Snow and Ice Control: Guidelines for Materials and Methods

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 526

Snow and Ice Control: Guidelines for Materials and Methods

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NCHRP PROJECT F6-13 PANEL
Field of Maintenance—Area of Snow and Ice Control

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report provides guidelines for selecting roadway snow and ice control strategies and tactics for a wide range of winter maintenance operating conditions. These guidelines apply to highways, roads, streets, and other paved surfaces that carry motor vehicles—under state or local jurisdictions. The guidelines will assist winter maintenance personnel in selecting the appropriate level-of-service (LOS)-driven roadway snow and ice control operations and will help effectively manage snow and ice control resources. The report is a useful resource for state and local highway agency personnel and others involved in snow and ice control.

Snow and ice control on the U.S. highway system consumes billion of dollars—in direct costs and costs associated with corrosion and environmental impacts—each year. Strategies and tactics that employ solid and liquid chemicals, abrasives, and mechanical methods—individually or in combination—have been used by state and local agencies. In spite of many studies of issues associated with snow and ice control treatments, widely accepted guidelines for selecting roadway snow and ice control strategies and tactics for specific climatic, site, and traffic conditions have not emerged. Without such guidelines, the process of selecting treatment strategies and tactics that meet highway agency objectives can be difficult and costly. NCHRP Project 6-13 was conducted to address this need.

Under NCHRP Project 6-13, "Guidelines for Snow and Ice Control Materials and Methods," Midwest Research Institute of Kansas City, Missouri was assigned the objective of developing guidelines—applicable to state and local agencies—for selecting roadway snow and ice control strategies and tactics for specific ranges of climatic and traffic conditions found in the United States. These strategies and tactics refer to the combinations of materials, equipment, and methods—both chemical and physical—used in snow and ice control to achieve a defined LOS; they also include road-weather information systems and weather forecasting. To accomplish this objective, the researchers performed the following tasks:

1. Identified the climatic, site, and traffic conditions that affect the selection of snow and ice control strategies and tactics to achieve agency objectives (e.g., LOS) and listed in a rank-order the criteria necessary to assess the performance of treatments.
2. Identified the snow and ice control strategies and tactics in current use that may be applicable to U.S. conditions and highlighted for each strategy and tactic the conditions of use, selection criteria, evaluation methods, effectiveness, and related problems.
3. Identified specific snow and ice control strategies and tactics that merited further evaluation and developed a plan for their field evaluation in different environments under different site and traffic conditions.

4. Conducted investigations of several potential snow and ice strategy and tactic combinations during three winter seasons and collected information necessary to relate the effectiveness of each of these combinations to the climatic, site, and traffic conditions.
5. Developed guidelines that can be used for selecting appropriate snow and ice control strategies and tactics for specific climatic, site, and traffic conditions to achieve agency objectives.

The following five primary combinations (1 through 5) were evaluated at different locations over three winter periods under a variety of weather and traffic conditions:

1. Anti-icing strategy with appropriate chemical forms (e.g., solids and prewetted solids) on lower-volume primary highways and local roads followed by a subsequent strategy of mechanical removal of snow and ice together with friction enhancement, if necessary.
2. Anti-icing strategy with appropriate chemical forms (e.g., solids, prewetted solids, and liquids) at selected highway locations such as hills, curves, intersections, grades, and selected bridge decks.
3. Anti-icing or deicing strategy with appropriate chemical forms on lower-volume primary highways and local road systems.
4. Anti-icing strategy with liquid chemical applications on bridge decks to prevent preferential icing.
5. Mechanical snow and ice removal strategy with abrasives prewetted with liquid chemicals.

A total of 24 highway agencies (13 state, 1 provincial, 4 county, and 6 city or town) made an attempt at testing the five strategy/tactic combinations at a total of 51 site locations over the three-winter periods; three highway agencies provided test data for the same location over all three winters. However, adjustments were made by some highway agencies to the assigned strategy/tactic combinations during some winter weather events because of weather-related circumstances and other limitations. These adjustments resulted in the following three additional strategy/tactic combinations (6 through 8):

6. Chemical priority strategy with straight chemicals (solid, prewet solid, or liquid) throughout an event to the extent possible and an occasional application of abrasives/chemical mixture.
7. Abrasive priority strategy with abrasives (pure or mixed with chemicals) throughout an event to the extent possible and an occasional application of straight chemicals (solid, prewet solid, or liquid).
8. Plowing only strategy without the use of snow and ice control materials (chemicals and/or abrasives) throughout the entire winter weather event.

To evaluate alternative strategy/tactic combinations, the researchers considered possible indicators/measures of effectiveness and developed a condition index—termed Pavement Snow and Ice Condition (PSIC) index—that describes the road condition in one of seven levels. These levels range from a pavement surface that remains in a bare/wet condition at all times (Condition 1) to a pavement surface that is covered with a significant buildup of packed snow and ice (Condition 6) and even a pavement surface that is exposed to drifting and excessive unplowed snow to warrant temporary closure (Condition 7). The index was used to evaluate both within-event and end-of-event LOS achieved by the winter maintenance treatments for comparing the effectiveness of the different strategy/tactic combinations. The researchers also investigated the factors influencing the choice of materials, their form, and associated application rates.

The findings of this research pointed out the importance of (1) ensuring that snow and ice control strategy/tactic combinations are LOS driven; (2) using nowcasting results, materials characteristics, traffic volume, and cycle time considerations in the treatment decision making; and (3) providing flexible winter maintenance operations to deal with the variety of precipitation types, especially those occurring within a given weather event.

Results of the analytical and field investigations conducted in this research were used to develop the guidelines for winter maintenance materials and methods presented in this report. These guidelines will assist in selecting materials and methods that best address LOS, weather, site, and traffic conditions and, therefore, be useful to highway agencies and contracting firms involved in snow and ice control work.

CONTENTS

CHAPTER 1

INTRODUCTION

Snow and ice control on the U.S. highway system consumes over $2 billion in direct costs each year (*1*). Indirect costs associated with corrosion and environmental impacts add at least $5 billion (*1*). Strategies and tactics that employ solid and liquid chemicals, abrasives, and mechanical methods—individually or in combination—have been used by different state and local agencies. Research by the Strategic Highway Research Program (SHRP), the Federal Highway Administration (FHWA), the American Association of State Highway Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), and other organizations in the United States and other countries has addressed many of the issues associated with snow and ice control treatments (*2–5*). However, widely accepted guidelines for selecting level-of-service (LOS)-driven roadway snow and ice control strategies and tactics for specific climatic, site, and traffic conditions have not been developed. Without this information, the process of selecting treatment strategies and tactics that meet highway agencies LOS objectives is difficult.

This report presents a realistic set of guidelines for selecting roadway snow and ice control strategies and tactics for a wide range of climate, site, and traffic conditions found in the United States. These guidelines apply to both state and local highway agencies. The term "roadway" used in this document refers to any highway, road, street, or other paved surface that carries motor vehicles.

The guidelines were developed from appropriate existing documentation plus data collected from field testing of selected snow and ice control strategies and tactics over three winters.

In the general sense, a strategy is a careful plan or method directed at achieving a specific goal or goals. Tactics, on the other hand, are the systematic employment of available means or resources to accomplish a desired end condition of a strategy. For purposes of these guidelines, strategies and tactics refer to the combination of material, equipment, and methods, including both chemical and physical, that are used in snow and ice control operations to achieve a defined level of service.

The various roadway snow and ice control strategies used in winter maintenance operations in the United States can be classified into four general categories:

- Anti-icing,
- Deicing,
- Mechanical removal of snow and ice together with friction enhancement, and
- Mechanical removal alone.

Roadway anti-icing is a snow and ice control strategy of preventing the formation or development of bonded snow and ice to a pavement surface by timely applications of a chemical freezing-point depressant. The tactics employed during anti-icing operations consist of chemical applications that are coordinated with plowing.

Deicing is a snow and ice control strategy of destroying the bond between snow and ice and the pavement surface by chemical or mechanical means or a combination of the two.

Mechanical removal of snow and ice together with friction enhancement is a strategy in which abrasives or a mixture of abrasives and a chemical are applied to a layer of compacted snow or ice already bonded to the pavement surface that may or may not have been partially removed by mechanical means (plowing and scraping). This strategy is used to provide an increase in the coefficient of friction for vehicular traffic, although this increase may be short lived. Abrasives, by themselves, are not ice control chemicals and will not support the fundamental objective of either anti-icing or deicing.

Mechanical removal alone is a strategy that involves the physical process of attempting to remove an accumulation of snow or ice by means such as plowing, brooming, blowing, and so on, without the use of snow and ice control chemicals. This strategy is strictly a physical process that has some merit during and/or after frozen precipitation has occurred at very low pavement temperatures, say below 15°F, and on very low volume and unpaved roads.

The guidelines were developed to assist maintenance managers, local maintenance supervisors, and other field personnel in selecting LOS-driven roadway snow and ice control strategies and tactics. The guidelines focus on the snow and ice control materials and methods that best address such items as LOS, weather, site, and traffic conditions.

Following this Introduction, the guidelines are divided into seven major chapters:

- **Chapter 2: Level of Service**—This chapter describes the various winter-time LOS definitions used by highway agencies in the United States. Stressed is the need to define LOS in terms of measures of effectiveness that can be used by the agencies in their evaluation process. Factors affecting LOS are discussed in general and then more specifically in later chapters. The discussion includes the need for describing within-storm, end-of-storm, and post-storm conditions when developing LOS.

- **Chapter 3: Snow and Ice Control Operational Considerations**—This chapter describes the various climatic, site, and traffic conditions found in the United States that are considered important in the selection of appropriate roadway snow and ice control strategies and tactics. Described are the various types and distribution of winter weather conditions within the general climates of the United States. and their relationship to snow and ice control. This chapter also contains a description of microclimates and their importance in selecting appropriate strategies and tactics for snow and ice control. Those site conditions that influence snow and ice control are discussed. Major influences include the area development setting, roadway features, and solar influences. Also described are the influences of site considerations on LOS goals that are achievable with various resources. This chapter also describes the traffic-related influences on snow and ice control. The influences include traffic volume, vehicle mixes, essential or functional traffic patterns, and vehicle speeds. The influence of traffic considerations on LOS is presented. Finally, this chapter concludes with a summary of the important factors of these three considerations that influence the choice of snow and ice control strategies and tactics.
- **Chapter 4: Performance-Based Level of Service**—This chapter describes a process for use by agencies in developing a performance-based LOS. This discussion includes the use of Pavement Snow and Ice Condition (PSIC) indices, a suggested set of PSIC definitions, and the establishment of LOS classes using PSIC for various highway classifications and for within-storm and end-of-storm conditions.
- **Chapter 5: Strategies and Tactics and Their Application to Support Level of Service Choices**—This chapter describes the four snow and ice control strategies: anti-icing, deicing, mechanical removal of snow or ice with traction enhancement, and mechanical removal of snow or ice. For each of these strategies, the guidelines describe the effects of climate, site, and traffic considerations. In addition, and considering PSIC and LOS, the guidelines discuss the strategies with respect to pre-storm, within-storm, and end-of-storm operations. Various tactics that can be used to support each of the strategies are also discussed. The chapter concludes with special discussions of traction enhancement and the use of combinations of strategies and tactics.
- **Chapter 6: Factors Influencing the Choice of Materials, Their Form, and Associated Application Rates**—In order to attain LOS classes, managers must select appropriate resources. This chapter first describes the influence of pavement temperatures and the dilution potential of winter weather events. Then discussed are the properties of materials used in support of strategies and tactics and the effects of dilution with respect to attaining LOS goals.
- **Chapter 7: Recommended Snow and Ice Control Practices**—This chapter describes a recommended process and sets of procedures to follow for snow and ice control operations for various LOS goals. The recommended practices are based on the results of the strategies and tactics evaluated in this project, supplemented by data assembled from various sources. A discussion on treatment decision making concludes the chapter.
- **Chapter 8: Recommended Operational Guidelines for Winter Maintenance Field Personnel**—This chapter contains tables that suggest appropriate maintenance actions to take during various strategy and tactic operations for winter weather events. These tables are suitable for reproduction and use by field personnel.

CHAPTER 2

LEVEL OF SERVICE

Level of service (LOS) in the context of roadway snow and ice control operations is a set of operational guidelines and procedures that establish the timing, type, and frequency of treatments. The maintenance actions are directed toward achieving specific pavement condition goals for various highway sections. Examples of LOS for highways, roads, and streets under snow and ice control conditions are given in AASHTO's "Guide for Snow and Ice Control" (*5*). How highway agencies characterize LOS, how they assign LOS goals, and how they measure the performance of maintenance operations in achieving the LOS goals are very important topics. These are briefly described below.

