the loose snow and ice particles left on the surface. The device works best with heavy snow or slush. Light snow is just blown around and left behind; hard packed snow is not completely removed. The brush and blower might be most effectively used in combination with a snow plow--plow on the front, brush under the truck, and blower at the rear.

The Environmental Protection Agency offers guidelines for

TABLE 4-18

PERCENT OF SALT USE BY CONDITIONS

Number of Loads	Condition Equivalent	Multiplier[1]	Factored Ratio[2]	Percent Salt Use (5A)[3]	Estimated Percent Salt Use by State[4]
1284	1	1	1284	3.8	3.8
1586	2, 3	2.5	3965	11.7	11.7
5662	4, 5	5	28310	83.3	83.3
68	greater 4, 5	6	408	1.2	1.2

1. The Multiplier is the number (of the number of loads) which translates all loads into salt equivalent loads of 10% salt. 1284 loads were loads with 10% salt, hence, a multiplier of 1. 1586 loads were loads with salt between 10% and 50%, hence, a multiplier of 2.5. 5662 loads were 50% salt, hence a multiplier of 5. And, 68 loads were greater than 50%, hence a multiplier of 6. (See figure 4-9 on page 100 and table 4-17 on page 98, Supra)
2. The factored ratio is the number of loads times its multiplier.
3. The percent salt use (5A) is the percentage factored ratio of the sum of the factored ratios.
4. The estimated percent salt use by state is an estimate of the salt use by condition based on the assumption that the percentages for maintenance area 5A are the same for all maintenance areas. (Note: The final figure is halfed to avoid Gross Estimates-See page 103, Infra.)

critical application rates of salt. Generally, they do not recommend the use of salt for dry snow below 15° to 20° F. The EPA guidelines are found in Table 4-19.

In addition, the Salt Institute recommends that if the temperature is 20° F. and falling and the snow is dry, then "Plow as soon as possible. DO NOT APPLY SALT. Continue to plow to check for wet, packed or icy spots; treat them with heavy salt applications."[42] This is the exact opposite of what the state maintenance areas are required to do under conditions 4 and 5. There they are required to use a 50-50 mixture of sand and salt. Dry snow does not usually adhere to the road surface. It may become compacted, but it does not compact so that the adhesive strength exceeds the tensile strength of the road surface.

Therefore, most of the salt used to meet conditions 3 through 5 could be eliminated by greater plowing and the use of alternative technologies. If 50% of this salt could be eliminated it would reduce salt use by 47,700 tons (based on 1976-1977 salt use) with an estimated costs saving of nearly 1/2 million dollars. If counties adopted this system it would reduce salt use by 18,700 tons for a savings of $187,000. If municipalities could save 10% using this system, it would reduce salt use by 8,400 tons with a savings of $84,000.

There are other technologies that have been evaluated for use in snow and ice control. These include the use of liquid calcium chloride, slag as an abrasive, snowfencing, the use of underbody blades, ground-speed control on applicating trucks, and the use of weather forecasting systems. Many of these technologies could reduce waste in salt applications.

5. Slag is available at the A S King plant near Stillwater and the Riverside plant in northeast Minneapolis. The material is available directly from the plant when produced or from stockpiles maintained near both plants. A copy of a gradation analysis is attached.

6. Slag is convenient and easy to use. It does not freeze in stockpiles because of its free draining characteristics and therefore does not have to be treated or protected.

7. It provides improved traction for better safety.

8. It stays in place on ice or snow. Crews placing the material have praised it because the contrast between slag and snow makes it easier to see where it has been placed.

9. Because of the black color of the slag it attracts heat from the sun, speeding the melting process.

10. In the last two years Pozzolan Products, Inc. has marketed over 45,000 tons of slag for ice and snow control.

11. All revenue received by NSP from the sales of this material is credited toward the cost of fuel to produce electricity--another savings for our customers.

If salt use could be reduced by 50% using slag, then the state, counties and municipalities could reduce salt use by 50,200, 19,800, and 42,200 tons, respectively, each year.

Most of the literature reviewed indicates that snowfencing, when properly installed, can be an effective aid in controlling the adverse effects of snow.[45] It does not reduce the use of salt on lane miles where snowfencing exists. The survey sent to state, county and municipal maintenance areas shows that 100% of the state, 62.3% of the counties, and 42.4% of the municipalities salt, sand, or salt-sand in a mixture snowfenced lane miles (see Table 4-20). The use of snowfences will not necessarily reduce salt usage.

Some maintenance areas use underbody blades to help remove

TABLE 4-20

Question 7: "Do you salt, sand or salt/sand lane miles where snow fencing exists?"

Maintenance Area	Population	Sample	Percent Response
STATE	16	14	87.5
COUNTY	86	61	70.9
MUNICIPAL	96	33	34.4

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	14	0	100	0
COUNTY	38	23	62.3	37.7
MUNICIPAL	14	19	42.4	57.6

TABLE 5-1 (cont.)

Deicing Agent	Eutectic Temperature	Concentration at Eutectic %	Cost Per Ton
Sodium & Calcium Formate			
Sodium Sulfate			
Sucrose			
Tetrapotassium Pyrophosphate			
Tripotassium Phosphate - Formamide			
UCAR II			
Urea	11.0	32.6	90
Urea - Calcium Formate(2:1)	-3.0	42.5	
Urea - Calcium Formate - Formamide (1:1:1)	-8.0	42	

TABLE 5-1a

EUTECTIC TEMPERATURE, CONCENTRATION, AND COST OF: SODIUM CHLORIDE & CALCIUM CHLORIDE

Deicing Agent	Eutectic Temp. F.	Concentration at Eutectic %	Cost Per Ton
Sodium Chloride	-6.0	23.3	10
Calcium Chloride	-67.0	29.8	34

Source: Oil, Paint and Drug Reporter, December 9, 1965 all have an influence aside from the air temperature. Therefore, the deicing agent cannot be expected to melt ice at the eutectic temperature. For example, the eutectic temperature of sodium chloride is -6^{o} F., but it performs better at 10^{o} F.

Enough research has been done on some of these compounds to reject them as deicing agents. Table 5-2 summarizes the research showing the negative impacts that the use of these chemicals would entail. However, many of these agents look promising. These agents are listed in Table 5-3. Generally, the limitations on the use of these agents is cost. As may be seen in Table 5-1a, sodium and calcium chloride are relatively inexpensive. It may be possible to limit the use of these alternative agents to bridges or elevated roadways where the impact of chloride deicing agents is more acute.(See Section 2.4 of Chapter Two for more detail on the impact of chlorides on bridges.)

The crucial question to be addressed is whether any of the alternative deicing agents listed in Table 5-3 can be successfully used as a substitute for sodium and calcium chloride in Minnesota. Whether any of these alternatives can successfully be used in Minnesota as a replacement or partial substitute for sodium and calcium chloride is beyond the scope of this study. Therefore, additional studies must be conducted that evaluate the effectiveness, environmental impact and potential of using alternative deicing agents by the Minnesota Department of Transportation and other deicing salt users.

TABLE 5-2

NEGATIVE IMPACTS OF ALTERNATIVE DEICING AGENTS

Alternative Deicing Agent	Negative Impact If Used
Alcohols (Methanol, Ethyl Alcohol, etc.)	These materials pose a fire hazard and, because of relatively quick evaporation, have a short reaction time. (1-2)
Chlorides (Aluminum, Lithium, Potassium, Magnesium, etc.)	These chlorides pose the same negative impacts as sodium and calcium chloride. In addition, aluminum chloride reacts violently with water; lithium chloride is too expensive; and potassium chloride has a higher eutectic temperature than sodium chloride. (3-4)
Ammonium Nitrate	This material is extremely harmful to steel and concrete. (5)
Ammonium Sulfate	This material is extremely harmful to concrete. (6)
Glycols (Ethylene, Propylene)	These materials cause a slippery pavement and cause runoff problems. (7-8)
Ammonium Acetate	This material is highly corrosive to metals. (9)
Sodium Formate	This material damages concrete. (10)
Ammonium Carbonate	This material reacts with copper and copper alloys. (11)
Sodium Sulfate, Acetamide, Glycerine, Sucrose, UCAR II, Calcium and Magnesium Acetate, Liquified Ammonia and Carbon Dioxide, and Potassium Carbonate and Bicarbonate	Insufficient data is available on these substances. Many are still under investigation. (12-14)

Sources: The sources are listed in the footnotes under Chapter Five corresponding to the number(s) by the comments.

TABLE 5-3

POTENTIAL ALTERNATIVE DEICING AGENTS

Formamide (15)

Urea (16-20)

Tetrapotassium Pyrophosphate (21-23)

Formamide - Urea - Water (24)

Tripotassium Phosphate - Formamide (25)

Urea - Calcium Formate (26)

Urea - Calcium Formate - Formamide (27)

Sources: The sources are listed in the footnotes under Chapter Five corresponding to the number(s) following the listed agents.

5.2 Alternative Deicing Technologies

Alternative deicing technologies, which do not include chemical deicing agents, include hydrophobic compounds to prevent ice adhesion, heat to melt ice, and mechanical and other devices to break up the ice.

A hydrophobic compound is a substance that, when applied to a road surface, will provide a low strength of adhesion between ice and the road surface. The advantage of creating such a situation is that a blade or other mechanical device can easily break ice loose from the road, thereby creating a "bare road" environment without the use of deicing salts. In addition, it is theorized that the addition of a hydrophobic compound would produce such a significant reduction in surface adhesion that the stresses created by traffic would be sufficient to break ice loose.[28]

A specific substance which can successfully be used as a hydrophobic compound has yet to be identified.[29-37] There are three major classes of compounds that show promise of working. These include: (1) catatonic surface active agents; (2) organo-fluorochemical compounds; and (3) organo-silicone compounds.[38-40] Two compounds in particular show promise. These are:[41]

- A modified (no pigment) Federal Specification TT-P-115D traffic paint containing a room-temperature-curing silicone rubber (Dow Corning DC732) as a release agent. Formulation is identified as A in the Phase IV road test evaluation.
- A silicone resin waterproofing compound (Dow Corning DRI-SIL-73) combined with the silicone rubber as above and identified as formulation C in Phase IV.

There are a number of positive things to be said about these compounds:[42]

As applied to roadway surfaces in dried films about 0.01 cm (0.004 inch) thick, these two coatings:

- Show greatly reduced ice adhesion until physically worn away.
- Have an applied cost of about 40¢/m^2 and 69¢/m^2 (33¢ and 58¢/yd^2) as of December, 1974.
- Show excellent stability to weathering.
- exhibit total water-soluble material equivalent to a maximum of about 18 grams per lane meter (64 pounds per lane mile) (see Section 9.3 of Chapter 4).
- Have low pollution impact.
- Show negligible corrosiveness and zero road damage.
- Can be applied with standard spray truck techniques.
- Require a maximum lane closure time of one to three hours depending on ambient temperature.
- Do not greatly reduce rubber-to-road friction coefficient.