HOW AGENCIES CHARACTERIZE LEVEL OF SERVICE

There are several ways (singularly and in combination) by which highway agencies characterize the LOS they provide. These include level of effort, priority of treatment, types of treatments, and results in terms of pavement conditions at various points in time during and after snow and ice events.

The level of effort category includes assigning more people and equipment to higher priority routes, providing more or less effort during certain time frames, varying the number of people and equipment providing treatment in relationship to the predicted severity of the event, and so on.

The priority of treatment category includes giving first and/or more frequent treatment to higher traffic routes, high accident/problem locations, commercial/business locations, school bus routes, transit routes, health facilities, fire house locations, and schools. Some highway agencies use a system of providing treatment on a highway priority basis whereby the next lower category of highway is not treated until higher category roads are in "satisfactory" condition.

In the type of treatment category, the treatments at various locations are specifically defined. Examples include sanding hills and intersections, plowing-only on certain roads, using nonchloride or reduced chloride applications in certain areas, anti-icing areas, pre-treating areas, applying chemicals only at the beginning and end of the event, and so on.

RECOMMENDED LEVEL OF SERVICE GOALS

A good way to define LOS is in terms of results at various points in time. Examples include maximum accumulation of snow on highways during a storm, absence of pack or bond during a storm, bare/wet pavement (x) hours after end-of-event, plowed and sanded (x) hours after end-of-event, friction number > (y) (x) hours after end-of-event, road plowed, and road passable.

ASSIGNING LEVEL OF SERVICE GOALS

There are two fundamental approaches for highway agencies to use when assigning their LOS goals. The first is to evaluate existing resources and direct them toward providing a balanced LOS on a priority of treatment basis. This is realistically the more common approach. The second, and preferred, approach is to assign pavement condition goals at intervals within and after a "design storm" of "X" inches of snow per hour to the various priority elements of the highway system. Using this, and production rate (lane-miles per hour) of equipment (including deadheading and reloading) in both the plowing and materials spreading modes, the necessary personnel and equipment can then be determined to provide the desired LOS.

PERFORMANCE MEASURING OF LEVEL OF SERVICE

A variety of performance measures are being tried and used relative to LOS. These include (in order of popularity) pavement conditions (visual) at various points in time (some agencies use pictorial reference templates as an aid to condition observers); performance indices that relate the amount of time pavement areas are snow/ice covered to total storm time (visual); report cards (customer satisfaction surveys); and friction measurements at various points in time and rating slipperiness at various points in time based on vehicle handling characteristics.

The visual approach appears to be gaining in popularity in the United States and abroad. Examples of visual characterization of roadway surfaces include the following:

- Centerline bare,
- Wheel path bare,
- Loose snow covered (percent area and depth),
- Packed snow covered (percent area and depth),
- Bare (percent area),
- Thin ice covered (percent area),
- Thick ice covered (percent area),
- Dry,
- Damp,
- Slush (percent area and depth),
- Frost, and
- Wet.

Using the descriptors above together with traffic flow and other visual information, a Pavement Snow and Ice Condition (PSIC) can be established for any point in time. The descriptions of the various PSICs appear in Table 1.

Whatever performance measure is chosen, it must be part of a continuing evaluation plan that addresses individual winter weather events; early, mid, and late winter season events that tend to have similar characteristics; and full winter seasons. This will allow critical judgment to be made on resource levels, strategies and tactics, materials choices and materials application rates.

SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS RELATING TO LEVEL OF SERVICE

The primary snow and ice control operational considerations relating to LOS are cycle time, available material treatments, weather conditions, site conditions, and traffic considerations.

Cycle time is primarily a function of the number of personnel and the amount of equipment available to treat the assigned roadway system or route. Other factors, including traffic volume/speed, traffic control devices, roadway geometry/complexity, and the location of material stockpiles also contribute to achievable cycle time.

LOS and cycle time of maintenance treatment operations are clearly interconnected. The LOS and cycle time for a facility will largely be determined by the importance or functional classification of the road, which may be strongly related to the roadway's average daily traffic volume (ADT) (*5*). High winter maintenance LOS requirements are described many times as "bare pavement" policies. Anti-icing strategies with appropriate tactics have been shown to be consistent with the requirements of a high-LOS facility (*3*).

The type of material treatments an agency is capable of delivering has a major impact on achievable LOS. Agencies capable of providing appropriate liquid and/or solid chemi-

TABLE 1 Descriptions of pavement snow and ice conditions (PSIC)

Condition 1: All snow and ice are prevented from bonding and accumulating on the road surface. Bare/wet pavement surface is maintained at all times. Traffic does not experience weather-related delays other than those associated with wet pavement surfaces, reduced visibility, incidents, and "normal" congestion.
Condition 2: Bare/wet pavement surface is the general condition. There are occasional areas having snow or ice accumulations resulting from drifting, sheltering, cold spots, frozen melt-water, etc. Prudent speed reduction and general minor delays are associated with traversing those areas.
Condition 3: Accumulations of loose snow or slush ranging up to (2 in.) are found on the pavement surface. Packed and bonded snow and ice are not present. There are some moderate delays due to a general speed reduction. However, the roads are passable at all times.
Condition 4: The pavement surface has continuous stretches of packed snow with or without loose snow on top of the packed snow or ice. Wheel tracks may range from bare/wet to having up to (1.5 in.) of slush or unpacked snow. On multilane highways, only one lane will exhibit these pavement surface conditions. The use of snow tires is recommended to the public. There is a reduction in traveling speed and moderate delays due to reduced capacity. However, the roads are passable.
Condition 5: The pavement surface is completely covered with packed snow and ice that has been treated with abrasives or abrasive/chemical mixtures. There may be loose snow of up to (2 in.) on top of the packed surface. The use of snow tires is required. Chains and/or four-wheel drive may also be required. Traveling speed is significantly reduced and there are general moderate delays with some incidental severe delays.
Condition 6: The pavement surface is covered with a significant buildup of packed snow and ice that has not been treated with abrasives or abrasives/chemical mixtures. There may be (2 in.) of loose or wind-transported snow on top of the packed surface due to high snowfall rate and/or wind. There may be deep ruts in the packed snow and ice that may have been treated with chemicals, abrasives, or abrasives/chemical mixtures. The use of snow tires is the minimum requirement. Chains and snow tire equipped four-wheel drive are required in these circumstances. Travelers experience severe delays and low travel speeds due to reduced visibility, unplowed loose, or wind-compacted snow, or ruts in the packed snow and ice.
Condition 7: The road is temporarily closed. This may be the result of severe weather (low visibility, etc.) or road conditions (drifting, excessive unplowed snow, avalanche potential or actuality, glare ice, accidents, vehicles stuck on the road, etc.).

cal treatment will achieve higher LOS than those who provide only mixtures of chemicals and abrasives or no material treatment at all.

The character and intensity of particular winter weather events influence how long chemical snow and ice control treatments will remain effective and the amount of snow/ice accumulation on the roadway between plowing cycles. The climatology of a particular area defines the historical average (usually over a 30-year period) of the type and amount of frozen precipitation the area can be expected to receive in an average winter. What is important for winter maintenance operations in a given area is not so much climatology, but the distribution of precipitation types associated with winter weather events. Winter maintenance forces across the United States need to be prepared to treat a wide variety of precipitation types, even within a given winter weather event. Only the distribution of the likelihood of precipitation type occurrence changes from area to area, or agency to agency.

The three site conditions of major importance are (1) pavement temperature, (2) the amount of snow/ice remaining on the roadway after plowing and/or before chemical treatment, and (3) most significantly, the presence or absence of ice/pavement bond. Other site conditions that relate more to operational difficulty include curvature, variable pavement widths, and many of those variables listed in next chapter. These latter items directly or indirectly can contribute to the presence of ice/pavement bond because of special needs imposed on snow and ice control field operations.

Traffic considerations include those relating to operational difficulty (e.g., slow- and fast-moving traffic, stranded blocking vehicles); timing (e.g., rush-hour, congestion); and influences on treatment effectiveness and longevity. The variation of traffic rate throughout a 24-hr period is an important consideration in the operational decision-making process.

Vehicular traffic can affect the pavement surface in several ways. Tires compact snow, abrade it, displace, or disperse it. Heat from tire friction, engine, and the exhaust system can add measurable heat to the pavement surface. Traffic wheel passages can help in the deicing of local streets when treated in the early morning hours. Traffic can also result in applied chemicals and abrasives being blown from the pavement surface when applied before precipitation. Thus, traffic can have both positive and negative influences on the effectiveness of snow and ice control operations. However, most of the influences are difficult to quantify. Further research is needed to quantify the effects of traffic.

CHAPTER 3

SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS

The major snow and ice control operational considerations, exclusive of agency resources, are climate, weather, site conditions, and traffic. Each has a profound effect on some aspect of operations.

CLIMATE CONDITIONS

Climate can be defined as the weather that occurs averaged over a specified period of time, normally 30 years. The climate is also defined by statistics about the frequency of extreme events. Climate elements are the averaged meteorological elements.

Table 2 provides a listing of major climate-related issues. Most of these have value in the planning phase of operations. LOS goals are to some extent climate driven in terms of what is and is not possible. Strategies and tactics that support LOS goals are similarly climate driven. Certain recurring site conditions (microclimates) are climate driven and require specific recurring operational responses. These include cold spots, high humidity locations, persistent windy areas, etc.

In any climate, the achievable LOS is limited by the rate of precipitation, cycle time capability, sustainability of the maintenance effort, site conditions that may cause road closure, and materials options. Higher LOS for similar weather conditions can be provided with shorter cycle times and the use of straight ice control chemicals.

WEATHER CONDITIONS

Field winter maintenance personnel in a given area are mostly concerned with anticipated winter weather conditions and not with climate considerations. "Weather" usually refers to the measurable or identifiable meteorological events that occur at a given site or in a given area at a particular point in time. Weather can be characterized by describing the meteorological elements associated with those events (e.g., precipitation type and amount, visibility, wind speed and direction, temperature, and relative humidity).

Precipitation is arguably the most important weather condition. Having a working knowledge of precipitation definitions is essential when designing a snow and ice control treatment. Those definitions appear in Table 3 and are taken from the *Federal Meteorological Handbook (FMH)* No. 1 (*6*).

Other important meteorological variables that have an impact on winter pavement conditions are sky, or cloud cover conditions (solar radiation effects); air temperature, to the extent it establishes the trend in pavement temperature; dew point temperature; condensation; pavement temperature; relative humidity; wind speed and direction; and evaporation.

Condensation occurs when the pavement, or bridge deck, temperature is above 32°F and below the dew point temperature. Frost, on the other hand, occurs when the pavement temperature is at or below 32°F and below the dew point temperature. It is common for bridge deck surfaces to develop frost when the adjacent highway surfaces do not. This typically happens in the fall and spring when these temperature conditions are satisfied, the sky is free of cloud cover, and the wind speed is calm (0 to 3 mph). The early morning hours, just before sunrise, are ideal times for bridge deck icing/frosting to occur. The prediction of these icing conditions is particularly difficult, especially for rural areas with elevation changes and varied roadside vegetation coverage. Location of Road Weather Information Systems (RWIS) sensors in these sensitive areas has been most helpful in detecting the onset of frost conditions.

Crosswind speeds in excess of about 15 mph may cause local snow drifting and inhibit anti-icing operations. Also, liquid chemical sprayers should be set closer to the pavement during windy conditions to avoid spray loss.

SITE CONDITIONS

Site conditions are those local situations that affect how snow and ice control operations are conducted. They influence type of equipment, materials choices, materials application rate, priority and sequence of treatment, and type of treatment. Table 4 is a listing of important site conditions.

TRAFFIC CONDITIONS

The influence of traffic was discussed in the Chapter 2 section on Snow and Ice Control Operational Considerations Relating to Level of Service. The traffic conditions of possible importance are listed in Table 5.