The deficiencies in these formulations are:[43]

1. An estimated effective wear life of only 150,000 to 300,000 vehicle passes (one to two months on the tested roads) for the thickness employed.
2. The release of flammable vapors, mostly VMP naphtha, into the atmosphere during application.

It is important to realize that on some stretches of road in the Twin Cities 300,000 vehicle passes could occur in less than three days.

In sum, the reduction of ice adhesion by use of a hydrophobic substance poses the greatest opportunity for reducing the use of deicing salts. Unfortunately, the development of such a substance is still far off. Consequently, hydrophobic compounds do not offer an alternative to deicing salts in the immediate future.

After two decades of experimentation, the technology of pavement heating systems has developed to the point that much of the mechanics of installation, maintenance, and automated sensor systems for ice, snow and temperature have been developed. There are three basic technologies that could potentially use heat to melt ice. These include heat created by electrical resistance and circulating heating systems.

Electrical pavement heating systems are resistance units (such as an electric stove or space heater) embedded in the pavement and connected to a power source. The system can be of the high voltage type with insulated cables, or a low voltage type with uninsulated wire or wire mesh, or an electrically conductive pavement constituent, such as graphite, for low voltage use.[44-47] These systems are expensive to install and operate, and may require considerable maintenance because of power failures, faulty units, or pavement disruption.[48] In addition, chemical pollution of the environment with deicing salts would be traded for pollution resulting from power requirements for road heating.

Another heating system for use in pavements utilizes circulating fluids that have low freezing points. These systems have low freezing point liquids or gases circulated by pumping or vapor transfer through piping which is incorporated in the pavement during its construction. The circulated fluid is heated by a furnace or some other energy source.[49] Examples of other sources include the utilization of natural hot springs or stored earth energy.[50-52]

A comparison of electrical heating and circulating heating systems shows that electrical systems using conductive pavement are cheaper to install, but more expensive to operate. Reports indicate that a fifty foot wide, one mile stretch of interstate would cost $8.5 million for electrical heating for installation alone.[53] However, electrical heat was shown to be more efficient than fluid circulating systems.[54] Circulating heating systems using stored earth energy would require no fossil or nuclear fuel power, thereby not creating a demand on the nation's energy supply. In sum, the use of pavement heating systems is economically unfeasible even though it is technologically possible.

There are a number of additional methods that have been used or proposed to be used to disbond ice from pavement. A number of mechanical devices have been proposed to produce continuous or impact stresses. These include scrapers, chisels, rollers, crushers, disks, high-velocity fluid jets, compressed air plow and brush and blower systems and "air blasters" which blow finely crushed abrasive materials.[55,56] Other ideas include electrolysis at the ice-pavement surface, thermal blades, ultrasonic (high frequency vibrational, mechanical waves of air) waves to induce ice fracture and microwaves.[57-61] A number of health effects are associated with microwaves including cataracts, blood disorders, cardiovascular problems, birth defects, mutational effects, altered behavior, and disorders of the central nervous system.[62-72]

In sum, the principal aim of any acceptable alternative should be the efficient disruption of the ice-pavement bond without involving high costs, large energy demands, or damage to the pavement surface. In general, none of the alternatives listed above satisfy these criteria. However, the use of a compressed air plow and brush and roller system for situations involving snow, augmented by sand or slag for traction purposes, would significantly reduce the state maintenance areas' reliance on salt by over 47.5 percent. (See Section 4.3, Chapter Four, for more details.)

5.3 Alternatives That Minimize Wet Weather Accidents

Reducing the human and economic losses due to wet-weather skidding accidents is a high priority goal of most police and highway departments. Speed is a critical factor in many wet weather accidents. Most drivers know that they must reduce their speed when the roadway is wet to maintain control of their vehicles. Unfortunately, the degree of speed reduction necessary for safe operation is not always apparent. Therefore, it is important that police and highway departments alter driving conditions so that the potential for skidding due to wet weather is at a minimum. This section reviews corrective measures for road improvements that minimize skidding and the concept of wet weather speed zoning which reduces the potential for skids and accidents.

In general, skidding accidents result from the active interaction of the vehicle, roadway, driver and environment. Many factors affect skid potential. The tire-pavement interaction can be affected by one or more of the following conditions: (1) the pavement polished by traffic; (2) weather conditions such as water depth, excessive temperature, or snow and ice; and (3) the vehicle with bald tires or low tire pressure.

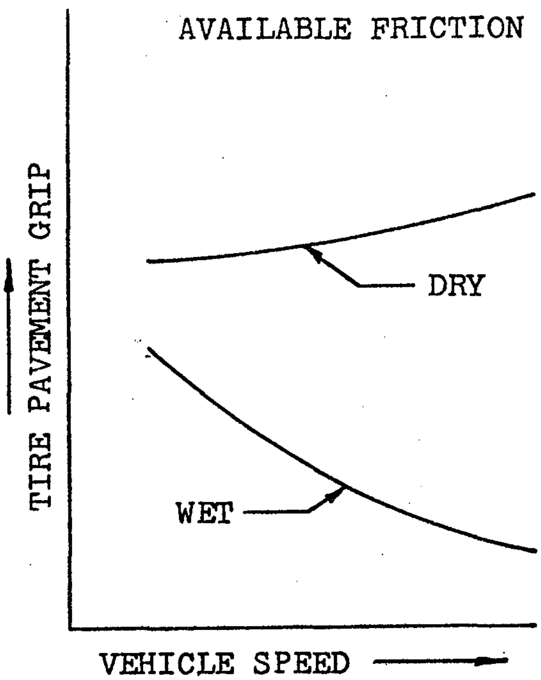
Considerable research has been conducted on these factors, particularly how the road surface affects vehicle skidding.[73-75] NASA has studied the phenomena of hydroplaning and found that it is due to the combination of the above three factors. They found that hydroplaning can be expected to occur when water depth on the road exceeds tire tread depth and when the vehicle's speed exceeds "10 times the square root of the tire pressure (PSI)."[76] Additional studies have examined the influence of water depth, tire condition, skid number (coefficient of friction times 100), pavement texture and speed.[77-79] (See Chapter One, Section 1.1 for explanation of the coefficient of friction.) Generally, they found that as speed increases, tire grip decreases (see Figure 5-1).[80] And, if the demand for friction exceeds the available supply of friction, skidding commences. Figure 5-2 shows this relationship.

There are two ways in which highway departments can improve the road surface which would increase the supply of friction. These include the use of skid resistant surfaces and grooved pavements. Coarse material can be mixed directly with asphalt or sprinkled on top of it during construction to increase skid resistance.[81,82] Generally, the results indicate that the skid numbers obtained after one year of use (about 50) are considered "very good" for the sprinkle treatment. Where abrasives were mixed in the asphalt, skid numbers of 63 were obtained after one year. In general, the use of abrasives in highway construction and repair should be a high priority with highway departments.

Grooved pavements have been shown to reduce accident rates considerably. In California, where grooved pavements have been tested extensively, accidents have decreased:[83]

> There were 1,133 accidents in the before period compared to 904 accidents in the after period. This was a 20% reduction in accidents despite a 17% increase in traffic. The projects were exposed to 365 million vehicle miles of travel in the before period and 429 million vehicle miles in the after period. (The 3/4-inch spaced grooves yielded a 37% reduction in accidents.)

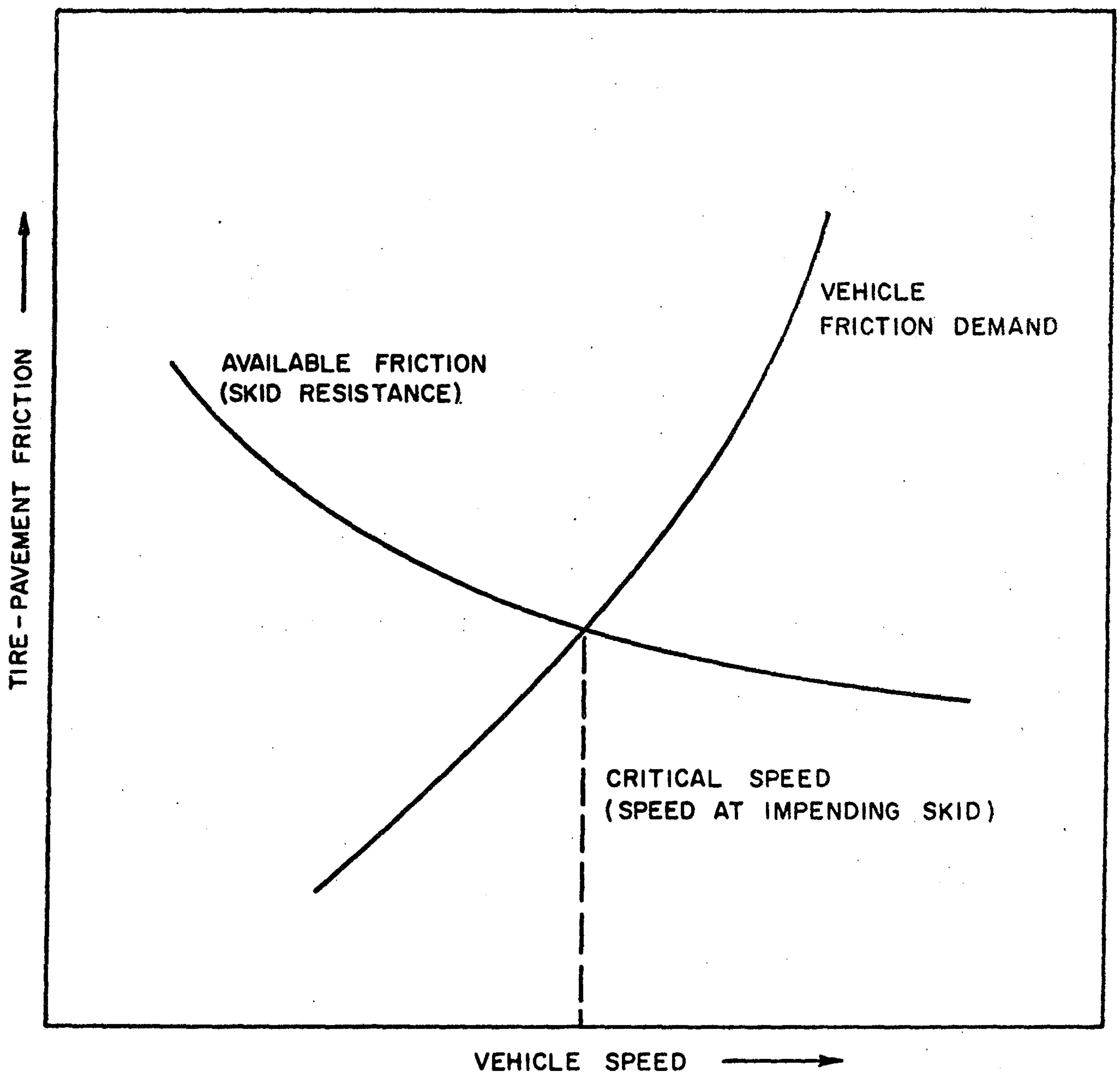
FIGURE 5-1



Source: Karr, J. I., Evaluation of Minor Improvements (Part 8) -- Grooved Pavements, California Division of Highways, December 1972.