TABLE 2 Climate-related items

- Frequency of Snow and Ice Events
  – Low
  – Moderate
  – High
- Severity of Winter Pavement Exposure
  – Mild
  – Moderate
  – Severe
- Wintertime Precipitation
  – Type
  – Rate
- Urban Influence
  – Small
  – Medium
  – Large
  – Industrial
- Water Influence
  – Minor
  – River
  – Lake
  – Ocean
- Elevation/Large Scale Topography
  – Plain
  – Rolling
  – Mountainous

SUMMARY OF SNOW AND ICE CONTROL OPERATIONAL CONSIDERATIONS

Climate is an issue that is primarily of importance in the planning phase of snow and ice control operations. With minor exception, the various snow belt climate zones in North America all experience similar types of winter weather events with mixtures of precipitation classes. The difference among the climate zones is in the distribution of expected precipitation class events. Mountain climates, for example, see very few freezing rain events; however, they may see more snow events with high accumulations. The bottom line is that all snow belt maintenance forces have to be prepared to deal with all types of precipitation events.

The ability to forecast and recognize the various types of precipitation is extremely important. This influences to a large degree the type of treatment, material choice, and material application rate.

Site conditions, especially pavement temperature, snow/ice on the highway surface, and ice/pavement bond, are major factors when deciding on material type and application rate. Traffic characteristics appear to be less important than weather and site conditions; however, higher traffic volume and speed can displace snow and ice control materials from the highway surface.

TABLE 3 Precipitation definitions

Light Rain. Small liquid droplets falling at a rate such that individual drops are easily detectable splashing from a wet surface. Include drizzle in this category.
Moderate Rain. Liquid drops falling are not clearly identifiable and spray from the falling drops is observable just above pavement or other hard surfaces.
Heavy Rain. Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray from falling rain can be observed several inches over hard surfaces.
Freezing Rain. When rain freezes upon impact and forms a glaze on the pavement or other exposed surfaces.
Sleet (Ice Pellets). Precipitation of transparent or translucent pellets of ice, which are round or irregular in shape.
Light Intensity of Sleet: Scattered pellets that do not completely cover an exposed surface regardless of duration. Visibility is not affected.
Moderate Intensity of Sleet: Slow accumulation on ground. Visibility reduced by ice pellets to less than 7 mi (13 km).
Heavy Intensity of Sleet: Rapid accumulation on ground. Visibility reduced by ice pellets to less than 3 mi (5.6 km).
Light Snow. Snow alone is falling and the visibility is greater than 1/2 mi (0.9 km).
Moderate Snow. Snow alone is falling and the visibility is greater than 1/4 mi (1/2 km) but less than or equal to 1/2 mi (0.9 km).
Heavy Snow. Snow alone is falling and the visibility is less than or equal to 1/4 mi (1/2 km).
Blowing Snow. When fallen snow is raised by the wind to a height of 6 ft (1.8 m) or more and is transported across a road.
None. No precipitation or blowing snow.
NOTE: An estimate can be made of the moisture content of falling snow as follows: 1 = powder snow 2 = ordinary snow 3 = wet/heavy snow

[a] Definitions taken from *Federal Meteorological Handbook (FMH)* No. 1 (*6*).

TABLE 4 Site conditions

- Area Type
  – Urban
  – Suburban
  – Rural
- Special Highway Segment Areas
  – Hills
  – Curves
  – Grades
  – Intersections
  – Bridges
  – Sags
  – Ramps
  – Crosslopes
  – Weaving Areas
  – Narrowings
  – Roadway Widenings
  – Elevated Roadways
  – Pavement Surface Types
  – Tangents
- Shadings from Solar Influence
  – Forest/vegetation
  – Buildings/structures
  – Cuts
- Pavement Conditions
  – Temperature
  – Ice/pavement bond
  – Frost or thin ice
  – Slush, loose snow, packed snow, thick ice

TABLE 5 Traffic conditions

- Traffic Volume
  – Very low
  – Low
  – Medium
  – High
  – Very high
- Commercial Vehicle Mix
  – Low
  – Moderate
  – High
- Vehicle Speeds
  – Low
  – Moderate
  – High

CHAPTER **4**

PERFORMANCE-BASED LEVEL OF SERVICE

The definition of terms, concepts, and a suggested Pavement Snow and Ice Condition (PSIC) rating system were described in Chapter 2 in the section entitled Performance Measuring of Level of Service (LOS). When defining LOS goals, two time frames relative to a winter weather event need to be considered:

- Within-winter weather event and
- After-end-of-winter weather event.

Higher LOS are associated with "better" within-event pavement ice conditions and more rapid achievement of "better" or "bare" pavement conditions after the event ends.

THE "DESIGN" WINTER WEATHER EVENT

A winter weather event having a snowfall rate of "X" inches per hour should be chosen as a basis for determining what level of service can be provided with existing resources or determining the necessary resources to provide a desired level of service. "X" should be a rate that is only exceeded in "Y" percent of snowfall records in an average year (from climatological records). "Y" of about 20 percent can be selected (*7*).

WITHIN-WINTER WEATHER EVENT LEVEL OF SERVICE

A within-winter weather event has two intertwined components—the amount of loose snow/ice/slush that is allowed to accumulate between plowing cycles and the condition of the ice/pavement interface in terms of bond and packed snow/ice.

The amount of loose snow allowed to accumulate on the roadway between plowing cycles is usually the driving force for plowing resource requirements. Plowing operations are limited to one lane at a time while material spreading operations can treat more than one lane at a time. Once the allowable amount of loose snow/ice is established, the necessary equipment resource can be determined. First, the local plowing production rate in terms of lane miles per hour (including reloading and deadheading) has to be determined. This, in conjunction with design snowfall rate, yields the cycle time required to meet the "accumulation" goal. Sufficient equipment has to be provided to achieve the desired cycle time(s).

The second issue is the condition of the snow/ice pavement interface in terms of bond or packed snow/ice. This is largely a function of pavement temperature, the type of materials treatment being provided, materials application rate, and cycle time. Generally, cycle times shorter than 1.5 hours using straight chemicals and plowing will allow a high within-event level of service.

AFTER-END-OF-WINTER WEATHER EVENT LEVEL OF SERVICE

The after-end-of-event LOS is usually expressed as a time to achieve particular pavement surface conditions in terms of ice or snow coverage, or PSIC level.

ESTABLISHING LEVEL OF SERVICE GOALS

The first step in the process of establishing LOS goals is to prioritize the roadway system and particular locations within the system into some type of LOS system. This is typically a numeric, alphabetic, or color system. The next step is to assign both within-winter weather event and after-end-of-winter weather event LOS goals. These goals may be described in terms of a PSIC as shown in Table 6 or a variety of other descriptors. The final step is a reality check to ensure that sufficient capability to meet the goals for the "design" conditions is available. Table 6 is an example of LOS goals for a small roadway system.

TABLE 6 Example of level of service assignment

Highway segment		LOS class[a]	Within-event LOS		After-end-of-event LOS	
Route	Mile post		PSIC	Maximum snow accumulation (in.)	PSIC	Hours after end-of-event
15	2-25	2	3	1.5	1	2.0
8	175-186	4	5	2.0	2	6.0
16	37-51	3	4	1.5	2	3.0
5	256-271	3	4	1.5	2	3.0
2	0-4	2	3	1.5	1	2.0
10	277-291	4	5	2.0	2	6.0
10	291-315	3	4	1.5	2	3.0
4	26-32	1	2	1.0	1	1.5
4	32-50	3	4	1.5	2	3.0
Main Street	–	1	2	1.0	1	1.5
Baxer Bridge	–	1	1	0.0	1	0.0

[a] "1" is the highest; 4 is the lowest LOS class.

CHAPTER 5

STRATEGIES AND TACTICS AND THEIR APPLICATION TO SUPPORT LEVEL OF SERVICE CHOICES

As stated in the Introduction, the various roadway snow and ice control strategies used in winter maintenance operations can be classified into four general categories and are discussed in details in this chapter:

- Anti-icing,
- Deicing,
- Mechanical removal of snow and ice together with friction enhancement, and
- Mechanical removal alone.

ANTI-ICING

Roadway anti-icing is a snow and ice control strategy of preventing the formation or development of bonded snow and ice to a pavement surface by timely applications of a chemical freezing-point depressant. The tactics employed during anti-icing operations consist of chemical applications that are coordinated with plowing.

Anti-icing is suitable for use during most weather, site, and traffic conditions. It is particularly beneficial as a pretreatment using liquid chemicals for anticipated frost and preferential icing situations. Anti-icing with a liquid chemical is a good strategy when the pavement temperatures are above about 20°F at the onset of a snowfall event. It is not a good strategy when the pavement temperatures are below about 20°F at the onset of a snowfall event, or at any freezing pavement temperatures when the snowfall event is preceded by rain. Anti-icing with liquid chemicals is not recommended during freezing rain or sleet events. Anti-icing with solid or prewetted solid chemicals is not a good strategy when the pavement temperatures are below about 15°F at the onset of a winter weather event. The use of chemicals below these minimum pavement temperatures will require excessive amounts of chemicals to be used as shown in Attachment 1.

Anti-icing can be initiated before a winter weather event or very early in the event. By continuing the strategy throughout the event there should be a very rapid recovery or achievement of a satisfactory pavement condition after the end of the event. Anti-icing produces very high within-winter weather event and after-winter weather event LOS.

DEICING

Deicing is a snow and ice control strategy of removing compacted snow or ice already bonded to the pavement surface by chemical or mechanical means or a combination of the two.

Deicing is a suitable strategy for most weather, site, and traffic conditions except when the pavement temperatures are below 20°F. Deicing operations can be accomplished at temperature lower than 20°F, but the number of chemical applications and/or chemical application rates will be excessive, as shown in Attachment 1, and the time to accomplish deicing will be long. Chemical treatments are usually initiated later in a winter weather event and continued well after the end until a satisfactory pavement condition is reached. Deicing usually produces lower within-winter weather event and after-winter weather event levels of service. Deicing usually will require more chemicals than anti-icing to produce the same LOS.

MECHANICAL REMOVAL OF SNOW AND ICE TOGETHER WITH FRICTION ENHANCEMENT

Mechanical removal of snow and ice together with friction enhancement is a strategy in which abrasives or a mixture of abrasives and a chemical are applied to the plowed or scraped roadway surface that may have a layer of compacted snow or ice already bonded to the pavement surface. This strategy is used to provide an increased level of friction for vehicular traffic, although this increase may be short lived. Abrasives, by themselves, are not ice-control chemicals and will not support the fundamental objective of either anti-icing or deicing.

This strategy has been used for many years in most snow and ice situations; however, its only real applications are in very low pavement temperature situations (about 12°F) where chemical treatments are not likely to be effective and on roads having a low traffic volume and a LOS designation. This strategy is sometimes used when agencies run out of chemical deicers.

The LOS expectation (within-event and after-end-of-event) for this strategy cannot be high unless there are significant amounts of ice control chemicals in the mixture, unless there are numerous applications of mixtures containing smaller amounts of chemicals, or unless there are very high application rates of mixes containing smaller amount of chemicals. This strategy is a viable option for unpaved roads if there is no, or very little, ice control chemical in the mixture.

MECHANICAL REMOVAL ALONE

Mechanical removal alone is a strategy that involves the physical process of attempting to remove an accumulation of snow or ice by means such as plowing, brooming, or blowing without the use of snow and ice control chemicals. This strategy is strictly a physical process.

This strategy is suitable for use in a variety of situations. It may be the only treatment rendered on unpaved or very low LOS roads. On higher LOS roads, it is effective when pavement temperatures are above freezing and snow is not bonding to the pavement. Similarly, when pavement temperatures are lower than about 12°F and snow is not bonding to the pavement, this is an effective treatment. This also may be the final treatment for a winter weather event after ice control chemicals or warming pavement temperatures have loosened any bonded snow or ice from the pavement.

TRACTION ENHANCEMENT

There are some techniques for enhancing the traction of snow/ice surfaces. Mechanical roughening, grooving, or texturing provides a small level of traction and directional stability enhancement. This technique is not suitable for higher volume roads as the effect is short lived. It may provide an option in environmentally sensitive areas with low traffic volume.

The most common technique for enhancing friction on a snow/ice surface is to apply abrasive materials such as sand, cinders, ash, tailings, and crushed stone/rock. These materials may be applied straight or with varying amounts of ice control chemical in a mixture. This is thought to make them "adhere" a little better to the surface and last a little longer. A solid form of ice control chemical may be mixed into the abrasive stockpile and allowed to age (to form a brine and coat some of the abrasive particles). A liquid chemical may be sprayed onto the abrasives while they are being applied to the road or while the stockpile is being created. Another technique for enhancing the "retention" and longevity properties is to spray the abrasives with warm water as they are being dispensed onto the road. This is reported to be quite effective.