FIGURE 5-2

Relationship Between Friction Demand and Pavement Skid Resistance



Source: Glennon, G. C., A Determination Framework for Wet Weather Speed Limits, Res. Rept. 134-8F, Texas Transportation Institute, August 1971.

Wet pavement accidents were most susceptible to correction and they were reduced 70%. Wet pavement accidents decreased from 535 accidents before grooving to 158 after grooving despite wetter after periods.

Dry accidents increased 28%. When allowance was made for the experience of the adjacent sections, the increase was 15%. A follow-up study of some 150 lane miles of grooving placed after February 1968 indicates that grooving does not affect dry accidents one way or the other.

Fatal accidents were cut in half. There were 21 fatal accidents in the before period and 10 in the after period. However, fatal plus injury reductions were about the same as PDO reductions. The severity of accidents after grooving was about 10% less than the statewide average.

Overall, 28 of the 39 projects improved. Fourteen of those improved significantly. Two projects significantly worsened. There were reductions in accidents as far as 0.2 mile downstream of projects.

Another way police departments of the Minnesota Department of Public Safety could reduce the number of accidents is by wet weather zoning. Speed is a very important variable when a vehicle exceeds the available supply of friction resulting in a skid and possible accidents. Wet weather speed zoning is designed to regulate this variable. A description of wet weather speed zoning is as follows:[84]

Wet weather speed limits may be implemented by two means: by introduction of a state-wide wet weather speed limit, or through speed zoning at selected sites. Although introduction of a state-wide wet weather speed limit would probably represent the most expedient attempt to reduce traffic operating speed during inclement weather, it offers one distinct disadvantage: the speed limit on all highways would be dictated by the safe wet weather speed on the lower quality highways. Thus, under blanket speed control, the level of service and vehicle speed would be reduced unnecessarily on many of the newer highways that provide surfaces and geometrics less susceptible to skidding.

The primary advantage of wet weather speed zoning at selected sites is that it offers a method to alleviate the most hazardous locations (those which exhibit a history of skid-related accidents) on a priority basis. Also, although allowable speeds can be predicted with some confidence for several individual situations, additional field experience must be obtained to permit confident estimates of safe wet weather speeds when all contributing factors act together. Use of wet weather speed zoning at selected sites on an "experimental" basis will permit evaluation of the designated safe speed and also the effect upon and acceptance by the driving public as well as an evaluation of the proposed method.

Altering the general state-wide speed limits to fit existing traffic and physical conditions of the highway consitutes the basic principle of speed zoning. In this respect, establishment of wet weather speed limits at selected sites would become a logical extension of the current speed zoning principles.

The process for determination of the safe wet weather speed limit involves equating the available friction at the selected site to friction demand for traffic operational maneuvers expected at that site. Therefore, certain engineering characteristics of the site must be known from which the available friction may be determined. Similarly, certain traffic operating characteristics must be determined. A critical speed is determined for each expected maneuver. The speed limit will be governed by the expected maneuver producing the lowest critical speed.

Texas has already taken steps to implement wet weather speed zoning with the passage of S.B. No. 183, Section 167 a few years ago:[85]

Section 167. (a) Whenever the State Highway Commission shall determine upon the basis of an engineering and traffic investigation that any prima facie maximum speed limit hereinbefore set forth is greater or less than is reasonable or safe under the conditions found to exist at any intersection or other place or upon any part of the highway system, taking into consideration the width and condition of the pavement and other circumstances on such portion of said highway as well as the usual traffic thereon, said State Highway Commission may determine and declare a reasonable and safe prima facie maximum speed limit thereat or thereon, and another reasonable and safe speed when conditions caused by wet or inclement weather require it, by proper order of the Commission entered on its minutes, which limits, when appropriate signs giving notice thereof are erected, shall be effective at such intersection or other place or part of the highway system at all times or during hours of daylight or darkness, or at such other times as may be determined; provided, however, that said State Highway Commission shall not have the authority to modify or alter the rules established in Paragraph (b) of Section 166, nor to establish a speed limit higher than seventy (70) miles per hour; and provided further that the speed limits for vehicles described in Paragraphs a, b, and c of Subdivision 5 of Subsection (a) of Section 166 shall not be increased.

By wet or inclement weather is meant conditions of the pavement or roadway caused by precipitation, water, ice or snow which make driving thereon unsafe and hazardous.

CHAPTER SIX

RECOMMENDATIONS

As may be seen from the previous five chapters, the use of deicing agents such as sodium and calcium chloride have severe effects on autos, roadways and the environment. The negative effects are severe enough that many scientists and policy makers strongly question the cost-effectiveness and usefulness of deicing agents. In addition, many agencies and political sub-divisions are extremely lax in their concern and control over salt use. In general most alternatives to deicing agents under investigation are either not practical or are in the developmental phases. The two exceptions are the use of underbody blades and brush and blower systems for snow removal. The following recommendations are offered to reduce reliance on deicing agents for snow and ice control and to mitigate the negative effects of salt use.

These recommendations are offered to comply with, and are in response to, House Advisory No. 4. This advisory requested recommendations on: (1) alternative deicing materials; (2) methods to protect vehicles and roadways; (3) methods to protect the environment; and (4) recommendations for further research.

The recommendations are divided into four categories. These are: (1) salt application guidelines; (2) salt management and control practices; (3) environment; and (4) accident prevention. These recommendations are offered in their order of importance and usefulness in reducing salt use and mitigating the negative effects of its continued use.

6.1 Salt Application Guidelines

There are eight salt application recommendations that would substantially reduce salt use. This reduction in salt use would go a long way toward eliminating or reducing the negative impacts of deicing agents. These recommendations involve: (1) establishing salt application guidelines; (2) establishing levels of service for snow and ice removal that reduce the necessity for a "bare road" policy; (3) mandating the use of alternative technologies; (4) requiring the use of liquid calcium chloride as a deicing agent; (5) requiring the use of slag as a traction agent; (6) establishing a weather forecasting service; (7) requiring that maintenance crews plow early in the storm; and (8) providing funding for the establishment of a salt use benchmark. The rationale and the specific recommendations are discussed below.

1. In the winter of 1976-1977 the Minnesota Department of Transportation used 100,430 tons of deicing salts on Minnesota roads. Of this salt use, 83.3% was for weather conditions where the temperature was 10^{o} F. and falling and the type of precipitation was dry snow. In addition, a substantial portion of another 11.7% involves conditions where the temperature is 25^{o} F. and falling and where the type of precipitation is dry snow. Both the Environmental Protection Agency (EPA) and the Salt Institute recommend that NO salt be applied under these conditions. Even if only half of this total 95% salt use could be eliminated, then salt use would be reduced by 47,700 tons (47.5%). County use could be reduced 18,700 tons and municipal use could be reduced 8,400 tons (at a 10% reduction). In addition, adequate snow removal technology exists for snow removal under

these conditions without the use of deicing agents.

RECOMMENDATION: ADOPT SALT APPLICATION GUIDELINES THAT EMPHASIZE NON-SALT TECHNOLOGIES FOR SNOW REMOVAL, AND PROHIBIT THE USE OF SODIUM CHLORIDE WHEN TEMPERATURES FALL BELOW 15°F.

2. The Minnesota Department of Transportation includes in their guidelines a service level policy which requires "bare roads" whenever there are more than 2,000 vehicles per day on a roadway. Hennepin County has a service level policy, but only for roadways which have 7,500 or more vehicles per day. If the state adopted Hennepin County's service level, then salt use could be reduced by an estimated 30% or 30,100 tons.

RECOMMENDATION: ESTABLISH LEVELS OF SERVICE FOR SNOW AND ICE REMOVAL THAT ALLOW "BARE ROAD" POLICIES ONLY WHEN THE TRAFFIC VOLUME IS 7,500 OR MORE VEHICLES PER DAY, OR WHERE THE TERRAIN REQUIRES A "BARE ROAD" IN ORDER TO NEGOTIATE THE GRADES.
The Minnesota Department of Transportation should undertake research to see if it is possible to establish "bare road" policies at traffic levels higher than 7,500 vehicles per day.

3. Studies on the use of alternative technologies to the use of "chloride" deicing agents have identified three physical, mechanical alternatives for the removal of snow. These include the use of underbody blades for the removal of pack snow and brush and blower systems to augment the plow for removal of loose snow regardless of its moisture content. A deicing agent will still be needed for the removal of ice.

RECOMMENDATION: MANDATE THE USE OF ALTERNATIVE TECHNOLOGIES SUCH AS UNDERBODY BLADES AND BRUSH AND BLOWER SYSTEMS FOR SNOW REMOVAL. MINNDOT SHOULD DO RESEARCH AND EXPERIMENTATION ON THE FEASIBILITY OF "UNPROVEN" TECHNOLOGY.

4. Since a deicing agent must go into solution (liquid form) before it becomes effective, the use of a liquid deicing agent would substantially shorten the time for ice removal. The State of Iowa has successfully used a liquid calcium chloride mixture with a 40% reduction in salt use and a reduction in accidents. If Minnesota achieved the same reduction in salt use, then 89,600 tons of salt would not be needed.

RECOMMENDATION: REQUIRE THE USE OF LIQUID CALCIUM CHLORIDE TO AUGMENT SODIUM CHLORIDE FOR SALT APPLICATIONS WHERE THE TEMPERATURE IS 15°F AND FALLING TO A LIMIT OF 5°F.

5. Northern States Power Co. markets slag from its coal-fired generating facilities as a traction agent. Presently, most maintenance areas use sand as a traction agent. Sand has three drawbacks. First, its low density allows it to be easily blown off the road. Second, its light color stops the penetration of solar radiation needed for the melting of snow and ice. Finally, it does not melt snow or ice. The slag is a course material, black in color and, as such, may help to melt snow or ice. NSP states that the use of slag may reduce salt use 50%. If so, then the reduction of salt use by 112,200 tons per year would be a significant savings, as well as the utilization of a resource which is presently going to waste.

RECOMMENDATION: REQUIRE THE USE OF CRUSHED SLAG FOR SAND WHENEVER POSSIBLE TO AUGMENT OTHER SNOW AND ICE REMOVAL PRACTICES.