Traction enhancement's primary role is limited to lower volume roads, situations where ice control chemicals will not likely "work," and in environmentally sensitive situations where the use of ice control chemicals must be limited. There are potential environmental impacts associated with the (excessive) use of abrasives just as there are potential environmental impacts associated with the (excessive) use of chemicals in deicing operations. Winter maintenance field personnel, as stewards of the highway and its environment, must be ever vigilant in resisting the temptation to use more snow and ice control materials than are needed for the operational conditions.

COMBINATIONS OF STRATEGIES

Combinations of strategies are almost always used. Many winter weather events present a variety of weather and pavement conditions. To deal effectively with these changes, strategies and tactics need to be adapted. The most common scenario requiring changes is when pavement temperatures fall to a low level during a winter weather event. As ice control chemicals become much less effective in colder temperatures, agencies often switch from straight chemical treatments to treatment with abrasives or mixtures of abrasives and chemicals.

Achieving stated LOS goals may require using different strategies and tactics during a single winter weather event. An example is where an agency wants a low within-winter weather event LOS and a high LOS at or after the end of a winter weather event. In this case, an agency may initially do anti-icing with ice control chemical, use only mechanical removal techniques during the event, and utilize deicing at the end of the event. The early anti-icing treatment makes the later deicing treatment more effective.

SUMMARY

Higher LOS can only be provided if snow/ice is not bonded to the pavement. There are only two mechanisms that will achieve this: (1) the use of ice control chemicals and (2) favorable pavement temperatures. Using the right amount of chemical for the operational, weather, and pavement conditions is the most efficient and effective way to meet most higher LOS goals.

Warm pavement temperatures above 32°F will usually not allow light to moderate rates of precipitation to bond. Very cold pavement temperatures, lower than about 12°F, together with dry or powder snow will usually not produce ice/pavement bond. In either case, mechanical removal alone may be all that is necessary to achieve a high LOS.

There is always the potential danger of chemical residuals becoming diluted and resulting in a refreeze condition, whether at elevated or low temperatures. The material treatment design process which follows considers the impact of weather and road conditions that occur after a given treatment and before the next scheduled treatment in order to prevent refreezing of chemical solutions.

CHAPTER 6

FACTORS INFLUENCING THE CHOICE OF MATERIALS, THEIR FORM, AND ASSOCIATED APPLICATION RATES

The major factors to consider when choosing a snow and ice control materials treatment are pavement conditions, weather conditions, and the performance characteristics of the materials.

DILUTION POTENTIAL

Dilution potential is a term that relates precipitation, pavement conditions, pavement surface conditions, and operational conditions to the choice of snow and ice control material and application rate that will generally produce a "successful" result. For simplicity, dilution potential is divided into three categories: low, medium, and high.

Precipitation Dilution Potential

Precipitation dilution potential is the contribution to overall dilution potential caused by the type and rate of precipitation of a winter weather event in progress. The higher the moisture content of the event per unit or time, the higher the dilution potential.

Pavement Conditions

Pavement conditions are the properties of the pavement itself that influence snow and ice control operations. The most important of those is pavement surface temperature. Other factors that sometimes warrant consideration are severely textured pavement surfaces such as open-graded asphalt concrete surfaces and grooved or heavily textured Portland cement concrete surfaces.

Pavement surface temperature has a major effect on how ice control chemicals perform and ultimately, on the treatment decision itself. As pavement temperatures decline below about 12°F, most ice control chemicals become very inefficient because of the slow melting rate and the amount of ice melted per unit of chemical applied. Pavement temperature therefore drives the decision to plow only, plow and apply chemicals, or plow and apply abrasives (depending also on LOS goals).

Severe pavement surface texture is another factor that influences the choice of chemical application rates. It is widely known from operational experiences that chemical application rates need to be increased for severely textured pavement surfaces such as found with open-graded asphaltic concrete and newly grooved/tined Portland cement concrete. How much of an increase in chemical application rate is required for these surfaces compared to smoother surfaces for equivalent chemical performance for a range of operating conditions is a subject for further research.

Pavement type can influence solar heat absorption and ultimately pavement surface temperature at the time of treatment. Unpaved or gravel roads are not suitable for chemical treatment.

Pavement Surface Conditions

Pavement surface conditions describe any accumulations of snow and ice that may remain on the pavement at the time of treatment (after plowing). These include loose snow, packed snow, and ice. A critical surface condition is whether or not the snow or ice is bonded to the pavement surface.

Any remaining snow or ice on the roadway surface after plowing will cause chemical treatments to dilute more quickly (in addition to the dilution caused by precipitation). If the snow or ice is bonded to the pavement, considerably more chemical will have to be applied in order to achieve an unbonded condition.

Operational Conditions

The most important operational conditions influencing dilution potential are treatment cycle time and traffic. Longer cycle times allow more precipitation to accumulate on the roadway between treatments. For equivalent effectiveness, more chemical must be applied for longer cycle times.

The two traffic characteristics thought to influence dilution potential are traffic volume and traffic speed. Higher speeds and higher volume will displace ice control chemicals from the roadway.

PROPERTIES OF ICE CONTROL MATERIALS

The four basic types of ice control materials are (1) abrasives, (2) solid ice control chemicals, (3) prewet solid ice control chemicals, and (4) liquid ice control chemicals.

Abrasives

Abrasives are a vital part of most snow and ice control programs. They support lower LOS and can provide at least some measure of traction enhancement when it is too cold for chemicals to work effectively. They are suitable for use on unpaved roads and on thick snow pack/ice surfaces that are too thick for chemicals to penetrate.

When mixed with enough ice control chemical, abrasives will support anti-icing and deicing strategies; however, this is very inefficient and costly as the abrasives for the most part are "going along for the ride" while the chemical portion of the mix is doing the "work."

Solid Ice Control Chemicals

Solid ice control chemicals are a very popular treatment option for most highway maintenance agencies. They support high LOS and both anti-icing and deicing strategies. When anti-icing, they are most effective when applied early in a winter weather event, before ice/pavement bond has a chance to develop. Some snow/ice/water on the pavement will minimize bouncing and scattering of the chemicals. Field observations indicate solid chemicals may be used as a pretreatment, especially when applied at traffic speeds under about 30 mph and traffic volumes under 100 vehicles per hour.

Solid chemicals, particularly those with a "coarser" gradation or particle size distribution, are well suited to deicing operations. The larger particles are able to "melt" through snow/ice on the surface and continue to cause melting at the ice/pavement interface until the ice/pavement bond is broken and the snow/ice can be removed mechanically.

The use of fine graded salt during anti-icing operations generally is not cost effective compared to the use of coarse graded salt (*8*). This is true for most forms of frozen precipitation, including freezing rain and sleet. Fine graded salt dilutes faster than coarse graded salt and has to be reapplied more often and at greater rates during a winter weather event than does coarse graded salt to achieve a similar chemical effectiveness. The fast brine generation of fine graded salt when applied to a pavement will produce a wet pavement sooner than coarse graded salt, but the condition will not be long lasting. This situation can quickly lead to a refreeze of the brine solution unless additional salt applications are made.

The use of fine graded salt is better suited for the treatment of thin ice and, when prewetted, as a pretreatment for frost conditions when applied just prior to daylight.

Fine graded salt applications are not well suited for deicing operations because of the high dilution potential.

Solid ice control chemicals are often mixed in small quantity (less than 10 percent) with abrasives to prevent "chunking" and freezing in stockpiles. They are also mixed with abrasives in sufficient quantity (greater than 20 percent) to do some ice melting.

Prewet Solid Ice Control Chemicals

Prewet solid ice control chemicals are used in the same way as solid chemicals except they are generally not mixed with abrasives. They consist of solid ice control chemicals that have been "coated" with liquid ice control chemicals by a variety of mechanisms. The water in the liquid ice control chemical starts the process of allowing the solid chemical to generate "brine" more quickly than "uncoated" solid chemical the coating also allows the solid chemical to better "stick" to the surface. This reduces bounce and scatter and accelerates deicing.

Liquid Ice Control Chemicals

Liquid ice control chemicals are generally a solution of solid ice control chemicals with water being the predominant component. They support high LOS and anti-icing strategy. They are particularly well suited to pretreating for anticipated frost/icing/black ice situations. Here, the water evaporates and the residual dry chemical is relatively immune to dispersal by traffic. Liquid chemicals are also used to pretreat roadways prior to a general snow or ice event. This is an effective way to initiate the anti-icing strategy.

Since liquid ice control chemicals are mostly water, they are already fairly well diluted. They are not well suited to deicing operations as they have little ability to penetrate thick snow ice. However, they may be used in limited situations for deicing if the treatment is immediately followed by an application of solid chemicals or the process is reversed. The Illinois DOT has reported success with a deicing strategy that utilizes approximately 250 lb/LM (lane mile) dry salt applied on top of compacted snow followed immediately by 30 to 50 gal/LM of liquid salt or calcium chloride with air temperatures above 10°F and sunny conditions (*9*). This is a variation of prewetting.

Liquid chemicals are probably not a good choice at pavement temperatures below about 20°F. Here, the limited ice melting ability of most chemicals would make application rates excessive and potentially cause refreeze if the pavement was not dried by traffic or other atmospheric mechanisms.

Liquid chemicals, as a within-winter weather event treatment, should be limited to lower moisture content events, pavement temperatures above 20°F, and cycle times less than about 1.5 hours. This will minimize the risk of ice/pavement bond formation. It is not advisable, however, to use liquid chemicals during moderate or heavy snow, sleet, and freezing rain events.

At pavement temperatures higher than about 28°F, liquid chemicals are a very effective treatment for thin ice in the absence of precipitation. The ice melting process in this situation is almost immediate.

CHAPTER 7

RECOMMENDED SNOW AND ICE CONTROL PRACTICES

The goal of effective snow and ice control programs should be to provide the highest LOS possible within the constraints of available resources and environmental responsibility. LOS goals are viewed from the time frames of within-winter weather event and after-end-of-winter weather event. After-event LOS is sometimes a moving target due to blowing and drifting snow conditions. In this case, those conditions may be considered to be part of the event.

In general, higher within-event LOS can be produced with an anti-icing strategy and relatively short operational cycle times of less than 1.5 hours. As cycle times increase, there are opportunities for higher accumulations of snow and ice on the roadway prior to plowing and retreating. Thus, maintaining an unbonded pavement/snow/ice interface becomes increasingly more difficult as cycle times increase.

For the purpose of the following discussion, pavement condition LOS is divided into three categories of low, medium, and high that can be related to PSIC defined in Table 1 in the following way:

Pavement condition LOS	PSIC
Low	5 and 6
Medium	3 and 4
High	1 and 2

With respect to after-event LOS, most agencies provide treatment until "bare" pavement is achieved. The measure of LOS then becomes the time, in hours, needed to reach a high LOS (a PSIC of 2 or 1). Again, for the purpose of this discussion, after-end-of-event LOS is divided into the three categories of low, medium, and high in the following way:

After-event LOS	Time (hr) to achieve a PSIC of 2 or 1
Low	>8.0
Medium	3.1–8.0
High	<3.1

STRATEGIES AND LEVEL OF SERVICE

Table 7 shows the expected LOS levels that can be achieved within- and after-winter weather events from various snow and ice control strategies and from tactics. For convenience, each strategy/tactic is described again below. It must be recognized that these are general approaches and changing conditions within an event often necessitate changes in strategies and tactics.

Anti-icing

Anti-icing is a general strategy that attempts to prevent the formation of ice/pavement bond by the timely application of ice control chemicals. Chemicals may be applied before the event (pretreating), early in the event, and as necessary throughout the event. This strategy generally produces high LOS during and after the event.

Deicing

Deicing is a strategy of allowing ice/pavement bond to form during an event and periodically treating it with chemicals until the ice/pavement bond is broken and snow/ice can be mechanically removed or displaced by traffic. This strategy generally produced low to medium within- and after-event LOS.

Mechanical

Mechanical removal is the displacement of snow/ice from the roadway by plows, rotary plows (snow blowers), brooms, and other mechanical means. This approach, as a strategy, is capable of producing low within- and after-event LOS. At pavement temperatures above 32°F and below about 12°F, higher LOS may be possible with mechanical removal.

Mechanical and Abrasives

The practice of plowing snow and spreading abrasives (either straight or mixed with a small amount of chemical) is common on lower-volume roads. It also may be a necessary treatment due to low pavement temperatures. As a strategy by itself, it only is capable of producing low within- and after-event LOS unless a very warm pavement temperature above 32°F is involved that does not allow ice/pavement bond to occur.

TABLE 7 Strategies and tactics and LOS expectations

Strategies and Tactics	Within-event LOS			After-event LOS		
	Low	Medium	High	Low	Medium	High
Anti-icing			X			X
Deicing	X	X		X	X	
Mechanical	X			X		
Mechanical and Abrasives	X			X		
Mechanical and Anti-icing			X			X
Mechanical and Deicing	X	X		X	X	
Mechanical and Prewetted Abrasives	X			X		
Anti-icing for Frost/Black Ice/ Icing Protection			X			X
Mechanical and Abrasives Containing > 100 lb/LM of Chemical	X	X	X	X	X	X
Chemical Treatment Before or Early in Event, Mechanical Removal During Event, and Deicing at End of Event	X				X	

Mechanical and Anti-icing

Timely mechanical removal of snow/ice within an event, in conjunction with an overall anti-icing strategy, will produce the highest possible LOS within and after events.

Mechanical and Deicing

Mechanical removal in conjunction with a deicing strategy within an event will produce low to medium LOS within and after winter weather events. This primarily results from controlling the depth of loose snow and ice on the roadway.

Mechanical and Prewetted Abrasives

Mechanical removal plus treatment with abrasives that have been prewetted with liquid chemical is capable of producing low within- and after-event LOS. Pavement temperatures above 32°F that will not allow ice/pavement bond may allow higher LOS to be achieved. Limited research shows prewetting abrasives might produce a slightly higher LOS than a stockpile mix alone.

Anti-icing for Frost/Black Ice/Icing Protection

Use of a liquid ice control chemical for pretreating areas susceptible to frost/black ice/icing that may occur in the absence of precipitation is a proven effective anti-icing tactic that prevents ice formation. Since the ice does not form, the LOS is always high.

Mechanical and Abrasives Containing More than 100 lb/LM of Chemical

"Rich" abrasives/chemical mixtures containing more than 20 percent chemicals by weight have been used for many years. They are capable of providing all ranges of LOS, depending on pavement and weather conditions. The LOS provided is generally in proportion to the amount of chemical in the mix and the application rate. Research has shown that to produce a high LOS, a strategy of using chemicals alone will be more effective and less costly than using mixtures of chemicals and abrasives.

Chemical Treatment Before or Early in an Event, Mechanical Snow/Ice Removal During an Event, and Deicing at the End of an Event

This is a hybrid strategy suitable for lower priority roads that produces a medium after-event LOS for a small chemical investment. The initial chemical application seems to prevent a strong ice/pavement bond. This, in conjunction with the later chemical application and any solar pavement warming, leads to a fairly quick recovery. This is particularly effective when the chemicals are placed in a narrow band around the center of a two-lane crowned roadway.

TREATMENT SELECTION

When selecting treatments, the most important consideration is LOS goals. Depending on a variety of factors, the goals may change during an event.

Every snow and ice control treatment should be individually designed to produce an effect that is consistent with the LOS goals, weather conditions, pavement conditions, and available resources of the moment. Weather and pavement conditions are continually changing and may require tactical adjustments. LOS goals may be changing with the time of day and pavement conditions. Available resources may be changing with equipment breakdowns and mandatory personnel rest periods.

The actual formula or process for making wise and appropriate treatment decisions is simple. It involves using timely information on weather and pavement conditions plus having an understanding of the LOS goals and capabilities of available resources. These resources include snow and ice control strategies and tactics, materials, equipment, and manpower. Attachment 1 provides recommended guidelines for using road and weather information to make snow and ice control treatment decisions. Chapter 8 provides recommended operational guidelines for winter maintenance field personnel.

CHAPTER 8

RECOMMENDED OPERATIONAL GUIDELINES FOR WINTER MAINTENANCE FIELD PERSONNEL

This chapter presents operational guidelines for winter maintenance field personnel on the selection of appropriate snow and ice control materials and associated application rates for various combinations of operating conditions. These conditions include precipitation type and rate, pavement temperature, pavement wheelpath area condition, treatment cycle time, traffic volume, and ice/pavement bond conditions. The information presented is discussed in terms of snow and ice control strategies, and tactics and their application to support LOS choices. It also complements the previous chapters describing the factors influencing the choice of materials, their forms, and associated application rates; and the recommended snow and ice control practices.

The snow and ice control materials discussed in this chapter are solid chemicals, liquid chemicals, prewetted solid chemicals, abrasives, abrasive/chemical mixtures, and prewetted abrasives including abrasive/chemical mixtures. Plowing and other mechanical removal methods are necessary to support LOS goals and allow material treatments to be more effective. If needed, plowing and other mechanical removal methods should precede any material applications so that excess snow, slush, or ice is removed and the pavement is left wet, slushy, or lightly snow-covered when treated.

This chapter is intended as a companion and background to Attachment 1, which presents specific recommendations for using road and weather information to make snow and ice control treatment decisions. Attachment 2 then provides an example of how to select a snow and ice control treatment using the treatment design procedure in Attachment 1.

The guidance presented in this chapter and in Attachment 1 is based upon the results of the three winters of field testing of various strategy/tactic combinations by 24 highway agencies as described in the main part of this report. The guidance has been augmented with practices developed within the United States, where necessary, for completeness. State and local highway agencies engaged in snow and ice control operations on highways, roads, and streets are encouraged to use the guidance in this document as a starting point for their operations. They are encouraged also to modify the recommendations when necessary in order to accommodate local experience, specific site concerns, and highway agency objectives.

SOLID ICE CONTROL CHEMICALS

Solid ice control chemicals serve a number of functions in snow and ice control operations. They are used in anti-icing, in deicing, in mixing with abrasives, and in the production of liquid ice control chemicals.

Anti-icing with Solid Ice Control Chemicals

Solid chemicals have been used for many years in anti-icing operations. They are typically applied early in an event before ice/pavement bond forms and then periodically throughout the event. The first application is made when there is just enough precipitation on the roadway to minimize "bounce and scatter" and displacement by traffic.

Dry solid chemicals can be used to pretreat roadways before a snow or ice event if applied at traffic speeds below 30 mph and with traffic volume less than about 100 vehicles per hour. The prewetting of a solid chemical prior to spreading can improve the effectiveness of the solid chemical and help the granules adhere better to the road surface. In theory, only a sufficient amount of liquid to wet every particle of a dry chemical is required for prewetting. The actual rate to achieve this wetting will vary with the particle size distribution. In practice it has been found that 10 to 12 gallons of a sodium chloride (NaCl) solution will be sufficient for 1 ton of dry chemical of coarse gradation *(3)*. Some agencies have used three times this quantity so that the material is applied as a slurry in order to reduce losses by traffic action. Prewetted finer gradations of a solid chemical will also adhere better to the road surface. Prewetted finer gradations of a solid chemical may be successfully applied at traffic speeds below 40 mph and with traffic volumes below about 250 vehicles per hour.

The role of a gradation size of solid ice control chemicals during anti-icing operations is discussed earlier under the section dealing with properties of solid ice control chemicals.

Application rate guidance for the use of solid NaCl with anti-icing operations (unbonded case) can be found in Attachment 1.

Deicing with Solid Ice Control Chemicals

With the exception of very thin ice situations, solid chemicals are the most effective treatment for packed/bonded snow and ice. Prewetting dry solid chemical with a liquid ice control chemical further enhances performance. Coarser graded chemicals do a better job of deicing thicker snow/ice accumulations.

Application rate guidance for the use of solid NaCl with deicing operations (bonded case) can be found in Attachment 1.

Mixing Solid Ice Control Chemicals with Abrasives

The mixing of solid chemicals with abrasives has been a popular practice for many years. The primary reason for this practice is to keep stockpiles of abrasives from freezing or chunking. The amount of chemicals in stockpiles is usually less than 10 percent by weight.

It is also a common practice to mix higher amounts of chemicals with abrasives in order to improve LOS. A popular practice is to mix equal volumes of abrasives and chemical. This mixing ratio will produce a chemical content by weight of about 42 percent with most naturally occurring abrasives. This mixture is used with anti-icing and deicing operations in some circumstances; however, anti-icing and deicing can be accomplished more effectively and more cost effectively by using straight chemicals.

Producing Liquid Ice Control Chemicals with Solid Ice Control Chemicals

Liquid ice control chemicals are becoming increasingly popular with highway maintenance agencies. In most cases a significant part of the cost of the liquid chemical is in the transportation from the point of production to the maintenance facility. As liquid chemicals are typically 50 percent to 77 percent water, much of the cost is for transporting water. By purchasing solid chemicals and mixing them with water on site, significant savings can often be realized. There are systems for making "brine" that range from site-fabricated manual operations to commercially available fully automated systems. Instructions for preparing salt brine are given in the *Manual of Practice* (*3*).

Application of Solid Snow and Ice Control Chemicals

The appropriate solid chemical application rate can be selected for the prevailing conditions using the guidance in Attachment 1. However, several special factors need to be considered in the operational treatments with solid snow and ice control chemicals. The following application techniques can help optimize the treatment effectiveness for each of these factors.

Two-Lane, Two-Way Traffic Highways (One-Lane Each Way)

The most effective way to treat this highway is to spread the ice control chemical in about the middle third of the highway. The slope of the highway and traffic will distribute the chemical fairly quickly across the entire pavement. When doing simultaneous plowing operations, care must be taken not to plow chemicals off too quickly. The spreader should be set to spread only in the plowed path. If plowing is not anticipated, spread the entire middle third on the "out" run of an "out and return" route.

Multi-Lane Highways

Most agencies spread ice control chemicals on multi-lane highways at as nearly full width as possible. Care must be taken not to spread beyond the pavement limits. Narrow bands of material spread near the high edge of each lane are also effective.

Hills, Curves, and Intersections

Because of the higher traction requirements on hills, curves, and intersections, many agencies use a higher application rate on these special sections than on straight sections of highway. On lower LOS highways, these are sometimes the only areas that receive treatment. When making special treatment at intersections, it is important to carry the treatment beyond the point where traffic normally backs up in snow and ice conditions.

Bridges and Other Elevated Structures Not Resting on Earth

In the fall, bridges and other elevated structures are likely to be colder than the adjacent pavement on earth. These situations can occur when the structures are cooled by outgoing radiation to the clear night sky even as the air temperature in the vicinity is above freezing. At other times in the fall when there is a rapid, severe decrease in air temperature, the elevated structures also are likely to be colder than the adjacent pavement on earth. It is appropriate to increase the application rate on these structures so refreezing will not occur or will occur at about the same time as the surrounding pavement. Toward spring, when air temperatures are warming, structure temperatures are likely to be warmer than the surrounding pavement. Higher application rates on these structures are not necessary in these situations.

Banked or Superelevated Curves

The spread pattern should be kept on the high side of superelevated curves. As the chemical goes into solution, the brine will migrate over the remainder of the roadway.

Strong Crosswinds

When spreading in strong crosswinds situations, the spreader should be kept upwind of the intended spread location. Spreading may not be appropriate on downwind lanes when crosswind speeds are in excess of about 25 mph.

Parking Areas

Spreading ice control chemicals as evenly as possible over the entire paved area is recommended for parking areas. These areas present a unique opportunity for anti-icing with solid chemicals because traffic generally will not displace them from the surface.

Changes in Maintenance Jurisdiction or Level of Service

Sometimes, where maintenance jurisdiction or mandated LOS changes, there will be a dramatic change in pavement conditions, including slipperiness. This is a dangerous condition as it is usually unexpected. Appropriate signing should be used to alert motorists of the situation, or more correctly, transitioning of the LOS treatment should be used by maintenance.

Worst-Case Scenarios

The worst cases usually occur when the chemical treatment is quickly overwhelmed (diluted) by excessive amounts of water or ice. Blizzard conditions (i.e., intense snowfall, wind, very cold temperatures) quickly dilute ice control chemicals and render them virtually useless. If the pavement temperature going into and coming out of a blizzard is expected to be below about 12°F, then plowing–only is probably the best strategy. If it is still very cold after the blizzard, abrasives should be used as necessary until warmer temperatures will allow chemical deicing to work. If the pavement temperature throughout and after the blizzard is likely to be above 12°F, a treatment with an ice control chemical before or early in the winter weather event followed by plowing–only throughout the winter weather event, will make deicing at the end of the winter weather event more efficient and cleanup will be accomplished much quicker.

Rapidly accumulating freezing rain is another maintenance nightmare. The best strategy is to apply solid ice control chemicals, at a high rate, in very narrow bands in the high-side wheel path of each lane. This approach should produce a location in each lane that will provide enough traction to allow vehicles to stop and steer.