6. An important parameter in the planning process for snow and ice removal is that of weather forecasting. While the National Weather Service can provide some information on a broad general basis, it lacks the specificity necessary for planning

on a local basis. In addition, they do not provide data on key parameters such as snow moisture content. The Environmental Protection Agency and the Federal Highway Administration recommend the establishment of a separate weather forecasting service for snow and ice removal. This can be accomplished by contracting the services of local and regional weather services who have the capability for weather analysis for all key parameters including: wind direction, speed and change; temperature and direction of change; amount of snowfall, moisture content, and duration of storm; amount of sunshine; and direction and location of the storm front.

RECOMMENDATION: ESTABLISH A WEATHER FORECASTING SERVICE THAT WILL GIVE UP-TO-DATE AND COMPLETE INFORMATION ON WEATHER CONDITIONS NECESSARY FOR SNOW AND ICE REMOVAL.

7. The survey sent to all state, county and municipal maintenance areas revealed that most maintenance areas preferred to start their snow and ice removal practices after the storm. The longer one waits to engage in snow removal operations, the greater the quantity of "pack" snow and ice that needs to be removed. Therefore, it is important to start removal operations early in the storm to minimize the formation of "pack" snow and ice.

RECOMMENDATION: REQUIRE MAINTENANCE CREWS TO START SNOW REMOVAL OPERATIONS EARLY IN THE STORM.

8. Implementing all the recommendations in this report would reduce salt use by about 86%. This can be considered a conservative estimate. The remaining 14% would be used primarily for ice

control. Research is being undertaken to find alternative deicing agents and alternative deicing technologies. However, the research effort is not receiving as much attention and money as it deserves. Therefore, additional research should be undertaken in Minnesota to discover and successfully implement alternatives to chloride deicing agents.

RECOMMENDATION: PROVIDE FUNDING TO THE MINNESOTA DEPARTMENT OF TRANSPORTATION AND/OR THE UNIVERSITY OF MINNESOTA TO DO RESEARCH ON ALTERNATIVE DEICING AGENTS AND TECHNOLOGIES.

6.2 Salt Management and Control Practices

There are six management and control practice recommendations that would reduce salt waste. Many of these recommendations would substantially contribute to salt reduction. These recommendations involve: (1) calibration of machinery; (2) the use of ground-oriented spreaders; (3) salt storage procedures; (4) training and education of personnel; (5) recordkeeping; and (6) the development of a salt use benchmark. The rationale and specific recommendations are discussed below.

1. Calibration refers to the techniques that insure that the proper application and spreading efficiency of machinery is used in salt application. Proper calibration eliminates waste and reduces costs. Highway departments which calibrate their equipment achieve a 30% to 40% reduction in salt use. The survey sent to state, county and municipal maintenance areas revealed that, while all state maintenance areas calibrate their equipment, only 6.1% of the counties and 10.8% of the municipalities do so.

If all counties and municipalities achieved a 20% reduction by calibrating their equipment, salt use could be reduced 7,900 and 16,900 tons, respectively.

RECOMMENDATION: REQUIRE THAT ALL SALT APPLICATION MACHINERY BE PERIODICALLY CALIBRATED.

2. Another technique for reducing waste in salt application is the use of ground-oriented, speed controlled application machinery. This type of machinery relieves the driver of the burden of manual control for salt application. This frees the driver to focus his attention on driving, plowing and other responsibilities. This type of machinery prevents waste by insuring a uniform and controlled flow of salt regardless of speed. This technique may reduce waste by as much as 5%.

RECOMMENDATION: MANDATE THE USE OF GROUND-ORIENTED, SPEED CONTROLLED SPREADERS.

3. For the last six years an average of over 250,000 tons of salt were applied to Minnesota roads. In many instances this material requires storage either as straight salt or in a salt-sand mixture. An exposed salt pile can lose 5% of its volume to moisture or wind. In addition, salt storage piles pose a severe environmental risk. 43.9% of the counties and 51.9% of the municipalities store some or all of their salt or salt-sand mixtures in the open. Assuming a 2% loss for the counties and a 3% loss for the municipalities, 3,300 tons of salt are wasted each year. The EPA and the Salt Institute both recommend salt storage procedures that mandate the use of enclosed structures

for straight salt and a bituminous pad for salt-sand mixtures and the use of enclosed structures for salt-sand mixtures for storage over the summer.

RECOMMENDATION: MANDATE THE USE OF ENCLOSED STRUCTURES FOR SALT STORAGE, BITUMINOUS PADS FOR SALT-SAND MIXTURES WITH BRINE-CATCHING FACILITIES, AND THAT NO SALT-SAND MIXTURES BE STORED OUTSIDE OVER THE SUMMER.

4. Training and education is another fundamental area that can help maintain open roads in an efficient and effective manner. The vast majority of the counties and municipalities do not have a training course. While it is difficult to quantify the reduction in salt use that can be attributed to well-trained drivers and supervisors, it is considered to be significant.

RECOMMENDATION: REQUIRE DRIVER AND SUPERVISOR TRAINING AND EDUCATION ON SALT USE AND ITS EFFECTS.

5. In order for a maintenance area to effectively evaluate in an on-going and consistent fashion, certain records must be kept. These include when, where, how much and under what conditions salt is applied. Generally, it is agreed that recordkeeping practices are important to get some feedback and review of snow and ice removal operations.

RECOMMENDATION: REQUIRE RECORDKEEPING PRACTICES TO BE UNIFORMLY IMPLEMENTED FOR ALL SALT APPLICATIONS AND THAT WEATHER DATA ALSO BE INCLUDED.

6. One question that is often asked by those evaluating snow

and ice removal operations concerns the ability to compare salt use from storm to storm and year to year. A benchmark of salt use per lane mile is often used, but this type of benchmark is misleading and the conclusions drawn from it are usually erroneous. The problem is that the benchmark fails to consider most of the parameters that affect salt application such as temperature, snowfall, frequency of storms, moisture content of snow, wind speed and direction, amount of solar radiation and many more. Since questions concerning salt use from storm to storm and year to year are very important, a quality benchmark needs to be developed.

RECOMMENDATION: PROVIDE FUNDING TO MinnDOT AND THE UNIVERSITY TO DEVELOP A BENCHMARK TO ANALYZE SALT APPLICATIONS TO COMPARE SALT USE FROM STORM TO STORM AND YEAR TO YEAR AND TO PROVIDE FEEDBACK TO SUPERVISORS AND DRIVERS ON THEIR SALT APPLICATION PROCEDURES.

6.3 Environment

Research indicates that there are many negative environmental effects associated with the use of deicing salts. These effects center primarily on vegetation and soils and aquatic biota. Other environmental effects include corrosion of autos and deterioration of roads and bridges. There are a number of measures that can be undertaken by state environmental agencies and MinnDOT that would mitigate the impact of salt use and develop methods for protecting the environment. These measures include monitoring, studies, information dissemination, mandating corrective measures and undertaking cost-benefit analyses.

1. One of the most important environmental issues involving snow and ice removal operations is the impact of deicing salts on

water quality. Deicing salts pose many threats. In addition to the sodium, calcium and chloride one expects in the salts, there are cyanide compounds used as anti-caking agents and chromates as an anti-corrosion inhibitor. While all these substances can affect the general water quality, cyanide and chromate compounds pose a severe threat to aquatic biota and human health. The greatest threats come from inadequate storage procedures and the proximity of salted roads to surface and ground waters.

<u>RECOMMENDATION</u>: THE MINNESOTA POLLUTION CONTROL AGENCY (MPCA) IN COOPERATION WITH MinnDOT AND COUNTY AND LOCAL GOVERNMENTS SHOULD MONITOR THE WATER QUALITY NEAR ALL SALT STORAGE SITES AND WATER BODIES NEAR HIGHWAYS INCLUDING GROUND WATER TO DETERMINE IF SODIUM, CALCIUM, CHLORIDES, CHROMATES OR CYANIDES HAVE AFFECTED THE WATER QUALITY IN THIS STATE.

2. Concern has been expressed in Massachusetts and elsewhere about the direct impact of sodium levels on human health and their contribution to heart disease. While the above recommendation would determine the sodium levels within the water, some interpretation would be necessary to determine if the sodium levels pose a threat to human health.

<u>RECOMMENDATION</u>: THE MINNESOTA DEPARTMENT OF HEALTH IN COOPERATION WITH THE MPCA SHOULD UNDERTAKE A STUDY TO DETERMINE IF SODIUM LEVELS IN DRINKING WATER POSE A HAZARD TO HUMAN HEALTH, PARTICULARLY BY THOSE INDIVIDUALS WHO MUST RESTRICT THEIR SODIUM INTAKE.

3. The use of deicing salts in Minnesota is a major cause

of twig dieback in many deciduous trees. Studies undertaken by the University of Minnesota and elsewhere have shown that many trees are sensitive to salts. Salt runoff and salt spray due to wheel splash reduces vegetation growth, worsens appearance and lowers the economic value of trees. Because many roads go through parks and preserves, and because of extensive salt use along boulevards, special efforts are needed to protect these sensitive areas.

RECOMMENDATION: THE MINNESOTA DEPARTMENT OF NATURAL RESOURCES IN COOPERATION WITH MinnDOT AND COUNTY AND LOCAL GOVERNMENTS SHOULD STUDY THE IMPACT OF DEICING SALT USE ON SENSITIVE AREAS TO FIND WAYS TO PREVENT OR REDUCE ITS EFFECTS.

4. Since the Minnesota Department of Transportation is the largest user of deicing salts in Minnesota, it should take the primary responsibility to understand and reduce the environmental impacts of using deicing salts. This understanding can best be achieved by undertaking a detailed environmental analysis as provided under the Minnesota Environmental Policy Act.

RECOMMENDATION: THE MINNESOTA DEPARTMENT OF TRANSPORTATION SHOULD UNDERTAKE AN ENVIRONMENTAL IMPACT STATEMENT ON THE ENVIRONMENTAL EFFECTS OF DEICING SALT USE AND ITS ALTERNATIVES.

5. In order to protect the roadside environment from deicing salts, salt resistant plant species should be planted.

RECOMMENDATION: MANDATE THAT AGENCIES IN CHARGE OF HIGHWAY MAINTENANCE BE INFORMED AND REQUIRED TO PLANT SALT RESISTANT PLANT SPECIES ALONG ROADSIDES.

6. It is fairly well known that deicing salts and atmospheric pollutants are the principal agents in the corrosive process of the automobile. Corrosion costs automobile owners between $207 million and $7.4 billion each year. The principal methods of preventing corrosion can be undertaken by the auto companies through design and construction changes. Since the total elimination of deicing salts, atmospheric pollutants and nature itself is not practical, one must rely primarily on the auto companies to obtain a longlasting (non-corroding) vehicle. The following recommendation is offered as an incentive to encourage the development of a corrosion-proof (for at least 10 years) car.