Getting the Application Right

Application rates for ice control chemicals are usually specified in pound-per-lane-mile (lb/LM) or kilogram-per-lane-kilometer (kg/Lkm). Spreaders are usually calibrated to deliver pounds per mile or kilograms per kilometer (the discharge rate). It is important to understand that relationship in order to ensure that the proper application rate is being used. The application rate is the number of pounds or kilograms dispensed per mile or kilometer (the discharge rate) divided by the number of lanes being treated. Table 8 demonstrates the relationship between discharge rates and application rates.

LIQUID ICE CONTROL CHEMICALS

Liquid chemicals serve a number of functions in snow and ice control operations. They are used to prewet solid ice control chemicals, abrasives, and abrasive/solid chemical mixtures to make those applications more effective. Liquid chemicals are used to pretreat and treat “colder highway spots” for frost, black ice, and localized icing. They are used as a pretreatment for general storms to facilitate higher LOS in the initial storm phase and to “buy time” until treatments with solid chemicals can be made. They may be used also as a treatment within certain low moisture winter weather events. Liquid chemicals should generally not be used for freezing rain and sleet events nor as a treatment when pavement temperatures are expected to fall below about 20°F during the period of treatment effectiveness.

Prewetting with Liquid Ice Control Chemicals

Most commercially available liquid ice control chemicals can be used for prewetting solid ice control chemicals, abrasives, and abrasive/solid chemical mixtures. The primary function of the liquid in prewetting is to provide the water necessary to start the brine generation process for the solid chemicals. When used on abrasives, they help them adhere to the ice surface and provide some ice control chemical to

TABLE 8 Correspondence between discharge rate and application rate

Discharge rate in lb/mi (kg/km)	Application rate in lb/LM (kg/Lkm) Number of lanes being treated		
	1	2	3
100 (28)	100 (28)	50 (14)	33 (9)
200 (56)	200 (56)	100 (28)	67 (19)
300 (84)	300 (84)	150 (42)	100 (28)
400 (112)	400 (112)	200 (56)	133 (37)
500 (140)	500 (140)	250 (70)	167 (47)
600 (168)	600 (168)	300 (84)	200 (56)
700 (196)	700 (196)	350 (98)	233 (65)
800 (224)	800 (224)	400 (112)	267 (75)

the roadway that may at some point improve LOS. Organic based chemicals provide some corrosion protection properties and environmental friendliness.

Pretreating for and Treating Frost, Black Ice, and Icing with Liquid Chemicals

This tactic provides arguably the best use of liquid ice control chemicals. A 23-percent solution of liquid NaCl applied at 40 to 60 gal/LM (or equivalent effective amount of other chemical) has proven to provide protection from these conditions that are nonprecipitation events. Table 9 provides the multipliers based on a liquid NaCl application rate to achieve equivalent results with other chemicals. In the absence of precipitation, these treatments are effective for at least 3 days and possibly up to 5 days depending on traffic volume. If the liquid treatment is allowed to dry before the event, it will be slightly more effective.

To use the equivalency table shown in Table 9, simply multiply the rate of a 23-percent solution of NaCl by the appropriate multiplier corresponding to the temperature range and specified chemical. For example, if the treatment were to require 100 lb/LM of dry NaCl in a 23-percent solution and assuming a temperature in the range of 20° to 18°F, then it would only take 85 lb/LM of a 32-percent solution of $CaCl_2$. However, the same temperature condition would require a rate of 194 lb/LM of a 25-percent CMA solution.

Treating frost/black ice/icing that has already occurred with liquid chemicals is an excellent tactic. Using application

TABLE 9 Multipliers for liquid chemical application rates, normalized to 100 lb/LM of dry NaCl in a 23-percent solution

Temperature range (°F)	23% NaCl	32% $CaCl_2$	27% $MgCl_2$	50% KAc	25% CMA
32-30	1.00	1.11	0.94	1.58	1.64
30-28	1.00	1.06	0.90	1.50	1.69
28-26	1.00	1.02	0.86	1.42	1.74
26-24	1.00	0.98	0.82	1.34	1.79
24-22	1.00	0.94	0.78	1.25	1.84
22-20	1.00	0.89	0.74	1.17	1.89
20-18	1.00	0.85	0.70	1.09	1.94
18-16	1.00	0.81	0.66	1.01	1.99
16-14	1.00	0.76	0.62	0.92	2.04
14-12	1.00	0.72	0.59	0.84	2.09
12-10	1.00	0.68	0.55	0.76	–
10-8	1.00	0.63	0.51	0.67	–
8-6	1.00	0.59	0.47	0.59	–
6-4	1.00	0.55	0.43	0.51	–

rates for sodium chloride found in Attachment 1 for a low adjusted dilution potential and bonded condition will provide almost immediate results.

Pretreating for and Treating General Snow and Ice Events with Liquid Chemicals

The use of liquid chemicals during general snow and ice events requires more caution and information in order to achieve satisfactory results. Liquid chemicals are more sensitive to pavement temperature, dilution, and ice/pavement bond than solid chemicals. Analytical results were generated during the study to define the time to freeze of chemical brines as a function of application rate, pavement temperature, and rate and moisture content of precipitation. A discussion of time to freeze for chemical brines follows.

Relationships Between Time to Freeze of a Chemical Brine and Controlling Variables

The nature of the relationships between the time to freeze of a chemical brine and the controlling variables can be summarized as follows:

- The time to freeze increases proportionally with chemical application rate for a given pavement temperature and rate of precipitation. This relationship is a straight-line relationship.
- The time to freeze decreases with increasing rate of precipitation for a given chemical application rate and pavement temperature. However, this relationship is not a straight-line relationship. It is of the type shown in Figures 1 through 4, where the rate of decrease is high at low precipitation rates and tapers off as the rate of snowfall increases.
- The time to freeze decreases nonlinearly with decreasing pavement temperature for a given chemical application rate and rate of precipitation. This relationship is similar to the one described in the second point above.

Sample plots of the time to freeze of liquid NaCl versus snowfall precipitation rates in terms of meltwater equivalent (WE) in inches per hour and snowfall rate in inches per hour were generated to illustrate the second point above. The times to freeze for a 23-percent concentration of NaCl versus snowfall rate are presented in Figures 1 and 2. An application rate of 100 lb/LM equivalent dry NaCl was used in both figures. Figure 1 applies to a pavement temperature range of 28°F to 31.5°F. Figure 2 applies to a pavement temperature range of 20°F to 27°F.

The times to freeze for the dried case of NaCl versus snowfall rate are presented in Figures 3 and 4. Again, an application rate of 100 lb/LM equivalent dry NaCl was used in both figures. Figure 3 applies to a pavement temperature range of

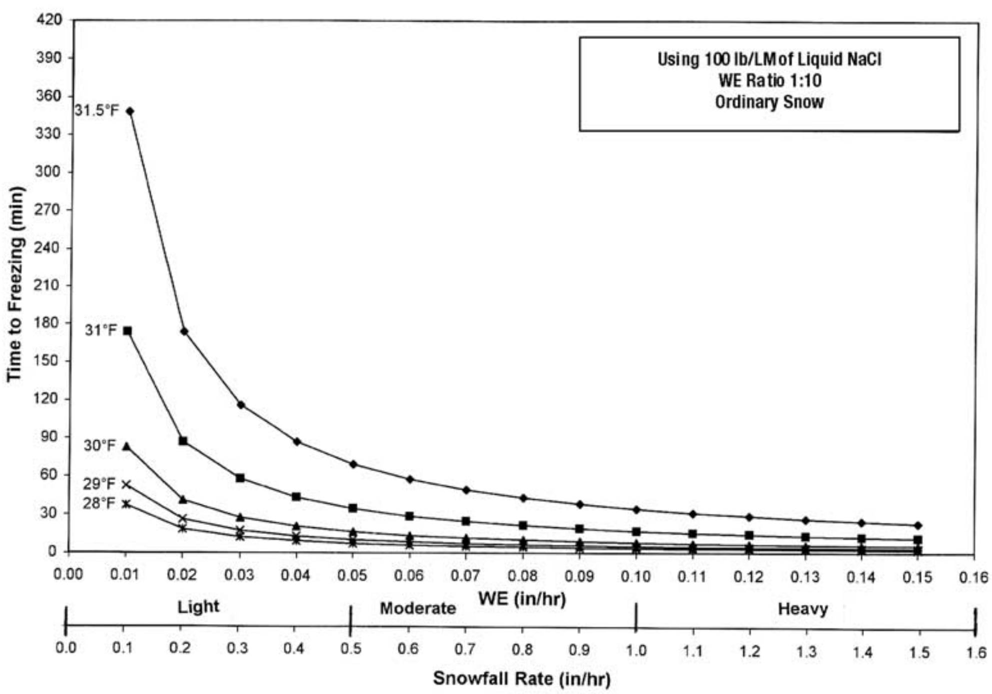

Figure 1. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 28°F to 31.5°F using 23-percent concentration liquid NaCl.

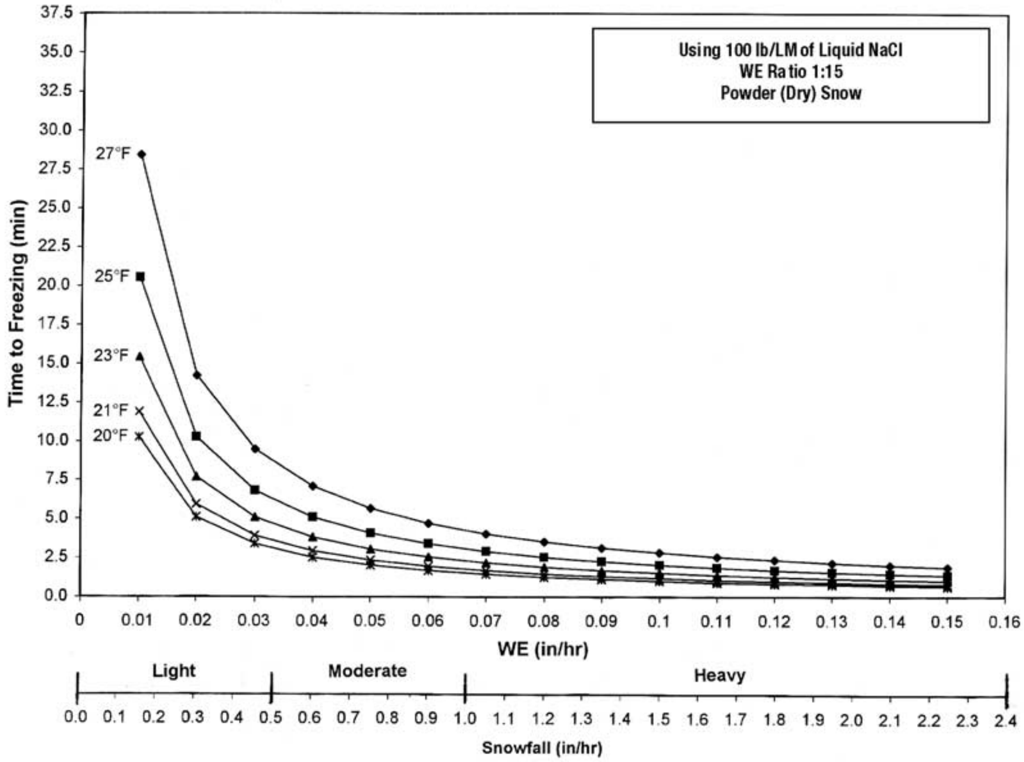

Figure 2. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 20°F to 27°F using 23-percent concentration liquid NaCl.