<u>RECOMMENDATION</u>: REQUIRE THE AUTO COMPANIES TO DEVELOP AND SELL A CORROSION-PROOF AUTO BY 1985 IN ORDER TO SELL THEIR VEHICLES IN MINNESOTA.

7. Studies undertaken by the Minnesota Department of Transportation and elsewhere show that the primary cause of bridgedeck deterioration is due to deicing salts. While there are many proposed alternatives to the use of deicing salts on bridges, the feasibility of using one or more alternatives is not clear.

<u>RECOMMENDATION</u>: THE MINNESOTA DEPARTMENT OF TRANSPORTATION SHOULD UNDERTAKE A STUDY TO DETERMINE IF IT IS FEASIBLE TO HEAT BRIDGES ELECTRICALLY OR BY SOME OTHER METHOD OR TECHNOLOGY AS A SUBSTITUTE FOR DEICING SALTS.

8. Since hundreds of millions of dollars are spent on the building and maintaining of roadways, special efforts should be undertaken by highway departments to insure that the road lasts

its projected life. The best method of insuring this is by building test tracks to determine which technologies minimize scaling, cracking, spalling, delamination and other effects.

RECOMMENDATION: MinnDOT SHOULD UNDERTAKE A COST-BENEFIT ANALYSIS TO DETERMINE IF BUILDING TEST TRACKS WOULD IMPROVE ROAD CONSTRUCTION AND REDUCE ACCIDENTS.

6.4 Accident Prevention

Reducing the human and economic losses due to wet weather skidding accidents is a high priority goal of most police and highway departments. There are four techniques, which, if implemented, would help to reduce accidents due to wet weather. These techniques include wet weather speed zoning; reporting requirements; grooved pavements; and skid resistant surfaces.

1. Most drivers know that they must reduce their speed when the roadway is wet to maintain control of their cars. Unfortunately, the degree of speed reduction necessary for safe operation is not always apparent. Therefore, it is important that police and highway departments alter driving conditions so that the potential for skidding due to wet weather is reduced to a minimum. One method to accomplish this is to set wet weather speed limits. Wet weather speed zoning offers a method to alleviate the potential for accidents at hazardous locations on a priority basis. Generally, wet weather speed zoning is a logical extension of current speed zoning principles.

RECOMMENDATION: PROVIDE AUTHORITY TO THE MINNESOTA DEPARTMENT OF PUBLIC SAFETY TO DEVELOP A WET WEATHER SPEED ZONING PLAN WHICH WOULD REQUIRE REDUCED SPEEDS DURING RAIN OR SNOW ON KNOWN ACCIDENT

PRONE SEGMENTS OF ROADWAYS.

2. Many studies have attempted to examine snow and ice related traffic accidents. However, a crucial link that biases the results of these studies is inadequate or poor reporting of the road conditions and their contribution to the accident. A detailed reporting system by police, sheriff, and the Highway Patrol groups would accomplish two things. First, it would help to determine those segments of the roads where accident rates are high due to wet weather. This would help to implement the previous recommendation. Second, it would help to determine if salt use increases or decreases road safety.

<u>RECOMMENDATION</u>: THE MINNESOTA DEPARTMENT OF PUBLIC SAFETY SHOULD DEVELOP A SYSTEM OF ACCIDENT REPORTING THAT PROVIDES FOR ANALYSIS OF THE ROAD CONDITIONS BY THE INVESTIGATING OFFICER.

In addition, this reporting procedure should be mandatory and uniformly implemented for all police departments. Further, an annual report summarizing the contributions that wet weather and road conditions had on accidents should be prepared.

3. Research has indicated that grooved pavements reduce accidents considerably. Wet pavement accidents are most susceptible to correction by this method.

<u>RECOMMENDATION</u>: REQUIRE GROOVED PAVEMENTS ON ROAD SEGMENTS WHERE LARGE NUMBERS OF ACCIDENTS OCCUR DUE TO WET WEATHER.

4. The use of skid resistant materials in highway construction and repair reduce wet weather accidents.

RECOMMENDATION: REQUIRE THAT SKID RESISTANT SURFACES BE GIVEN HIGH PRIORITY IN HIGHWAY DESIGN, CONSTRUCTION AND REPAIR.

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CHAPTER ONE

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APPENDIX

ROAD SALT SURVEY ANALYSIS

One readily discernable obstacle to evaluating the snow and ice removal management practices of the state maintenance areas and county and municipal highway departments was the lack of information. Since House Advisory No. 4 was concerned with the environmental impact, among other concerns, of deicing salt use, it is important to ascertain how much, under what circumstances and in what fashion deicing salts were being used. Because of the limited time available for doing this study, the Science and Technology Project with the cooperation of the House Committee on Transportation undertook a survey of snow and ice removal practices. It was felt that a survey could provide the greatest amount of data on snow and ice removal practices in the shortest period of time.

A survey was drafted and sent to Mr. Curt Christi of the Office of Maintenance, Minnesota Department of Transportation and Mr. Charles Swanson of the Washington County Highway Department for their review. Based on their comments the survey was revised (see Attachment #1). The same survey with a different heading was sent to all 16 state maintenance areas, the county engineers for all 87 counties, and 101 municipalities with populations of 5,000 or more. The Office of Maintenance of MinnDOT and the State Aid Division of MinnDOT provided the addresses for the engineers in these jurisdictions.

The survey was mailed by the House Committee on Transportation with a cover letter by the committee chairman, Representative Stanley Fudro, and included a copy of House Advisory No. 4 (see

Attachments #2 and #3). A reminder was mailed out on November 28, 1977 to all recipients of the survey who had not returned them. On November 29, 1977, a letter was sent to the state maintenance areas reminding them of the survey and apologizing for a mix-up in the cover letters.

As the surveys were returned, it became clear that the knowledge and implementation of snow and ice removal procedures varied considerably from state maintenance areas to counties and municipalities and within these groups as well. Data had been obtained from the National Weather Service from November through April for the years 1969-1970 through 1976-1977 on weather conditions throughout the state. The data provided by the Weather Service would indicate the temperature variation per hour, amount of snowfall and over what period of time, wind direction and speed, and percent of sunshine for each day. This data would be supplemented by questions 24 through 35 of the survey (see Attachment #1). It was hoped that the data derived and compared with average daily traffic count (ADT) for the number of lane miles within the jurisdiction (question #3) and the number of lane miles that salt is applied upon (question #6) compared with the known amount of salt used per year (question #8) would provide answers to two questions. First: how much salt should be applied for the weather conditions in that area? Second: how much more or less salt is being used by jurisdictions compared with a benchmark level derived above? Since accurate weather information only existed for five locations within the state, the analysis would be limited to these locations.

A number of problems arose in attempting to accomplish this. First, it would take a multivariate regression statistical procedure with the assistance of a computer and a large support staff with adequate time to arrive at the answers. The time and money was not available to accomplish this, thereby rendering these questions beyond the capability of this study. However, there is a second and more crucial reason why the answers cannot be determined. The respondents to the survey do not keep adequate records in order to sufficiently answer the questions necessary to create a benchmark and compare management practices.

To summarize: a number of other problems existed as well, and it was finally determined to limit the analysis of the survey to questions: 7, 8, 10, 12, 13, 14, 15, 17, 19, 20, 22, 23, and a group analysis of 6, 7, 15, and 20. An analysis of the responses to these questions follows.

Questions 1, 2, 4, 5, 6, 9, 11, 16, 18, 21, and 24 through 35 will not be analyzed because of a lack of response to the question and because no conclusions could be drawn from the question without more data. In addition, this analysis will not cover any conclusions that the data would permit to be drawn. Rather these conclusions have been discussed in Chapter Four of this report.

It is important to define some terms in order to adequately understand the calculations made in the analysis of the survey. The following terms require definition.

"ORIGINAL POPULATION" means the number of surveys mailed to state, county and municipal maintenance areas. The mailing consisted of 16 state, 87 county and 101 municipal maintenance areas.

"ADJUSTED POPULATION" means the number of survey recipients for whom the survey was relevant. For example, three municipalities contract their snow and ice removal operations out to their respective counties. Consequently, the survey is not relevant to them. For the sake of simplicity it is assumed that the survey itself was relevant for all maintenance areas that did not return the survey. The ADJUSTED POPULATION will equal the ORIGINAL POPULATION unless a survey response indicates that the survey in its entirety was not relevant.

"SURVEY RESPONSE" means the number of surveys that were returned for whom the survey was applicable.

"SURVEY QUESTION POPULATION" means those respondents who completed the survey and for whom the question was relevant. For example, on question 7 two municipalities do not have snowfences, thereby rendering the question irrelevant to them. For the sake of simplicity, it is assumed that all questions were relevant for those maintenance areas that did not return the survey. The SURVEY QUESTION POPULATION is found by subtracting the number of maintenance areas for whom the question is not relevant from the ADJUSTED POPULATION. The SURVEY RESPONSE number will drop by the same amount. The SURVEY QUESTION POPULATION will equal the ADJUSTED POPULATION unless a survey response indicates a question is not relevant.

"SURVEY QUESTION SAMPLE" means those respondents who did answer the question. The SURVEY QUESTION SAMPLE is found by subtracting the non-responses to a question from the SURVEY RESPONSE.

"PERCENT SURVEY RESPONSE" means the percent of those responding to the question of the SURVEY QUESTION POPULATION.

In each of the following tables two sections are provided. The first provides the population and sample data for the question. The second part gives the responses to the survey question.

TABLE A-1

Question 7: "Do you salt, sand or salt/sand lane miles where snow fencing exists?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Respond'g	Survey Question Sample (SQS)	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	9	61	70.9
MUNICIPAL	101	98	96	57	24	33	34.4

Maintenance Area	Number Responding YES	Number Responding NO	Percent of SQS Responding YES	Percent of SQS Responding NO
STATE	14	0	100	0
COUNTY	38	23	62.3	37.7
MUNICIPAL	14	19	42.4	57.6

(a) The original question asked was: "Do you salt, sand or salt and sand these lane miles?" The question above has been rewritten to clarify the question for the reader of this report. The two other questions included within question seven will not be analyzed.

(b) Three municipalities contract their snow and ice removal operations out to their respective counties, hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt or sand, hence, a survey question population for counties of 86. Two municipalities (Fridley and Robbinsdale) do not have any snow fences, hence, a survey question population for municipalities of 96.

TABLE A-2

Question 8: "How many tons of salt did you use each winter from 1972 to 1977?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop. (b)	Survey Question Pop. (c)	Survey Response	Number Not Respond'g	Survey Question Sample (SQS)	Percent Survey Response
STATE	16	16	16	14	2	14	87.5
COUNTY	87	87	86	70	3	67	77.9
MUNICIPAL	101	98	98	59	9	50	51

ESTIMATED TOTAL SALT USED

Maintenance Area	1972	1973	1974	1975	1976	1977
STATE	122,850	110,540	119,530	155,980	141,210	100,430
COUNTY	47,350	42,600	39,490	47,240	55,280	39,630
MUNICIPAL	80,550	75,050	83,720	81,890	88,310	84,360
TOTAL	250,750	228,190	242,740	285,110	284,800	224,420

(a) Question 8 also asked for the number of tons of sand and "other" as well as the price of salt, sand and "other" for years 1970 to 1977. Because the price varied on the basis of the delivery distance and the mode of transportation, it is not possible to determine the average cost per ton with any accuracy. "Other" was not included since only 21 of a sample of 142 used "other". Sand was not included because it offered no severe environmental impact and, therefore, the data was not considered useful for policy decisions involving harmful agents.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties, hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt, hence, the adjusted survey question population of 86.

TABLE A-2a

Calculations for Question 8

SALT USE: STATE MAINTENANCE AREAS

	1972	1973	1974	1975	1976	1977
ST KNOWN (a)	106,258	93,931	103,473	142,506	130,317	90,343
NUMBER (b)	13	13	13	14	14	14
+ AVERAGE (c)	6,564	6,564	6,564	0	0	0
SUBTOTAL A (d)	112,822	100,495	110,037	142,506	130,317	90,343
AVERAGE NA (e)	--	--	--	--	--	--
SUBTOTAL B (f)	10,030	9,967	9,492	13,470	10,892	10,088
ESTIMATED TOTAL (g)	122,852	110,542	119,529	155,976	141,209	100,431

(a) The SUBTOTAL KNOWN (ST KNOWN) is the sum of the amount of salt used per year by the maintenance areas who responded to the question.

(b) NUMBER indicates the number of respondents who indicated their tonnage used for each year. Since not all respondents provided complete information for all years, the NUMBER indicates those respondents who provided information for that year.

(c) + AVERAGE is the estimated amount of tonnage of those respondents who provided information for some years and not others. It is found by taking the arithmetic average of the years that information was provided and, summing the arithmetic average of each respondent for each year of data requested.

Example: State maintenance area 6A.

The data was provided as follows:

1972	1973	1974	1975	1976	1977
-	-	-	7,179	6,139	6,374

The arithmetic average for these three years (1975-1977) = 6,564
The number 6,564 is substituted for the years 1972 to 1974.
The sum of respondents so situated equals the + AVERAGE

TABLE A-2a (continued)

(d) SUBTOTAL A is the sum of the ST KNOWN and the + AVERAGE

(e) AVERAGE NA is the arithmetic average of SUBTOTAL A. This number is the amount of salt assumed to be used by each maintenance area who did not return the survey or answer the question. For state maintenance areas only: 7A = 6A and 4A = 3A.

(f) SUBTOTAL B is the sum of those maintenance areas that did not return the survey or answer the question.

(g) ESTIMATED TOTAL is the sum of SUBTOTAL A and SUBTOTAL B.

SALT USE: COUNTY MAINTENANCE AREAS

	1972	1973	1974	1975	1976	1977
ST KNOWN (a)	31,168.9	30,145.8	29,429.3	36,425.1	43,066.2	30,571.8
NUMBER (b)	52	59	63	65	67	66
+ AVERAGE (c)	5,716.4	3,040.5	1,339	379	0	300
SUBTOTAL A (d)	36,885.3	33,186.3	30,768.3	36,804.1	43,066.2	30,871.8
AVERAGE NA (e)	550.5	495.3	459.2	549.3	642.8	460.8
SUBTOTAL B (f)	10,460	9,411	8,725.3	10,437	12,212.8	8,755.2
ESTIMATED TOTAL (g)	47,345.3	42,597.3	39,493.6	47,241.1	55,279	39,627

(a), (b), (c), (d), (e), (f), and (g): See above.

TABLE A-2a (continued)

SALT USE: MUNICIPAL MAINTENANCE AREAS

	1972	1973	1974	1975	1976	1977
ST KNOWN (a)	37,433.2	35,086.1	40,143	40,858.6	44,032	41,818.5
NUMBER (b)	39	42	45	48	49	49
+ AVERAGE (c)	3,663.5	3,205.6	2,572.1	920	120	361.7
SUBTOTAL A (d)	41,096.7	38,291.7	42,715.1	41,778.6	44,152	42,180.2
AVERAGE NA (e)	821.9	765.8	854.3	835.6	901.1	860.8
SUBTOTAL B (f)	39,451.2	36,758.4	41,006.4	40,108.8	44,153.9	42,179.2
ESTIMATED TOTAL (g)	80,547.9	75,050.1	83,721.5	81,887.4	88,305.9	84,359.4

(a), (b), (c), (d), (e), (f), and (g): See above.

TABLE A-3

Question 10: "How do you store your salt (in the: open, under tarp, building, or other)?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	4	66	77.6
MUNICIPAL	101	98	97	58	6	52	53.6

Maintenance Area	Number Open	Number Under Tarp	Number Bldg.	Number Other	Pct. Open of Sample	Pct. Under Tarp of Sample	Pct. Bldg. of Sample	Pct. Other of Sample
STATE	1	6	14	0	7.1	42.9	100	0
COUNTY	29	10	40	0	43.9	15.1	60.6	0
MUNICIPAL	27	6	20	6	51.9	11.5	38.5	11.5

(a) The question origionally asked for the tonnage stored. However, many respondents simply checked which type or types of sites were applicable. Therefore, the analysis indicates the number and percent of maintenance areas that store salt or a salt/sand mixture in one or more of those kinds of sites. The question asked the respondent to specify "other", but most did not.

(b) Three municipalities contract their snow and ice removal operations out to their respective counties, hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt, hence, a survey question population for counties of 86. One municipality (Ramsey) purchases its salt as needed, thereby not needing any storage facility, hence, a survey question population of 97.

TABLE A-4

Question 12: "Do you calibrate the spreaders on your application vehicles?" (a, b)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	4	66	76.7
MUNICIPAL	101	98	98	59	22	37	37.8

Maintenance Area	Number Responding YES	Number Responding NO	Percent Of Sample Responding YES	Percent Of Sample Responding NO
STATE	14	0	100	0
COUNTY	4	62	6.1	93.9
MUNICIPAL	4	33	10.8	89.2

(a) Calibration is a term that refers to a process through which an engineer can determine the rate of application of a snow and ice removal material at a given setting and speed.

(b) The original question asked was: "How do you calibrate your spreaders (tons released per mile)?" Since many jurisdictions did not calibrate their spreaders or know what calibration meant, the data was interpreted with the following question in mind: Do you calibrate the spreaders on your application vehicles?"

(c) One county (Lake of the Woods) does not use salt or sand; therefore, they do not need spreading equipment. Hence, a survey question population of 86. Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

TABLE A-5

Question 13: "Do you use underbody blades on your trucks?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	87	71	0	71	81.6
MUNICIPAL	101	98	98	59	5	54	55.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent Of Sample Responding YES	Percent Of Sample Responding NO
STATE	4	10	28.6	71.4
COUNTY	3	68	4.2	95.8
MUNICIPAL	7	47	13	87

(a) Question 13 included a corollary question of: "If yes, on how many trucks?" This question was omitted, because so few maintenance areas use underbody blades.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

TABLE A-6

Question 14: "Do you have a training course on snow removal for your drivers?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop. (b)	Survey Question Pop. (c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	87	71	3	68	78.2
MUNICIPAL	101	98	98	59	4	55	56.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent Of Sample Responding YES	Percent Of Sample Responding NO
STATE	12	2	85.7	14.3
COUNTY	14	54	20.6	79.4
MUNICIPAL	17	38	30.9	69.1

(a) There was a corollary question to question 14 that requested information on the training course of those responding in the affirmative. Since so few provided this information, no attempt at analysis will be made.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

TABLE A-7

Question 15: "Do you have any formal or informal criteria to determine whether to apply salt, sand, or a salt/sand mixture?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	4	66	76.7
MUNICIPAL	101	98	98	59	13	46	45.9

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent Of Sample Responding NO
STATE	14	0	100	0
COUNTY	25	41	37.9	62.1
MUNICIPAL	16	30	34.8	65.2

(a) Included within question 15 was a request to check those of the following parameters that a maintenance area would use in determining what and when to apply a snow and ice removal substance (temperature, snowfall, number of vehicles, sunshine, wind, time of day, or any other the respondent deemed appropriate). In addition, a question was asked for each parameter with regard for the snow and ice removal substance (see Attachment #3 for more detail). No attempt was made to analyze this material due to a poor response.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt or sand; therefore, it does not need such a policy. Hence, a survey question population of 86.

TABLE A-8

Question 17: "Which do you rely on most in snow removal maintenance: blading, plowing, sanding, salting, salt/sand mixture, nature, and/or other (rank in order)?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop. (b)	Survey Question Pop. (SQP)	Survey Response	Number Not Responding	Survey Question Sample (SQS)	Percent Survey Response
STATE	16	16	16	14	3	11	68.8
COUNTY	87	87	87	71	0	71	81.6
MUNICIPAL	101	98	98	59	5	54	55.1

Maintenance Area	Adjusted Survey Question Sample (ASQS) (c)	Percent ASQS is of SQS (c)	Percent ASQS is of SQP (c)	Number That Checked (d)	Percent of SQS That Checked (d)
STATE	10	90.9	62.5	1	9.1
COUNTY	59	83.1	67.8	12	16.9
MUNICIPAL	42	77.8	42.9	12	22.2

(a) This question called for rank ordering of the responses. It was recognized that some maintenance areas would not find all choices applicable, but it was assumed that the respondents would at least rank order their applicable choices. As may be seen above, one state, twelve county and twelve municipal respondents indicated a preference but did not rank order them. This mandates a new statistic that factors in this type of response (see note (c) below).

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

(c) The Adjusted Survey Question Sample (ASQS) is the number of those who responded to the question and who rank-ordered their responses. The Percent ASQS of the SQS is the percentage of the SQS who rank-ordered their responses. The Percent ASQS of SQS is the percentage of the relevant population who rank-ordered their responses.

(d) The number that checked are those who indicated a preference but who did not rank order. The Percent of SQS that checked is the percentage of the sample that indicated a preference but did not rank order.