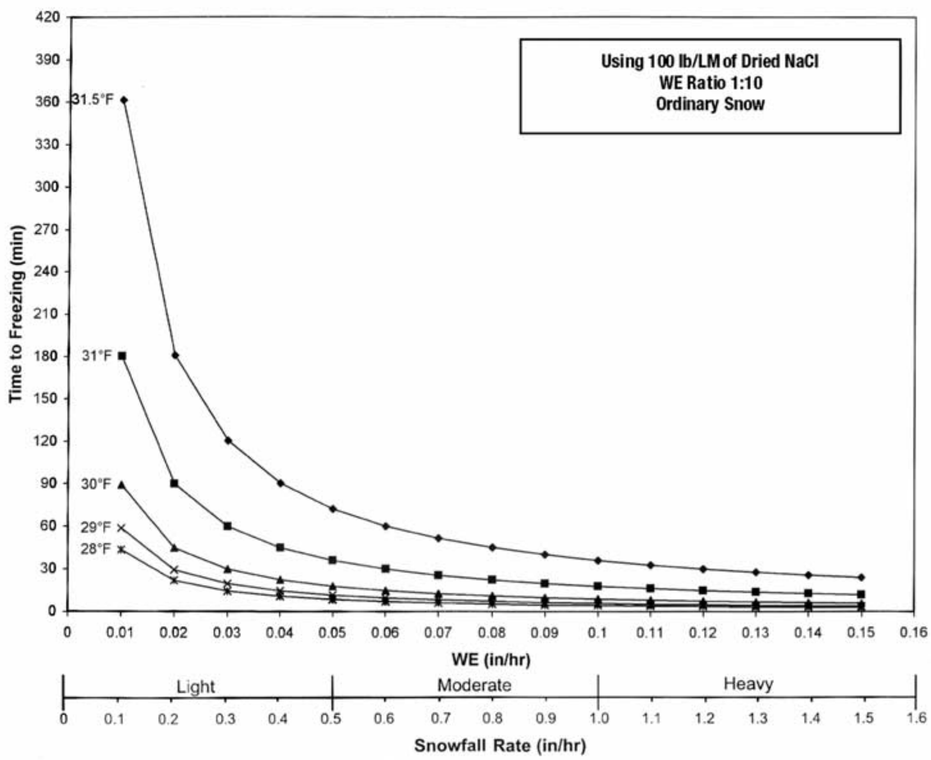

Figure 3. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 28°F to 31.5°F using dry NaCl.

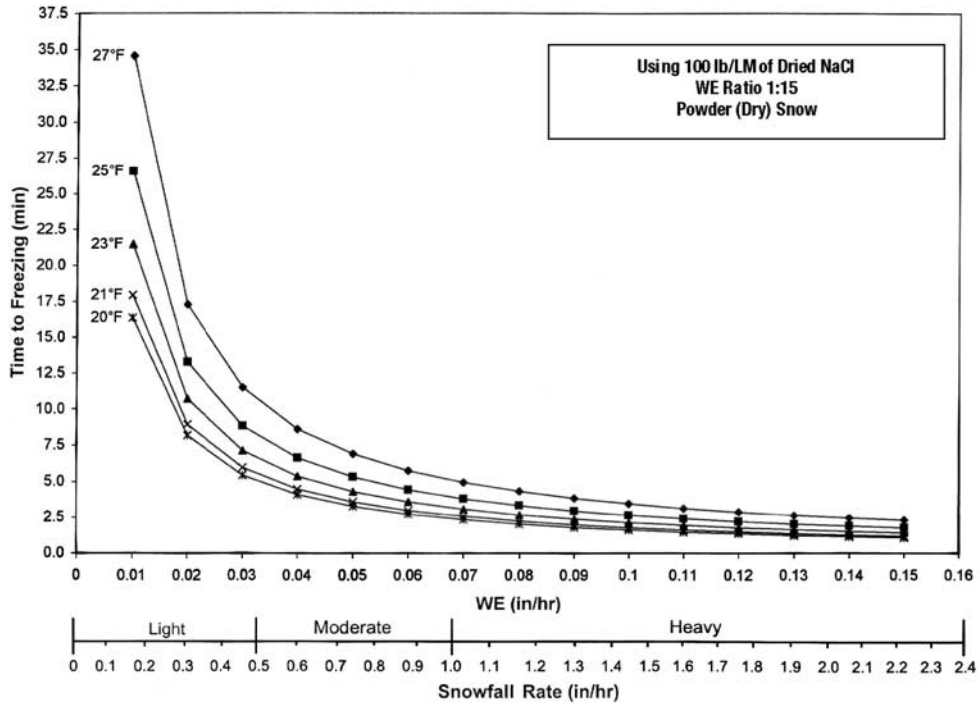

Figure 4. Time to freezing vs. WE/snowfall rate for a pavement temperature range of 20°F to 27°F using dry NaCl.

28°F to 31.5°F. Figure 4 applies to a pavement temperature range of 20°F to 27°F.

Figures 1 through 4 clearly show the limiting role that liquid chemicals play in snow and ice control operations as the pavement temperatures drop and application rates associated with anti-icing are used. The role of liquid chemicals for a given pavement temperature also diminishes as the snowfall rate increases.

The times to freezing for the "dried" state of NaCl are longer than those for the "liquid" state, all conditions being equal. The time differences between the two chemical states do not appear to be significant from an operational consideration at the upper temperature range of 28°F to 31.5°F. The time differences increase as the pavement temperature decreases. How significant the time differences are in the 20°F to 27°F temperature range is uncertain because of the small magnitude of the freezing times.

Conversion of NaCl Application Rates to Application Rates of Four Other Snow and Ice Control Chemicals

Calculations were performed to develop application rate data for calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), and calcium magnesium acetate (CMA), that were normalized with respect to the application rate data for dry solid NaCl. The ice melting characteristics of each chemical were used in the computations. The equivalent application rates for each of the five ice control chemicals are given in Table A-6 of Attachment 1 for a range of pavement temperatures. The application rates are normalized to 100 lb/LM of dry solid NaCl. The application rates corresponding to a dry solid NaCl rate other than 100 lb/LM are determined by multiplying the equivalent chemical application rates for a given temperature by the ratio of the desired dry solid NaCl rate to 100 lb/LM. For example, if a 200 lb/LM of dry solid NaCl application rate were recommended at a temperature of 20°F, then switching to a 90- to 92-percent concentration of solid $CaCl_2$ would require a slightly higher application rate of 216 lb/LM.

With the previous discussion in mind, liquid ice control chemicals can be effectively used in the treatment of general snow and ice events if the methodology given in Attachment 1 is utilized.

Applying Liquid Chemicals to Roadway Surfaces

Liquid chemicals are usually applied to the highway with spray bars or spinners. Spray bars may simply have holes in them or nozzles having various spray patterns. When using chemicals other than liquid NaCl, it is recommended that "streamer" or "pencil" nozzles or just holes in the spray bar be used to apply "strips" of chemical to the surface. The spacing of nozzles or holes should be in the range of 8 in. There have been rare circumstances when using a liquid chemical has resulted in slippery conditions in the absence of precipitation or freezing pavement temperature. This phenomenon seems to be related in many instances to the combined effect of relative humidity, pavement temperature, and chemical type. The untreated areas between strips should help minimize the potential for this type of slipperiness.

ABRASIVES

The primary function of abrasives is to provide temporary traction (friction) improvement on snow/ice surfaces. It should be realized that snow/ice covered roadways that have been treated with abrasives provide friction values that are far less than "bare" or "wet" pavement. The application rate for abrasives varies considerably among maintenance agencies. Application rates for most agencies fall within the 500 lb/LM to 1,500 lb/LM range with the overall average centering around 800 lb/LM.

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Attachment 1

Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions

Attachment 1

Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions

This Attachment contains recommended steps for using road and weather information to make snow and ice control treatment decisions. Its purpose is to define a step-by-step procedure that winter maintenance field personnel can follow in determining an appropriate treatment action to take in response to a variety of conditions.

Snow and ice control material rate guidelines are presented. These application rates are based upon results of three winters of field testing various strategy/tactic combinations by 24 highway agencies. The recommended rates apply to both state and local highway agencies engaged in snow and ice control operations on highways, roads, and streets. Appropriate application rates for solid, prewetted solid, and liquid sodium chloride are given as a function of pavement temperature range, adjusted dilution potential level, and the presence or absence of ice/pavement bond. The adjusted dilution potential level accounts for precipitation type and rate, snow and ice conditions on the road, and treatment cycle time and traffic volume conditions. The recommended snow and ice control material application rates depend on atmospheric and pavement conditions at the time of treatment and on how these conditions are expected to change over the time period (window) prior to the next anticipated treatment.

Implicit in the recommended treatment steps is the requirement that plowing, if needed, should be performed before chemical applications are made. This is necessary so that any excess snow, slush, or ice is removed and the pavement surface is wet, slushy, or lightly snow covered when treated.

When applying solid, prewetted solid, or liquid snow and ice control chemicals, the usual intent is to achieve or maintain an unbonded, bare, or wet pavement condition. The following procedure will provide a generally successful result.

STEP 1

The first step in the procedure is to determine the pavement temperature at the time of treatment and the temperature trend after treatment. A judgment, either estimated or predicted by modeling techniques, will need to be made of what the pavement temperature will be in the near term, 1 to 2 hours after treatment. This is one aspect of what is commonly called “nowcasting.” Nowcasting refers to the use of real-time data, or best information available, for very short-term forecasting. It relies on the rapid transmittal of data from RWIS installations, weather radar, patrols, and other information sources for making a judgment of the probable weather and pavement condition/temperature over the next hour or two. Nowcasts can be provided by a private weather service or performed within the maintenance agency.

The end result of this step in the procedure will be the determination of the “pavement temperature and trend.”

STEP 2

The second step in the procedure is to establish the dilution potential that a chemical treatment must: (1) endure before another treatment is made during a winter weather event, or (2) produce a satisfactory result in the absence of precipitation at the end of an event. The establishment of the dilution potential for each treatment includes consideration of precipitation type and rate (including none), precipitation trend, the presence of various wheel path area conditions, treatment cycle time, and traffic speed and volume.

The dilution potential for the precipitation at the time of treatment and its anticipated trend in the short-term is determined from Table A-1. The level of precipitation dilution potential will be either low, medium, or high. In the absence of precipitation, the dilution potential is determined from the wheel path area condition and is shown in Table A-2.

STEP 3

In the third step, an adjustment to the precipitation dilution potential shown in Table A-1 may have to be made for various wheelpath area conditions. These adjustments are given in Table A-3.

STEP 4

In the fourth step, an additional adjustment to the precipitation dilution potential may have to be made for treatment cycle time. This is the time between anticipated successive treatment passes. In the case of pretreating, it is the time between the onset of precipitation and the next anticipated treatment. These adjustments are given in Table A-4.

STEP 5

In the fifth step, an extra adjustment to the precipitation dilution potential may have to be made for traffic speeds greater than 35 mph and traffic volume greater than 125 vehicles per hour. These adjustments are also given in Table A-4. No adjustment is made for traffic volume when traffic speeds are 35 mph or below.

When making additional level adjustments to the precipitation dilution potential, an adjustment level of 1 would change a low level to a medium level or a medium level to a high level. An adjustment level of 2 would change a low level to a high level. The end result of adding various factor adjustment levels to the precipitation dilution potential is termed “adjusted dilution potential.” The final adjusted dilution potential level cannot exceed “high.”

STEP 6

The sixth and final step in the procedure is to make a judgment of whether an ice/pavement bond condition exists. This determination (yes or no) is made based on field observations or sensor data.

TABLE A-1 Precipitation dilution potential in the presence of precipitation

	Precipitation type	Precipitation rate			
		Light	Moderate	Heavy	Unknown
1.	Snow 1 (powder)	Low	Low	Medium	Low
2.	Snow 2 (ordinary)	Low	Medium	High	Medium
3.	Snow 3 (wet/heavy)	Medium	High	High	High
4.	Snow U (unknown)	–	Medium	–	–
5.	Rain	Low	Medium	High	Medium
6.	Freezing rain	Low	Medium	High	Medium
7.	Sleet	Low	Medium	High	Medium
8.	Blowing snow	–	Medium	–	–
9.	Snow with blowing snow	(Same as type of snow)			
10.	Freezing rain with sleet	Low	Medium	High	Medium

TABLE A-2 Precipitation dilution potential in the absence of precipitation for various wheel path area conditions

Precipitation	Wheel path area condition	Precipitation dilution potential
None	Dry or damp	Not applicable ("NA")
	Wet	Low
	Frost or black ice (thin ice)	Low
	Slush or loose snow	Medium
	Packed snow or thick ice	High

TABLE A-3 Adjustment table to precipitation dilution potential for the presence of various wheel path area conditions

Precipitation	Wheel path condition	Increase precipitation dilution potential by number of levels
Yes	Bare	0
	Frost or thin ice	0
	Slush, loose snow, packed snow, or thick ice	1

TABLE A-4 Cycle time and traffic volume adjustments to precipitation dilution potential (final level not to exceed "high")

Cycle time, hours	Increase precipitation dilution potential by number of levels:
0 – 1.5	0
1.6 – 3.0	1
More than 3.0	2
For traffic speeds > 35 mph Traffic volume (vehicles per hour)	
Less than 125	0
More than 125	1

The appropriate application rates for solid, prewetted solid, and liquid sodium chloride can then be determined from Table A-5 using the results from the previously described steps.

Calculations were performed to develop application rate data for calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), potassium acetate (KAc), and calcium magnesium acetate (CMA), that were normalized with respect to the application rate data for dry solid NaCl. The ice melting characteristics of each chemical were used in the computations. The equivalent application rates for each of the five ice control chemicals are given in Table A-6 for a range of pavement temperatures. The application rates are normalized to 100 lb/LM of dry solid NaCl.