TABLE A-8a

The Response of State Maintenance Areas to Question 17

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Number Responding						
			Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
10	90.9	1	-	10	-	-	-	-	-
10	90.9	2	7	-	1	2	-	-	-
10	90.9	3	3	-	3	-	2	2	-
8	72.7	4	-	-	1	-	5	2	-
6	54.5	5	-	-	-	5	-	1	-
5	45.5	6	-	-	3	-	-	2	-
1	9.1	✓	-	-	-	-	-	-	1
Factoring Rank Number 1 and Check as Number			-	10	-	-	-	-	1 = 11 SQS

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Percent of SQS Responding						
			Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
10	90.9	1	-	90.9	-	-	-	-	-
10	90.9	2	63.6	-	9.1	18.2	-	-	-
10	90.9	3	27.3	-	27.3	-	18.2	18.2	-
8	72.7	4	-	-	9.1	-	45.5	18.2	-
6	54.5	5	-	-	-	45.5	-	9.1	-
5	45.5	6	-	-	27.3	-	-	18.2	-
1	9.1	✓	-	-	-	-	-	-	9.1
Factoring Rank Number 1 and Check as Percent			-	90.9	-	-	-	-	9.1 = 100% SQS

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Percent of ASQS Responding						
			Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
10	90.9	1	-	100	-	-	-	-	-
10	90.9	2	70	-	10	20	-	-	-
10	90.9	3	30	-	30	-	20	20	-
8	72.7	4	-	-	12.5	-	62.5	25	-
6	54.5	5	-	-	-	83.3	-	16.7	-
5	45.5	6	-	-	60	-	-	40	-
1	9.1	✓	-	-	-	-	-	-	100

TABLE A-8b

The Response of County Maintenance Areas to Question 17

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Number Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other	
59	83.1	1	7	52	-	-	-	-	-	
59	83.1	2	39	7	1	1	11	-	-	
55	77.5	3	5	-	3	-	31	15	1	
37	52.1	4	3	-	2	6	8	17	1	
14	19.7	5	1	-	6	3	-	4	-	
7	9.9	6	-	-	2	3	-	2	-	
12	16.9	✓	5	10	1	8	3	-	-	
Factoring Rank No. 1 and Check as: Number			12	62	1	8	3	-	-	= 71 SQS

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Percent of SQS Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other	
59	83.1	1	9.9	73.2	-	-	-	-	-	
59	83.1	2	54.9	9.9	1.4	1.4	15.5	-	-	
55	77.5	3	7	-	4.2	-	43.7	21.1	1.4	
37	52.1	4	4.2	-	2.8	8.5	11.3	23.9	1.4	
14	19.7	5	1.4	-	8.5	4.2	-	5.6	-	
7	9.9	6	-	-	2.8	4.2	-	2.8	-	
12	16.9	✓	7	14	1.4	11.3	4.2	-	-	
Factoring Rank No. 1 and Check as: Percent			16.9	87.3	1.4	11.3	4.2	-	-	= 100% SQS

Number ASQS Per Rank	Percent ASQS is of SQS Per Rank	Rank Order and Check	Percent of ASQS Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
59	83.1	1	11.9	88.1	-	-	-	-	-
59	83.1	2	66.1	11.9	1.7	1.7	18.6	-	-
55	77.5	3	9.1	-	5.5	-	56.4	27.3	1.8
37	52.1	4	8.1	-	5.4	16.2	21.6	45.9	2.7
14	19.7	5	7.1	-	42.9	21.4	-	28.6	-
7	9.9	6	-	-	28.6	42.9	-	28.6	-
12	16.9	✓	41.7	83.3	8.3	66.7	25	-	-

TABLE A-8c

The Response of Municipal Maintenance Areas to Question 17

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Number Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
42	77.8	1	9	31	-	1	1	-	-
42	77.8	2	21	9	-	1	11	-	-
39	72.2	3	5	2	1	2	27	2	-
17	31.5	4	1	-	3	4	1	7	1
6	11.1	5	1	-	2	2	-	1	-
2	3.7	6	-	-	-	-	-	2	-
12	22.2	✓	6	-	11	1	-	3	-
Factoring Rank No. 1 and Check as: Number			15	31	11	2	1	3	-

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Percent of SQS Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
42	77.8	1	16.7	57.4	-	1.9	1.9	-	-
42	77.8	2	38.9	16.7	-	1.9	20.4	-	-
39	72.2	3	9.3	3.7	1.9	3.7	50	3.7	-
17	31.5	4	1.9	-	5.6	7.4	1.9	13	1.9
6	11.1	5	1.9	-	3.7	3.7	-	1.9	-
2	3.7	6	-	-	-	-	-	3.7	-
12	22.2	✓	11.1	-	20.4	1.9	-	5.6	-
Factoring Rank No. 1 and Check as: Percent			27.8	57.4	20.4	3.7	1.9	5.6	-

Number ASQS Per Rank	Percent ASQS is Of SQS Per Rank	Rank Order and Check	Percent of ASQS Responding: Blade	Plow	Sand	Salt	Salt and Sand Mixture	Nature	Other
42	77.8	1	21.4	73.8	-	2.4	2.4	-	-
42	77.8	2	50	21.4	-	2.4	26.2	-	-
39	72.2	3	12.8	5.1	2.6	5.1	69.2	5.1	-
17	31.5	4	5.9	-	17.6	23.5	5.9	41.2	5.9
6	11.1	5	16.7	-	33.3	33.3	-	16.7	-
2	3.7	6	-	-	-	-	-	100	-
12	22.2	✓	50	-	91.7	8.3	-	25	-

TABLE A-9

Question 19: "Does the time of application for salt, sand, salt/sand mixture or other vary with any of the following parameters: temperature, snowfall, number of vehicles per day or other?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	3	67	77.9
MUNICIPAL	101	98	98	59	9	50	51

Maintenance Area	Number Responding YES	Number Responding NO	Percent Of Sample Responding YES	Percent Of Sample Responding NO
STATE	13	1	92.9	7.1
COUNTY	53	14	79.1	20.9
MUNICIPAL	38	12	76	24

(a) The question origionally included a request to check those parameters that affected the time of application. Because so few checked those that applied, no attempt was made to analyze this aspect of the question.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt or sand; therefore, this question is not applicable. Hence, a survey question population of 86.

TABLE A-10

Question 20: "When do you prefer to apply the following with regard to snow conditions (before storm starts, just as it starts, during storm, and/or after storm)?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample (SQS)	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	2	68	79.1
MUNICIPAL	101	98	98	59	5	54	55.1

Maintenance Area	Number				Percent of SQS			
	Before Storm Starts	Just As It Starts	During Storm	After Storm	Before Storm Starts	Just As It Starts	During Storm	After Storm
STATE	0	9	3	2	0	64.3	21.4	14.3
COUNTY	0	5	7	56	0	7.4	10.3	82.4
MUNICIPAL	3	7	9	35	5.6	13.0	11.7	64.8

(a) The question asked the respondents to qualify their preference by the use of the substance used (salt, sand, salt/sand, or other). However, as may be seen by Table A-13, infra, so few maintenance areas use straight salt, sand or other, it renders the responses to this aspect of the question relatively meaningless.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, an adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt or sand; therefore, it has no preference. Hence, a survey question population of 86.

TABLE A-11

Question 22: "Do you keep records of when, where, and how much sand, salt, or salt/sand or other that you apply in a storm?"

Maintenance Area	Orig. Pop.	Adjusted Pop. (a)	Survey Question Pop. (b)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	2	68	79.1
MUNICIPAL	101	98	98	59	4	55	56.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent of Sample Responding YES	Percent of Sample Responding NO
STATE	14	0	100	0
COUNTY	19	49	27.9	72.1
MUNICIPAL	11	44	20	80

(a) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

(b) One county (Lake of the Woods) does not use salt or sand; therefore, they have no records to keep. Hence, a survey question population of 86.

TABLE A-12

Question 23: "Have you received any complaints on salt usage between 1970 and 1977?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	5	9	56.3
COUNTY	87	87	86	70	4	66	76.7
MUNICIPAL	101	98	98	59	7	52	53.1

Maintenance Area	Number Responding YES	Number Responding NO	Percent Of Sample Responding YES	Percent Of Sample Responding NO
STATE	6	3	66.7	33.3
COUNTY	16	50	24.2	75.8
MUNICIPAL	22	30	43.3	57.7

(a) Question 23 asked for the number of complaints and whether the respondent felt there had been an increase, decrease or no change in the number of complaints if they did not keep records. Because of the wide variety of responses to this question, it has been analyzed from the perspective of whether the respondent had ever received any complaint on salt usage between 1970 and 1977.

(b) Three municipalities contract out their snow and ice removal operations to their respective counties; hence, the adjusted population of 98.

(c) Lake of the Woods County does not use salt, thereby rendering the question irrelevant for them and reducing the survey question population to 86.

TABLE A-13

Question - combination of 6, 7, 15, and 20: "In what form do you apply your snow and ice removal substances: salt, sand, salt/sand mixture or other?" (a)

Maintenance Area	Orig. Pop.	Adjusted Pop.(b)	Survey Question Pop.(c)	Survey Response	Number Not Responding	Survey Question Sample	Percent Survey Response
STATE	16	16	16	14	0	14	87.5
COUNTY	87	87	86	70	0	70	81.4
MUNICIPAL	101	98	98	59	1	58	59.2

Maintenance Area	Number				Percent of Survey Question Sample			
	Salt	Sand	Salt and Sand	Other	Salt	Sand	Salt and Sand	Other
STATE	0	5	14	0	0	35.7	100	0
COUNTY	13	44	65	12	18.6	62.9	92.9	17.1
MUNICIPAL	18	20	47	9	31	34.5	81	15.5

(a) Questions 6, 7, 15, and 20 all requested that the response be answered on the basis of the snow and ice removal substance(s) used. Therefore, the substance(s) that maintenance areas use for snow and ice removal can be ascertained by analyzing these questions. A list of those using "other" and what "other" is provided in Table A-13a.

(b) Three municipalities contract out their snow and ice removal practices to their respective counties; hence, the adjusted population of 98.

(c) One county (Lake of the Woods) does not use salt or sand; hence, a survey question population of 86.

TABLE A-13a

Jurisdictions using "other" and a description of "other." (a)

Maintenance Area	Sodium Chloride	Slag	Cinders	Heated Sand	Ice Control Rock	Not Specified
			Description of "Other"			
STATE		NO "OTHERS" USED				
COUNTY						
Anoka		X				
Blue Earth	X					
Chippewa	X					
Grant	X					
Itasca	X					
Jackson	X					
Lake	X					
Marshall	X					
Polk	X					
Sherburne			X			
Washington		X				
Winona	X					
MUNICIPAL						
Apple Valley				X		
Bloomington					X	
Fridley	X	X				
Inver Grove Hts.	X					
Maplewood	X					
Montivideo	X					
New Ulm			X			
No. Mankato						X
So. St. Paul		X				
White Bear Lake	X					
Winona	X					
TOTAL	15	4	2	1	1	1
STATE	0	0	0	0	0	0
COUNTY	9	2	1	0	0	0
MUNICIPAL	6	2	1	1	1	1

(a) Questions 6, 7, 15, and 20 requested the respondent to specify "other." This table is a result of that request.

Attachment #1

ROAD SALT SURVEY

Minnesota Municipal Highway Engineers

The person filling out this survey should provide the following information:

1. Name:______________________________ Telephone No.:____-____-________

   Street, Box, or RR:____

   City:____________________ County:____________________ District No:______

   Title:____________________ Position:____________________ Zip Code:______

2. How many lane miles of roads are under your authority?______________________

3. Classify the roads in your jurisdiction by the number of lane miles for each of the following:

Traffic Count	Under Your Authority
Less than 800	______________
800-2,000	______________
2,000-10,000	______________
More than 10,000	______________
Less than 7,500	______________
More than 7,500	______________

4. List the cities in your jurisdiction where you have the authority to remove snow (please provide on a separate sheet of paper). How many tons of salt, sand, or other products were purchased for each city from 1970 through 1977? How many tons were actually used in each of these years?

5. Are there any local or county ordinances in your jurisdiction governing the purchase, storage, or application of road salt, sand, or other similar products? If so, please provide a copy. Please check if you don't know.

6. To how many lane miles are the following applied?

Substance	1970	1971	1972	1973	1974	1975	1976	1977
Salt	____	____	____	____	____	____	____	____
Sand (4-10% salt)	____	____	____	____	____	____	____	____
Salt & sand (More than 10% salt)	____	____	____	____	____	____	____	____
Other (specify)	____	____	____	____	____	____	____	____
Other (specify)	____	____	____	____	____	____	____	____

7. How many lane miles of snow fencing is under your authority?________________________

   Do you salt, sand, or salt and sand these lane miles? Yes____________ No__________

   Do you use more, less or the same amount of salt, sand, salt/sand or other on these miles?

	More	Less	Same
Salt	____	____	____
Sand	____	____	____
Salt/Sand	____	____	____
Other	____	____	____

8. How many tons of salt did you use each winter (1970-1977)? What was the average price per ton for each year? How many tons of sand did you use each winter? What was the average price per ton for each year?

Substance	1970	1971	1972	1973	1974	1975	1976	1977
Tons of salt	____	____	____	____	____	____	____	____
Tons of Sand	____	____	____	____	____	____	____	____
Tons of Other (Specify)	____	____	____	____	____	____	____	____
Avg. Price of Salt	____	____	____	____	____	____	____	____
Avg. Price of Sand	____	____	____	____	____	____	____	____
Avg. Price of Other	____	____	____	____	____	____	____	____

9. From whom do you purchase you salt, sand, and other? If more than one, please list on back. Please provide for the last seven years.

   Salt____
   Name Address State Zip Telephone

   Sand____
   Name Address State Zip Telephone

   Other____
   Name Address State Zip Telephone

10. How do you store your salt? (If combination, specify tonnage.) Is salt delivered throughout the season at these locations?

   Open______________ Under Tarp________________ Building______________

   Other (specify)______________________________ Total tonnage stored____________

11. How many trucks do you have for snow and ice control? ______________________

    What kind of spreaders are they equipped with? (Indicate number of trucks.)

    Ground__________ Conventional__________ Other (specify) ______________________

12. How do you calibrate the spreaders (tons released per mile)? ____________________

    Do you have any general criteria on how much material to spread? Please elaborate.

    ____

    What is the maximum amount released (tons per lane mile)? ______________________

13. Do you use underbody blades on your trucks? Yes_____ No______

    If yes, on how many trucks? ____________

14. Do you have a training course on snow removal for your drivers? Yes_____ No_____

    If yes, please provide detailed information on the course. If no, please indicate how drivers know when to apply salt, sand, etc. Use the back of the page if necessary.

    ____

    ____

15. Do you have any formal or informal criteria to determine whether to apply salt, sand, or a salt/sand mixture? Yes_____ No_____ If yes, please provide a copy of the criteria and check below those criteria used.

Check	Parameter	Storm Condition	Salt	Sand	Salt/Sand	Other
_____	Temperature	At what temp do you apply:	____	____	_________	_____
_____	Snowfall	After how many inches do you apply:	____	____	_________	_____
_____	No. vehicles	How many vehicles in a storm before you apply:	____	____	_________	_____
_____	Sunshine	If it is cloudy, do you apply:	____	____	_________	_____
_____	Wind	How much wind before you stop applying:	____	____	_________	_____
_____	Time of day	How much more do you apply during rush hour?	____	____	_________	_____
_____	Other (specify)	____________________	____	____	_________	_____

16. If you have no formal or informal criteria to determine when to apply salt, sand, or a salt/sand mixture, how do you know when to apply these substances?

____

____

17. Which do you rely on most in snow removal maintenance? (Rank in order.)

Blading______ Plowing______ Sanding______ Salting______ Salt/Sand Mixture______

Nature______ Other (specify)______________________________

18. Do you prewet your salt before application? Yes______ No______

19. Does the time of application for salt, sand, salt/sand mixture, or other vary with any of the following: Yes______ No______ Please check which ones.

Temperature______ Snowfall______ No. of vehicles per day______ Other (specify)______

20. When do you prefer to apply the following with regard to snow conditions (elaborate if necessary)?

Storm Condition	Salt	Sand	Salt/Sand	Other (specify)
Before storm starts	____	____	________	____________
Just as it starts	____	____	________	____________
During storm	____	____	________	____________
After storm	____	____	________	____________

21. Does the time of application with regard to a storm make a difference as to what substance you apply or your rate of application? Please elaborate.

____

____

22. Do you keep records of when, where, and how much salt, sand, or salt/sand or other that you apply in a storm? Yes______ No______

23. How many complaints have you had on salt usage? 1970______ 1971______ 1972______

1973______ 1974______ 1975______ 1976______ 1977______

If you have not kept records of complaints, do you feel there has been an increase, decrease, or no change in the number of complaints?______________________

24. How long does it take to clear the roads with a traffic count of less than 800 and if the snow (moisture content) is:

Amount of Snow	Wet	Dry
Light snow (less than 3")	________	________
Med. snow (3-6")	________	________
Heavy snow (more than 6")	________	________
Ice storm	________	________
Rain changing to snow	________	________
Sleet	________	________

25. How long does it take to clear the roads with a traffic count of 800-2,000 and if the snow (moisture content) is:

Amount of Snow	Wet	Dry
Light snow (less than 3")	________	________
Med. snow (3-6")	________	________
Heavy snow (more than 6")	________	________
Ice storm	________	________
Rain changing to snow	________	________
Sleet	________	________

26. How long does it take to clear the roads with a traffic count of 2,000-10,000 and if the snow (moisture content) is:

Amount of Snow	Wet	Dry
Light snow (less than 3")	________	________
Med. snow (3-6")	________	________
Heavy snow (more than 6")	________	________
Ice storm	________	________
Rain changing to snow	________	________
Sleet	________	________

27. How long does it take to clear the roads with a traffic count of more than 10,000 if the snow(moisture content) is:

Amount of Snow	Wet	Dry
Light snow (less than 3")		
Med. snow (3-6")		
Heavy snow (more than 6")		
Ice storm		
Rain changing to snow		
Sleet		

28. How long does it take to clear the roads with a traffic count of less than 800 and the temperature is:

Amount of Snow	Below Freezing	Freezing	Above Freezing
Light snow (less than 3")			
Med snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

29. How long does it take to clear the roads with a traffic count of 800-2,000 and the temperature is:

Amount of Snow	Below Freezing	Freezing	Above Freezing
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

30. How long does it take to clear the roads with a traffic count of 2,000-10,000 and the temperature is:

Amount of Snow	Below Freezing	Freezing	Above Freezing
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

31. How long does it take to clear the roads with a traffic count of more than 10,000 and the temperature is:

Amount of Snow	Below Freezing	Freezing	Above Freezing
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

32. How long does it take to clear the roads with a traffic count of less than 800 and the wind is:

Amount of Snow	Less than 10 mph	10-25 mph	More than 25 mph
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

33. How long does it take to clear the roads with a traffic count of 800-2,000 and the wind is:

Amount of Snow	Less than 10 mph	10-25 mph	More than 25 mph
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

34. How long does it take to clear the roads with a traffic count of 2,000-10,000 and the wind is:

Amount of Snow	Less than 10 mph	10-25 mph	More than 25 mph
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

35. How long does it take to clear the roads with a traffic count of more than 10,000 and the wind is:

Amount of Snow	Less than 10 mph	10-25 mph	More than 25 mph
Light snow (less than 3")			
Med. snow (3-6")			
Heavy snow (more than 6")			
Ice storm			
Rain changing to snow			
Sleet			

Stanley J. Fudro
District 55A
Hennepin-Anoka Counties
Committees:
Transportation, Chairman
Commerce and Economic Development
General Legislation and
Veterans Affairs
Rules and Legislative Administration

Minnesota House of Representatives

Martin Olav Sabo, Speaker

November 21, 1977

Mr. J. R. Allen
1123 Mesaba Avenue
Duluth, Minnesota 55801

Dear Mr. Allen:

Enclosed is a copy of a survey that asks a number of questions regarding the use of road salt as a snow removal and highway maintenance practice. This survey was designed by the Science and Technology Project of the Minnesota Legislature with the cooperation of Mr. Curt Christie of the Maintenance Division of the Minnesota Department of Transportation. The Science & Technology Project staff will be compiling the results and a stamped, self-addressed envelope is provided for you to return the survey to them at Room 17 of the State Capitol.

In addition, a copy of House Advisory No. 4 is enclosed for your information. As may be seen, the goal behind HA 4 is to reduce the impact of salt on bridges, vehicles, and the environment. Your help in the completion of this survey will assist us in achieving our goal.

I expect that this survey, in conjunction with other research being conducted by the S & T Project, will help us determine the correct course of action to be taken on the road salt issue.

Thank you for your cooperation.

Sincerely,

Stanley J. Fudro, Chairman
House Committee on Transportation

mw

Enclosures

P.S. A copy of the research results will be sent to you upon completion.

TRIPLICATE

Attachment #3

State of Minnesota
House of Representatives
70th Session

HOUSE ADVISORY NO. 4

Introduced by Mann, Fudro, Lemke

January 17th, 1977

Referred to Committee on TRANSPORTATION

Title (not to exceed 12 words) "A PROPOSAL FOR/TO SNOW AND ICE CONTROL ON ROADS AND STREETS

It is proposed that the Committees on Transportation and Environment and Natural Resources establish a special subcommittee to examine the feasibility of the Department of Transportation's, and other road authorities' throughout the state, use of salt (sodium chloride and calcium chloride) for the purpose of snow and ice control on roads and streets.

Millions of dollars of damage are caused to vehicles each year because of the corrosive effects of such chemicals. The use of such salts cause environmental pollution to vegetation along roadways and to surface water and groundwater resources.

It is recognized that some means of snow and ice control most be applied to roads and streets as a means of reducing the hazards of winter driving.

The joint subcommittee shall undertake a study with the objective of finding substitute deicing materials that would replace or significantly reduce the deleterious effects of salts on vehicles and the environment, the results, together with the appropriate recommendations for any furthe research work, to be reported in writing to the Legislature. The subcommittee may draw upon the resources of research personnel on the Commissioner of the Department of Transportation staff.