A word of caution is in order concerning the use of the application rates in Table A-6. The equivalent application rates for a 23-percent concentration solution of NaCl determined from the use of Table A-6 are more conservative (larger) than those in Table A-5 for unbonded ice-pavement conditions. The liquid application rate data in Table A-6 were derived from freezing point (ice melting) data of the five chemical solutions. The liquid application rate data in Table A-5 for unbonded ice-pavement conditions were derived from field test data and include the influence of such variables as precipitation type and rate, pavement wheel path conditions, maintenance treatment cycle time, and traffic volume. As such, the equivalent application rates for the five ice control chemicals in Table A-6 should be considered as starting points in determining the appropriate rates for snow and ice control operations. Local experience should refine these values.

Two forms were developed to assist in the process of selecting an appropriate treatment chemical application rate. Form 1 shown in Figure A-1 is a weather and pavement condition sheet. Here, all relevant weather and pavement data are arrayed for various points in time of interest. These time points may be:

- shortly before a winter weather event begins
- at the onset of precipitation
- at the beginning of each treatment cycle
- at the end of an event
- at various points in time after the winter weather event

The data may come from a variety of sources. The form is intended to display all relevant weather and pavement condition data in one convenient location and format. The form could be used as a format for private sector weather forecasters to deliver their products.

Form 2 shown in Figure A-2 is a snow and ice control treatment design worksheet. It was developed to assist in determining an appropriate treatment and application rate by arraying the necessary data in a logical order.

Both forms could be easily computerized to assist in the treatment decision-making process in support of level of service requirements. An example of how to select a treatment using the treatment design procedure is given in Attachment 2.

TABLE A-5 Application rates for solid, prewetted solid, and liquid sodium chloride

Pavement Temperature (°F)	Adjusted dilution potential	Ice pavement bond	Application rate	
			Solid (1) lb/LM	Liquid (2) gal/LM
Over 32° F	Low	No	90 (3)	40 (3)
		Yes	200	NR (4)
	Medium	No	100 (3)	44 (3)
		Yes	225	NR (4)
	High	No	110 (3)	48 (3)
		Yes	250	NR (4)
32 to 30	Low	No	130	57
		Yes	275	NR (4)
	Medium	No	150	66
		Yes	300	NR (4)
	High	No	160	70
		Yes	325	NR (4)
30 to 25	Low	No	170	74
		Yes	350	NR (4)
	Medium	No	180	79
		Yes	375	NR (4)
	High	No	190	83
		Yes	400	NR (4)
25 to 20	Low	No	200	87
		Yes	425	NR (4)
	Medium	No	210	92
		Yes	450	NR (4)
	High	No	220	96
		Yes	475	NR
20 to 15	Low	No	230	NR
		Yes	500	NR
	Medium	No	240	NR
		Yes	525	NR
	High	No	250	NR
		Yes	550	NR
15 to 10	Low	No	260	NR
		Yes	575	NR
	Medium	No	270	NR
		Yes	600	NR
	High	No	280	NR
		Yes	625	NR
Below 10°F	A. If unbonded, try mechanical removal without chemical. B. If bonded, apply chemical at 700 lb/LM. Plow when slushy. Repeat as necessary. C. Apply abrasives as necessary.			

NR = Not recommended.

Specific Notes:
1. Values for "solid" also apply to prewet solid and include the equivalent dry chemical weight in prewetting solutions.
2. Liquid values are shown for the 23-percent concentration solution.
3. In unbonded, try mechanical removal without applying chemicals. If pretreating, use this application rate.
4. If very thin ice, liquids may be applied at the unbonded rates.

General Notes:
5. These application rates are starting points. Local experience should refine these recommendations.
6. Prewetting chemicals should allow application rates to be reduced by up to about 20% depending on such primary factors as spread pattern and spreading speed.
7. Application rates for chemicals other than sodium chloride will need to be adjusted using the equivalent application rates shown in Table A-6.
8. Before applying any ice control chemical, the surface should be cleared of as much snow and ice as possible.

TABLE A-6 Equivalent application rates for five ice control chemicals

	NaCl		$CaCl_2$		$MgCl_2$		KAc		CMA	
Temperature	100%* Solid	23%* Liquid	90-92%* Solid	32%* Liquid	50%* Solid	27%* Liquid	100%* Solid	50%* Liquid	100%* Solid	25%* Liquid
(°F)	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM	lb/LM	gal/LM
31.5	100	45	109	32	90	31	159	30	159	69
31	100	46	111	32	91	32	161	31	161	72
30.5	100	47	111	33	91	32	155	30	155	71
30	100	48	107	33	94	33	158	31	158	74
29	100	49	109	34	91	33	155	31	155	79
28	100	52	109	34	91	33	152	31	152	81
27	100	54	109	35	90	34	153	31	153	86
26	100	56	104	34	96	36	161	33	161	95
25	100	57	102	34	99	35	167	35	167	108
24	100	61	108	38	102	41	167	35	167	114
23	100	62	112	41	102	41	164	35	164	117
22	100	65	110	41	102	42	160	35	160	121
21	100	68	107	40	101	42	155	35	155	125
20	100	70	108	42	98	42	150	34	150	129
15	100	90	103	44	96	44	142	34	142	170
10	100	120	101	49	95	47	138	35	138	265
5	100	165	104	57	96	51	139	37	139	630

NaCl: Sodium chloride.
$CaCl_2$: Calcium chloride.
$MgCl_2$: Magnesium chloride.
KAc: Potassium acetate.
CMA: Calcium magnesium acetate.

* Typical percent concentrations of the solid and liquid forms with the balance being largely water.

General Notes:

1. The above application rates are normalized to 100 lb/LM of dry solid NaCl. The application rates corresponding to a dry solid NaCl rate other than 100 lb/LM are determined by multiplying the equivalent chemical application rates for a given temperature by the ratio of the desired dry solid NaCl rate to 100 lb/LM. For example, if a 200 lb/LM of dry solid NaCl application rate were recommended at a temperature of 20°F, then switching to a 90 to 92 percent concentration of solid $CaCl_2$ would require a slightly higher application rate of 216 lb/LM.
2. The above application rate data were derived from the freezing point (ice melting) data of the five chemical solutions. As such, the data are more conservative (larger) than field data would suggest for anti-icing operations.

Weather and Pavement Condition Sheet

Weather Data	Date										
	Time										
	Forecast (F) or Actual (A)										
	Precipitation Type										
	Precipitation Intensity (H, M, or L)										
	Percent Clouds										
	Cloud Density (H, M, or L)										
	Radiational Effects (0, + or –)										
	Air Temperature (°F)										
	Air Temperature Trend (0, + or –)										
	Wind Velocity (mph)										
	Wind Direction										
	Relative Humidity (%)										
	Dewpoint (°F)										
Pavement Condition Data	Pavement Temperature (°F)										
	Pavement Temperature Trend (0, + or –)										
	Treatment Cycle Time (hr)										
	Traffic Speed (mph)										
	Traffic Volume (vph)										
	Slush, Loose Snow, or Packed Snow in Wheelpath (Yes or No)										
	Ice Pavement Bond (Yes or No)										

Text Forecast and Other Operational Data

Figure A-1. Form 1—Example weather and pavement condition worksheet.

Agency________________________ Date___________________
Route__________________________________ Operator__________________________________

Date											
Time											
Dilution Potential	Precipitation and Trend (L, M, or H)										
	Cycle Time (0, +1, or +2)										
	Wheel Path Condition (0 or +1)										
	Traffic (0 or +1)										
	Final (do not exceed H)										
Pavement Temperature and Trend											
Ice/Pavement Bond (Yes or No)											
Recommended Treatment											

Figure A-2. Form 2—Example snow and ice control treatment design worksheet.

Attachment 2

Example of Designing a Chemical Snow and Ice Control Treatment

ATTACHMENT 2

EXAMPLE OF DESIGNING A CHEMICAL SNOW AND ICE CONTROL TREATMENT

This Attachment provides an example of how to select a snow and ice control treatment using the treatment design procedure given in Attachment 1—Using Road and Weather Information to Make Chemical Ice Control Treatment Decisions.

Assume a snow and ice winter weather event is in progress on January 16, 2002. It is 1100 hours and a treatment is being designed for immediate implementation. The available weather and pavement condition data are arrayed on Form 1 (Figure B-1).

Using the data in the column for 1100 hours on Form 1 and the data in Table A-1, go to Form 2 (Figure B-2) and complete the column for 1100 hours.

Precipitation and Trend: The precipitation is ordinary snow falling at a moderate rate. The trend is toward lighter intensity; however, we will choose the conservative approach and call it ordinary snow falling at a moderate rate. From line 1 of the Precipitation Dilution Potential Table A-1, the dilution potential is "medium." This is entered on Form 2.

Cycle Time: From Form 1, the anticipated cycle time is 2 hours. From Table A-4, the cycle time adjustment is "1." This is entered on Form 2.

Wheelpath Condition: On Form 1, there is no slush, loose snow, or packed snow in the wheelpath. From Table A-3, the adjustment for this is "0." This value is entered on Form 2.

Traffic Volume: From Form 1, the maximum traffic volume is likely to be 100 vph and the maximum speeds will be in the range of 50 mph. From Table A-4, the traffic adjustment is "0." This value is entered on Form 2.

Adjusted Dilution Potential: There is only one required adjustment of +1 level to the precipitation dilution potential of "medium." This comes from the cycle time effect and makes the adjusted dilution potential to "high." Note that even though the sum of the adjustment may exceed "high," the adjusted dilution potential cannot exceed "high."

Pavement Temperature and Trend: From Form 1, the projected pavement temperature for 1 to 2 hours after treatment is 28°F; this is entered for pavement temperature and trend on Form 2.

Ice/Pavement Bond: From Form 1, the ice/pavement bond has been determined from field reports to be "no." This is entered on Form 2.

Treatment: Using the data on Form 2 for Adjusted Dilution Potential, Pavement Temperature and Trend, and Ice Pavement Bond, go to Table A-5 and determine the proper application rate for solid sodium chloride. In this case, the appropriate application rate is 190 lb/LM of solid NaCl.

Weather and Pavement Condition Sheet

Weather Data	Date 2002	1/16	1/16	1/16	1/16	1/16	1/16	1/16			
	Time	1100	1200	1300	1400	1500	1600	1700			
	Forecast (F) or Actual (A)	A	F	F	F	F	F	F			
	Precipitation Type	OS[1]	OS[1]	OS[1]	PS[2]	None	None	None			
	Precipitation Intensity (H, M, or L)	M	L	L	L	–	–	–			
	Percent Clouds	100	100	100	100	90	70	50			
	Cloud Density (H, M, or L)	H	H	M	M	L	L	L			
	Radiational Effects (0, + or –)	0	0	0	0	+	0	–			
	Air Temperature (°F)	25	25	25	24	23	22	21			
	Air Temperature Trend (0, + or –)	0	0	–	–	–	–				
	Wind Velocity (mph)	6	7	8	8	9	10	12			
	Wind Direction	SE	S	SSW	SSW	W	W	NW			
	Relative Humidity (%)										
	Dewpoint (°F)										
Pavement Condition Data	Pavement Temperature (°F)	28	28	27	27	26	26	25			
	Pavement Temperature Trend (0, + or –)	0	–	0	–	0	–				
	Treatment Cycle Time (hr)	2.0									
	Traffic Speed (mph)	50									
	Traffic Volume (vph)	100									
	Slush, Loose Snow, or Packed Snow in Wheelpath (Yes or No)	No									
	Ice Pavement Bond (Yes or No)	No									

Text Forecast and Other Operational Data

[1] Ordinary snow.
[2] Powder snow.

Figure B-1. Completed Form 1—Example weather and pavement condition worksheet.

Agency_______________________ Date__________________
Route_________________________________ Operator_________________________________

Date		1/16/02									
Time		1100									
Dilution Potential	Precipitation and Trend (L, M, or H)	M									
	Cycle Time (0, +1, or +2)	1									
	Wheel Path Condition (0 or +1)	0									
	Traffic (0 or +1)	0									
	Adjusted (do not exceed H)	H									
Pavement Temperature (°F) and Trend		28									
Ice/Pavement Bond (Yes or No)		No									
Recommended Treatment		**190 lb/LM of solid sodium chloride**									

Figure B-2. Completed Form 2—Example snow and ice control treatment design worksheet.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation