National Cooperative Highway Research Program

NCHRP Synthesis 207

Managing Roadway Snow and Ice Control Operations

Transportation Research Board
National Research Council

ORTATION RESEARCH BOARD EXECUTIVE COMMITTEE 1994

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

National Cooperative Highway Research Program

Synthesis of Highway Practice 207

Managing Roadway Snow and Ice Control Operations

DAVID E. KUEMMEL, P.E.
Marquette University
Milwaukee, Wisconsin

Topic Panel

JAMES F. CONDRON, *Federal Highway Administration*
ERNEST N. HERRICK, *Connecticut Department of Transportation*
BRUCE A. LARSON, *Minnesota Department of Transportation*
FRANK N. LISLE, *Transportation Research Board*
BYRON N. LORD, *Federal Highway Administration*
THOMAS B. MENZIES, *Transportation Research Board*
L. DAVID MINSK, *Strategic Highway Research Program*
LELAND D. SMITHSON, *Iowa Department of Transportation*
DONALD M. WALKER, *University of Wisconsin-Madison*
DANIEL L. WALTERS, *Chevron Chemical Company*

Transportation Research Board
National Research Council

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
Washington, D.C. 1994

Subject Area
Maintenance

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials (AASHTO) initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research need to be included in the program are proposed to the National Research Council and the Board by AASHTO. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

NCHRP SYNTHESIS 207

Project 20-5 FY 1991 (Topic 23-03)
ISSN 0547-5570
ISBN 0-309-05666-7
Library of Congress Card Catalog No. 94-61902

Price: $15.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in the daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis report will be of interest to transportation agency maintenance engineers, managers, and operators and others involved with roadway snow and ice control including safety engineers, traffic engineers, and law enforcement agency personnel. It presents information on the state of the practice in managing roadway snow and ice control considering both rural and urban locations. The document describes the developments that have occurred during the past 20 years to improve winter maintenance.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board discusses winter maintenance policies and provides examples for state, city, and county agencies. Included in the discussion of winter maintenance policies are issues such as levels of service, public relations, liability for services, and experimenting with new policies. Additional information is included on estimating winter maintenance benefits and costs; personnel and management issues; weather information systems; and materials, equipment, and facilities for winter maintenance.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments.

A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

David A. Kuemmel, P.E., Director, Center for Highway and Traffic Engineering, Marquette University, was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of James F. Condron, Highway Engineer, Federal Highway Administration, Georgia Division (deceased); Ernest N. Herrick, Bureau of Highways, Connecticut Department of Transportation; Bruce A. Larson, Area Maintenance Engineer, Minnesota Department of Transportation; Frank N. Lisle, Engineer of Maintenance, Transportation Research Board; Byron N. Lord, Chief, Pavements Division, Federal Highway Administration, Research, Development, and Technology; Thomas B. Menzies, Program Officer, Transportation Research Board, who provided a substantive revision of the draft document; L. David Minsk, Senior Staff Engineer, Strategic Highway Research Program (retired); Leland D. Smithson, Maintenance Engineer, Iowa Department of Transportation; Donald M. Walker, Program Director, University of Wisconsin-Madison, Transportation Information Center; and Daniel L. Walters, Business Manager, Deicing Technology, Chevron Chemical Company.

The Principal Investigators responsible for the conduct of this synthesis were Sally D. Liff, Manager, Synthesis Studies, and Stephen F. Maher, Senior Program Officer. This synthesis was edited by Linda S. Mason, assisted by Rebecca B. Heaton.

Scott A. Sabol, Senior Program Officer, National Cooperative Highway Research Program, assisted the NCHRP 20-5 staff and the topic panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

MANAGING ROADWAY SNOW AND ICE CONTROL OPERATIONS

SUMMARY

State and local governments in North America spend about $2 billion annually ($1.5 billion in the United States) on winter maintenance of highway facilities. An estimated 46 of the 50 states, all of the Canadian provinces, and thousands of counties and municipalities have highway snow and ice control programs. This synthesis reports on the practices and state of the art in winter maintenance in North America.

The synthesis covers many issues of importance to highway agency managers responsible for winter maintenance, who must balance budgetary constraints with demands for high levels of service, safety, and minimal effects on the environment. Fortunately, many advances have been made in winter maintenance techniques that promise to minimize environmental impacts without adversely affecting service levels, safety, and agency budgets. Considerable progress has been made during the past 20 years in areas such as alternative deicing materials, anti-icing methods, snow removal equipment, more accurate spreaders, weather forecasting models and services, and road weather information systems (RWIS). These advances, and their growing use by state and local highway agencies, have improved the effectiveness and efficiency of winter maintenance programs, benefitting highway agencies, users, and the general public.

Some of these advances have been introduced into North America from Europe. The application of RWIS has altered winter maintenance practices in many European highway agencies, resulting in greater emphasis on anti-icing and reduced use of deicing chemicals. European highway agencies have also spurred improvements in snow and ice control equipment. For example, chemical spreaders are used in Europe that provide accurate spreading at low discharge rates. Many European countries require rigorous testing of spreaders to ensure proper calibration of discharge before they are approved for highway use.

During the past 20 years in the United States, further research has been conducted to improve the effectiveness and efficiency of snow and ice control operations. The Strategic Highway Research Program (SHRP) has recently concluded a 5-year, $12 million dollar research program to improve snow and ice control equipment and practices. The outcome from this research effort should affect winter maintenance operations in areas ranging from snow plowing and fencing to anti-icing procedures and weather information systems. Implementation by state and local highway agencies of recommendations resulting from the SHRP program are a high priority for the Federal Highway Administration (FHWA), the American Association of State Highway Officials (AASHTO), and the American Public Works Association (APWA).

A number of states, including Iowa, Minnesota, New York, Colorado, Nevada, and Wyoming, are especially active in sponsoring research to improve winter maintenance and participating in SHRP projects and FHWA-funded research. Research by these states, as well as ideas from maintenance engineers and operators in the field, has spurred many of the advances made in winter maintenance practices and technology reported in this synthesis.

CHAPTER ONE

INTRODUCTION

BACKGROUND AND PURPOSE

The previous NCHRP synthesis on winter maintenance practices, *Minimizing Deicing Chemical Use*, was published in 1974 (*1*). In the years following, there have been many important developments including extensive testing of alternative ice control chemicals, application of road weather information systems (RWIS), widespread experimentation with no-salt or low-salt programs, and other actions to control the environmental effects of snow and ice control operations. The microcomputer revolution has also affected many aspects of winter maintenance by enhancing management systems, improving access to weather forecasting information, and aiding in the development of control systems in vehicles for spreading salt and other materials.

During the past two decades, highway agencies at all levels have come under increased pressure to reduce winter maintenance budgets. Winter maintenance programs account for a large portion of highway operating expenditures in many northern jurisdictions, costing state and local governments an estimated $1.5 billion in the United States and $2 billion in North America each year (*2,3*). As a result of pressures to contain costs, highway agencies must maintain or enhance services while minimizing budgetary and environmental impacts.

The goal of this synthesis is to identify the means by which highway agencies are achieving these objectives. A questionnaire (Appendix A) was sent to the highway agencies of 44 states, 9 Canadian provinces, and 30 counties and cities. Responses to all or most of the questions were received from the agencies of 34 states, 6 provinces, and 11 counties and cities of various sizes located in several regions.

The information collected from the questionnaire was supplemented by articles, reports, and other literature pertaining to winter maintenance practices as well as personal communications with researchers and practitioners. Other important sources of information were technical conferences and trade meetings of suppliers, practitioners, researchers, and top highway management. Some of the meetings attended included the American Association of State Highway and Transportation Officials' (AASHTO) 1991 Technology Transfer Exhibit in Milwaukee; the American Public Works Association's (APWA) 1991 and 1992 Congress and Equipment Shows in San Francisco and Boston; the Strategic Highway Research Program's (SHRP) "Train the Trainer" program in Chicago, 1992; the Transportation Research Board's (TRB) 1992 and 1993 Annual Meetings in Washington, D.C.; and the 1992 Third International Symposium on Snow Removal and Ice Control Technology in Minneapolis, sponsored by TRB and the Federal Highway Administration (FHWA).

Because of the availability of hundreds of reports on all aspects of highway winter maintenance practices, equipment, materials, and techniques, it is not possible to synthesize all relevant information into one document. Therefore, several winter maintenance topics are covered in a brief and introductory manner. In these cases, references are listed to aid in obtaining more detailed information.

ORGANIZATION OF THE SYNTHESIS

The remainder of this report includes five chapters. Chapters 2 and 3 discuss policy and management issues related to winter maintenance. Chapter 2 describes how highway agencies develop and explain their overall policies for winter maintenance, including approaches to determining levels of service, handling liability issues, and ensuring that policies are understood by the public, elected officials, and agency personnel. Chapter 3 discusses how these policies are implemented by management, through development of procedure manuals, personnel practices, contracting of services, budgeting methods, and other means. Chapters 4 through 6 present the specific technologies, materials, and equipment used for snow and ice control. Chapter 4 discusses the progress that has been made in the use of weather information systems and Chapter 5 discusses new ice control methods and materials. Chapter 6 summarizes developments in winter maintenance equipment and facilities. The synthesis concludes by identifying some important research gaps. A glossary of terms used in this synthesis is provided, followed by References and by Appendix A, which contains the questionnaire.

CHAPTER TWO

POLICIES

WRITTEN POLICIES

Most large highway agencies have written policies for their winter maintenance programs. These policies are often published in a maintenance procedures manual or special policy manual or guide. The purpose of a published set of winter maintenance policies is to provide general guidance to operating personnel in implementing the winter maintenance program, to establish a legal basis for snow and ice control actions and practices, and to ensure that the public and elected officials understand and concur with the goals of the program.

Thirty-one of the 34 states responding to the questionnaire reported having policies written in a published manual or guide. All 11 of the responding counties and cities also reported having policy manuals. AASHTO's Maintenance Manual provides guidelines on what should be included in a policy manual (*4*). These guidelines and the practices of highway agencies indicate that policy manuals, as a minimum, should clearly define the program goals and the level of service provided for different classes of highways following a winter storm (level of service is discussed later in this chapter). Other types of information that may be included in the manual are general guidelines for resource allocation and budget preparation.

Maintenance policy and procedures or operations manuals differ. Illinois Department of Transportation (DOT) has combined its maintenance policy and procedures manuals into one document, although the agency has two of these combined manuals—one for the Chicago metropolitan area (*5*) and another for the remainder of the state (*6*). The separate manuals are necessary because maintenance and service demands differ significantly in the Chicago metropolitan area compared to the rest of the state, which is mainly rural. Minnesota DOT (MinnDOT) has two manuals, one for policy (*7*) and one for operations (*8*). All of the cities that responded to the questionnaire have developed combined policy and procedures manuals. The procedures manual of Barrington, Illinois contains a general statement of winter maintenance goals and objectives in the introduction (*9*). Very few other jurisdictions indicated that goals and objectives were included in their manuals. Denver's manual is more detailed, containing policies for four phases of winter maintenance operations: (1) early salting and sanding; (2) plowing, hauling, and blowing; (3) emergency circumstances that exceed agency capabilities; and (4) cleanup objectives (*10*).

POLICY MANDATES AND DIRECTIVES

Some winter maintenance policies are mandated or directed by legislation. Agencies in California, Minnesota, and Nevada reported that their state legislatures have passed laws that significantly affect winter maintenance policies. The California Department of Transportation (Caltrans), for example, is required by statute to submit a plan for reducing salt (sodium chloride) use levels to the yearly averages for the 1976 to 1988 time period or replace salt with environmentally safe deicing methods.

Statutes in Minnesota require MinnDOT to establish policies and practices to "minimize the harmful or corrosive effects of salt or other chemicals upon vehicles, roadways, and vegetation; reduce the pollution of waters; and reduce driving hazards resulting from chemicals on windshields" (*7*). The 15-year-old statute further requires state and local highway agencies to use salt and other deicing chemicals only on hills, at intersections, and on arterial roadways where vehicle traction is critical, and only if removal of snow and ice cannot be accomplished within a reasonable time by blading, plowing, sanding, or improved weather conditions. In practice, MinnDOT reports that the legislation has led to the use of salt/abrasive mixtures on all highways except some urban routes that may be treated with straight salt.

Highway agencies in Alaska, Nevada, Ohio, and Wisconsin reported that their states have considered laws that would eliminate, reduce, or alter use of ice control chemicals. During the past 25 years, the Wisconsin legislature has considered bills proposing salt bans or severe salting restrictions, but has not passed them. Denver was the only city that reported elected officials have considered such policy mandates.

LEVEL OF SERVICE (LOS) POLICIES

Most policy manuals contain information on LOS objectives, which describe how service will be maintained during winter storms on different types of highways. Twenty-eight states, 4 Canadian provinces, and all of the responding counties and cities have LOS information in their policy or procedural manuals. Of the 6 states and 2 provinces responding that do not, most have written LOS policies in other documents.

LOS policies vary greatly by agency. Some agencies have results-oriented policies that specify how different classes of highway should appear after snow and ice control treatments (i.e., bare or black pavement, or clear wheel tracks). Others have resource-oriented policies that specify the level of equipment usage, salting rates, and hours of coverage that should be provided on each highway type. Most agencies try to articulate LOS goals in sufficient detail to guide practices, while at the same time giving operating personnel sufficient flexibility to meet needs that arise under site-specific conditions.

Colorado provides a concise definition of LOS policies in its maintenance manual (*11*). The policies identify LOS criteria for three general classes of highways. The first class consists of all highways exceeding 2,500 ADT (average daily traffic); the second consists of highways with 1,000 to 2,500 ADT; and the third consists of roads with ADT less than 1,000. LOS policies for these highways are resource-oriented, emphasizing equipment coverage for each class of highway. The first two highway classes, which are of highest priority, are given 24-hour equipment coverage until near normal surface conditions are restored. The third class is given 14-hour coverage during storms, with added coverage if weather conditions indicate roads will close or special circumstances arise, such as the need to maintain school bus routes.

Caltrans' LOS policies are more prescriptive by comparison. In its policy manual, Caltrans states that for major routes:

> Salt should be applied as lightly and infrequently as possible to prevent the formation of snow pack. During light traffic periods, it is expected that ... controls will be needed during most storms. At other times, it may mean measured application of salt to prevent icing, or remove chain controls to prevent long delays. Carefully measured applications of salt will be applied at or near the end of storms to quickly return the major route to bare pavement. Where there is little sensitive roadside vegetation and large traffic volume not carrying chains, snow removal operations will strive for continued bare pavement and very infrequent application of chain controls. Salt will be used as needed under these conditions, but with careful control so as not to use excessive amounts. Service levels on lower priority routes in California allow for chain controls during storms with little use of salt (*12*).

Wyoming's LOS policies are more results-oriented. The agency's policy manual provides guidelines for servicing highways according to several general levels of condition. The manual states that high-volume roads should be maintained bare; medium-volume roads should be maintained open; low-volume roads should be maintained for reduced-speed roads, and seasonal roads can be closed (*13*). High-volume roads include freeways and primary routes, while the seasonal roads include mountain roads that are closed during heavy snowfall. The policy does not prescribe how these LOS conditions should be achieved, although Wyoming has established some general policies regarding the use of salt and abrasives.

Illinois DOT has moderately detailed LOS policies that tend to be results-oriented. In its maintenance manual, the agency defines three highway classes—A, B, and C. For Class A highways, which are high-volume, the goal is to achieve clear wheel tracks as quickly as is practical during a storm, and to clear the entire lane as quickly as practical following a storm. The goal for Class B highways is to keep the roadway open to traffic if possible, clear wheel tracks as soon as practical after a storm, and clear the entire roadway when conditions become favorable. For low-volume Class C highways, the policy is to keep pavement open to traffic and achieve clear wheel tracks after a storm, accepting the condition that temporary blockage may occur because equipment is being used on Class A and B roads (*6*).

Many agencies have service policies that emphasize both desired results and resources to be used according to highway class. Minnesota's LOS guidelines, shown in Table 1, define five highway types based on traffic levels (annual average daily traffic (AADT)), each with different equipment coverage times (hours per day) and recommended pavement conditions (*7*). Columbus, Ohio has LOS policies that contain both performance and coverage guidelines. For each of four classes of roads ranging from freeways to residential streets, the city has defined thresholds for acceptable snow levels, times for service completion, and pavement condition. Among other cities that reported their LOS policies, Milwaukee has service guidelines that call for sufficient equipment

TABLE 1
MINNESOTA'S LEVELS OF SERVICE (*7*)

Classification	AADT	Coverage Time (hours)	Recommended Levels of Service
Super Commuter	30,000+	24	All lanes will have substantially bare pavement before coverage time is reduced.
Urban Commuter	10,000-30,000	24	All lanes will have substannially bare pavement before coverage time is reduced.
Rural Commuter	2,000-10,000	20	The right lane on divided roadways and both lanes on two land roads will have bare wheel paths with intermittent bare pavement before coverage time is reduced. The left lane on divided roadways will have intermittent bare wheel paths with sanded hills and curves.
Primary	800-2,000	18	Both lanes will have intermittent bare wheel paths with sanded hills and curves before coverage time is reduced.
Secondary	<800	12	One wheel path in each lane willhave intermittent bare pavement with sanded hills and curves before coverage time is reduced.

to complete the first salting treatment of main highways in 90 minutes and a plow pass on all streets within 12 hours of a plowable storm under normal conditions. Denver specifies that service on residential streets should consist of a single plow pass down the middle of the roadway with no salt or sand applied (*10*).

Some agencies use more elaborate methods to establish and implement LOS policies. Ontario is developing a model for determining snow and ice control input needs to achieve various levels of service on its highways under different storm conditions (unpublished report from TRB's Third International Symposium). Highway agencies in Finland have highly defined standards for service quality by highway class (*14*). Maintenance engineers are given photographs of major roadways that illustrate how driving surfaces should appear, and the engineers use these as guidelines for practice. In addition, snow conditions on the roadway, including evenness and wetness, and pavement skid characteristics are monitored using a portable testing device. These conditions are compared to conditions considered acceptable for each class of highway and level of service (Table 2).

EXPLAINING WINTER MAINTENANCE POLICIES TO THE PUBLIC

Some highway agencies employ public relations programs to explain winter maintenance policies, including levels of service,

TABLE 2
FINLAND'S QUALITY STANDARD FOR WINTER MAINTENANCE (*14*)

Quality class variable	Level of service				
	1	2	3	4	5
SLIPPERY CONDITION					
Skid number	0.00-0.15	0.15-0.25	0.25-0.30	0.30-0.45	0.45-1.0
Road surface texture	Very icy driving or otherwise very slippery	Dry ice or snow path	Coarse ice or snow path in cold weather	Bare and wet or paths between traffic ruts	Bare and dry
SNOW CONDITION					
Dry frozen snow	> 50mm	≤ 50mm	≤ 30mm	≤ 20mm	--
Thawing snow	> 40mm	≤ 40mm	≤ 25mm	≤ 15mm	--
Slush	>130mm	≤ 30mm	≤ 20mm	≤ 10mm	--
Drifting snow	Easy passage may be difficult in some places, car may become stuck in a snowdrift	Projections over the road or moderate snow layer at the road edges, driving speed must sometimes be reduced	Projections here and there over the road, driving speed has to be reduced in some cases	Projections here and there to the middle of the outermost traffic lane, generally no need to reduce the driving speed	--
EVENNESS					
Ruts	> 30mm	≤ 30mm	≤ 20mm	≤ 10mm	--
Other roughness	Path very uneven, possible projecting bumps, driving speed must be reduced and uneven spots avoided	Plenty of worn spots or disturbing holes, driving speed must be reduced in some places	Path even, possible unevenness do not actually disturb driving	Thickness of path strips on the road portion under traffic ≤ 10mm	--

and to educate motorists about their responsibilities during snowstorms. About one-half of the states reported that they regularly conduct public information and preparation programs. Six of these states routinely conduct programs before and during winter maintenance operations, five do so prior to operations, and four do so during operations. The other three reported that they include winter maintenance information in other public relations programs. Three of the six provinces indicated that they regularly conduct public relations programs. Three counties and five cities also reported that they conduct programs on a regular basis.

Wisconsin DOT published a brochure entitled "Snow Plowing and Ice Control Guide," which discusses service level policies and also provides winter driving tips for motorists. The guide includes a map of highway routes color-coded according to service levels. Milwaukee has developed a pamphlet entitled "The Impact of Snow and Ice on City Travel, Street Parking, Garbage Collection and Other Related Subjects," which explains street maintenance procedures during snowstorms, including special circumstances that may arise during major storms. The pamphlet explains why streets are salted, when they are plowed, and what residents can do to assist city agencies during snowstorms. Minneapolis has a pamphlet that discusses the purpose of the city's emergency snow regulations and how parking regulations are affected during a declared emergency.

The APWA has published a brochure entitled "Fight Winter and Win—A Survival Guide for Public Officials" that explains the basics of winter maintenance to elected officials (*15*). Additional information on the public relations programs of highway agencies at the state and local levels can be found in trade publications such as *Roads and Bridges* (*16*).

The materials submitted by highway agencies indicate that the types of public relations activities employed most regularly are the following:

- Developing informational pamphlets that explain winter parking and driving procedures, such as keeping vehicles in good driving condition and using snow tires, chains, and windshield defrosters;
- Producing maps, brochures, and other means of public communication to explain LOS objectives on various categories of highways;
- Publicizing emergency planning efforts through equipment preparation and training exercises such as snow plow "roadeos";
- Reporting to the press and electronic media on snow and ice control techniques and progress of operations during storms; and
- Actively appealing for motorist cooperation in areas such as avoiding unnecessary driving, obeying parking regulations, and avoiding abandonment of vehicles.

LIABILITY FOR SERVICE

Highway agencies were asked in the questionnaire for this synthesis if they had been sued in the past 10 years for related winter maintenance activities in five areas: (1) level of service, (2) timeliness of service, (3) equipment accidents, (4) damage to private property, and (5) miscellaneous. One-half of the agencies reported that the most common lawsuit judgments involve damages to private property from plowing and other snow and ice control operations. Suits caused by equipment accidents were ranked next, with slightly less than one-half of the agencies reporting such cases. Eight agencies reported being sued for negligence in maintaining levels of service following winter storms, while nine agencies reported that they had been sued for not providing timely service.

A reference source for liability issues related to the provision of service levels is TRB's *Select Studies in Highway Law* (*17*). This document and its supplements (*18*) discuss a number of liability cases involving winter maintenance operations. Several types of liability cases are summarized below.

Reasonable Care and Known Dangerous Conditions Cases

Laws governing the provision of highway winter maintenance vary by state. Some courts have interpreted the function of maintaining safe roads to include removal of all snow and ice hazards, whereas others have been less inclusive. A general rule of thumb followed by many public agencies is that "although there is a duty to maintain the roads in a safe condition, there is no duty, in the absence of a statute, to remove general accumulations of ice and snow from the streets and highways" (*17*).

Because snowfall and ice formation are naturally occurring events, the presence of snow or ice on roadways does not necessarily cause liability. Liability potential may increase, however, if sufficient time has elapsed for an agency to take action and the action has not been taken or has been performed in a negligent manner (*17*). A number of cases have been reported involving court interpretations of reasonable care, including liability for the effects of compacted snow on guardrails, snow blowing hazards caused by plowing, and bridge ice warning and mitigation. Cases involving the latter issue provide insight into the difficulties of interpreting reasonable care.

In a 1982 Michigan lawsuit, the court recognized that icing can take place almost instantaneously and is unpredictable. Therefore, the court concluded that a sign such as Watch For Ice On Bridge provides motorists with sufficient warning. The court recognized that technology was not available to warn of ice. In another Michigan case in 1979, the court found that absence of a Watch For Ice On Bridge sign before a bridge with a known propensity to develop ice was negligent. In a 1984 Michigan case, the presence of such a sign on the Interstate system that was left in place all year was not sufficient to absolve the agency of negligence in permitting ice on the bridge, because "the value of the sign as a warning device was eroded because it was posted the entire year around" (*18*).

When an agency has actual or constructive notice of a known dangerous condition, adequate warning must be given to the motorist of the condition or it must be corrected. A Pennsylvania court deemed a highway agency negligent in a fatality when an unusual ice condition was treated but remained dangerous. This condition was known by agency officials, who did not take timely action to close the road. In a similar case in Texas, the court found the state highway agency negligent when agency personnel were aware that a bridge was icy, but failed to take timely action to warn motorists or correct the condition (*18*).

Immunity from Weather Statutes and Rulings

Some states have statutes that limit agency liability related to maintenance of highways during the winter. New Jersey law provides immunity to agencies for the effects of weather conditions on highways; state law also requires warning of known dangerous conditions. In a 1986 lawsuit, a state court ruled that the former statute took precedence over the latter, providing the agency with immunity from negligence in cases involving ice conditions regardless of the agency receiving timely warning of the known dangerous conditions (*18*).

Illinois also has a statute providing highway agencies with protection from liability because of weather conditions. In 1988, an Illinois court dismissed a suit involving a municipality that created snowpiles that obscured driver visibility and contributed to an accident at an intersection. The court found that snowpiles at intersections are common in the winter, and that the municipality was protected from liability because of the state statutes (*18*).

Some state courts have granted highway agencies immunity from liability in particular cases. In a 1984 Wisconsin case involving snowpiles at an intersection, the court ruled that, under the circumstances of the case in which the agency was required to remove snow as quickly as possible for public safety reasons, the agency should not be burdened with the added responsibility of avoiding the creation of snow mounds on medians near any intersections (*18*).

Measures to Reduce Liability and Risk

One of the reasons agencies have developed written winter maintenance policies is to reduce the potential for negligence and liability (*19*). Some additional measures to reduce exposure to lawsuits are described in a 1984 report by Pennsylvania DOT (*20*). The proposed measures include vigilant recording, processing, and follow-up of complaints and timely attention to highway sections with a propensity for icing.

The expanded use of Road Weather Information Systems (RWIS, discussed in Chapter 3) by themselves may not provide highway agencies with the "fail-safe" technology to provide advance warning of bridge icing. Each bridge is unique, and the variables of weather and the accuracy of temperature sensors in the RWIS cannot be considered fail safe. This does not take away their advantages as a tool in winter maintenance but, as with any tool, practical experience needs to be applied to determine the course of action, given the provision of a site-specific forecast with RWIS (personal communication, Don Lucas, Indiana DOT, 1994).

Agencies were asked to identify the risk management techniques they practice to reduce liability. The varied responses, which are categorized in Table 3, included the following:

- Development of winter maintenance polices that define levels of service;
- Use of a weather log for recording temperatures and precipitation;
- Retainment of records of areawide treatment orders to personnel and the time and type of treatment employed on each route;
- Management review of all accident reports;
- Regular safety training for all employees; and
- Frequent safety inspection of all equipment.

An FHWA report identifies a number of potential hazard situations that require special attention during and following snow and ice control operations (*21*). The report notes that a serious hazard can be created when melting snow is allowed to run across superelevated, curved highway sections. A serious hazard can also be created when snow windrows (snow mounds) accumulate on bridge parapets and railings because melt water may run onto the deck and refreeze. The report recommends that priority attention be given to the removal of snow from these highway features, as well as from the following:

- Intersections and interchanges;
- Narrow medians, shoulders, and gore areas;
- Drains, culverts, and channels;
- Railroad grade crossings;
- Pavement obstructions;
- Obscured highway signs;
- Impact attenuators and guardrails; and
- Truck escape ramps.

EXPERIMENTING WITH NEW POLICIES

Because of concerns about the adverse effects of salting operations and budgetary constraints, some highway agencies reported that they were experimenting with new policies that affected major aspects of their snow and ice control programs. About 40 percent of the responding agencies—consisting of 13 states, 1 province, 2 counties, and 4 cities—reported having programs aimed at curtailing or eliminating salt use on some highway segments. Arkansas, Idaho, Minnesota, Nevada, Nebraska, South Dakota, and Tennessee reported trying various salt substitutes to lower salt usage.

At the local level, Glastonbury, Connecticut reported success in gradually reducing salt use throughout its system. To avoid unnec-

TABLE 3
AGENCY RISK MANAGEMENT TECHNIQUES

Risk Managements Techniques	States	Provinces	Counties	Cities
Plan with policy and LOS	27	6	2	7
Weather log each storm	13	3	2	7
Record of treatment ordered and time log	12	2	2	7
Treatment recorded each route	16	5	1	--
Record time of treatment on each route	14	3	1	6
Management review of accidents	25	5	26	--
Ongoing safety training	31	5	3	7
Periodic equipment safety inspection	30	6	3	6
Procedural manual for operations	18	3	0	7
Others	5	0	0	1

essary applications when snow and ice conditions do not occur as expected, Columbus, Ohio reported that it experimented with delayed deicer application start times, as well as delayed reapplication, but was not satisfied with resulting service levels and cost savings.

Minnesota reduced levels of service on low-volume trunk highways during the winter of 1984-1985 (*22*). Salt/sand mixtures were applied only at hazardous locations and plowing coverage was limited to 8 hours per day. Results were compared to control sections and questionnaires were used to assess public reaction. Farmers were found to be more tolerant than other citizens of the lower levels of service, and the results indicated that motorists expected a higher level of service on state-maintained highways than on county highways, even when both are relatively low-volume roads. Savings of 40 percent in annual costs were achieved by the program.

New Hampshire DOT proposed reduced levels of service in the fall of 1992 because of growing budgetary and environmental concerns. Before implementing the plan, the agency scheduled nine public forums throughout the state to discuss the reduced service levels. Opposition to the plan came from police, fire, and ambulance personnel. In addition, school officials, school bus operators, trucking firms, and local officials also raised concerns about potential service disruptions. Because of the concerns expressed during the first four forums, plans for the additional scheduled forums were canceled, and the agency withdrew the proposal (personal communication, R. Hogan, New Hampshire DOT, 1992).

The City of Madison, Wisconsin initiated its reduced salting program in 1973 and has since monitored year-round accident rates and the ratio of winter to summer accidents. The program has involved reduced salt use (replaced by abrasives) on arterials and collectors and no salt on local roads except hills and bus routes (personal communication, W. Somerfield, Director of Transportation, City of Madison, 1994). In a 1987 assessment, the agency concluded that the program was successful from a traffic safety standpoint, although concerns were expressed during severe winters (F. Jones, City of Madison Traffic Engineer, "Road Salt Reduction Studies—Status Report," June 22, 1987, unpublished).

Highway agencies in Europe have also implemented programs to reduce salt use. In Sweden, several major experiments with salt-free and low-salt snow and ice control operations were conducted during the 1980s. The experiments were initiated during the winter of 1979 when all roads were salted as usual to provide control information. Researchers studied pavement friction and other road conditions, driver speed adaptation, accessibility to heavy vehicles, corrosion, dirt spray, and driver attitudes. In later years, the roads were unsalted, partially salted, or salted as control sections. In 1985, the following findings were reported (*23*).

- Given the techniques available, it was not possible to consistently achieve an acceptable road surface without some use of salt.
- Especially troublesome weather effects on unsalted roads were caused by freezing rain and wet, new snow on previously frozen road surfaces.
- Accidents increased slightly on level-grade highways, but significantly (53 percent) on hilly sections. Vehicle speeds, however, were lower on unsalted and low-salt roads than those that were salted.
- Vehicle corrosion, based on test panels, was reduced by one-half on unsalted roads.

Swedish authorities conducted additional low-salt experiments during the winters of 1985 to 1991. The purpose of the experiments was to find ways to reduce the undesirable effects of salt. The research indicated that chemical deicing should be increased on main roads to avoid accidents, but that minor roads should be untreated. Recognizing that winter maintenance costs would be higher in some reduced-salt areas because of greater mechanical effort required for additional applications of abrasives, authorities developed new snow and ice control guidelines to reduce total salt use by 20 to 40 percent (*24,25*). The guidelines are shown in Figure 1.

- When chemical deicing is required, the method used should be the one with the lowest salt consumption.
- When salting to prevent ice formation (anti-icing), the salt should always be pre-wetted with 80-100 l water per m³ salt (20-25 gal water per ton of salt) if equipment for spreading a saline solution or pre-wetting salt with a saline solution is not available.
- Pre-wetted salt should not be spread wider than 4 m (4.3 yd), regardless of road width. The application rate compensates for the width to be deiced.
- Salting combined with snow plowing should only be carried out when there is a danger of compaction or freezing.
- When salting and snow plowing are combined, the salt should be spread only on the width of the road that has been cleared of snow.
- Chemical deicing is not necessary on most local roads. If possible, salt-free abrasives such as crushed stone aggregate of 2 to 5 mm (0.08 to 0.20 in.) in size should be used.
- The lowest temperatures for chemical deicing should be
  - -12°C (10°F) on national roads,
  - -8°C (18°F) on regional roads, and
  - -3°C (27°F) on local roads.
- At lower temperatures, available material with the best adhesion characteristics and durability should be used.
- Sand mixed with salt should not be used when crushed limestone, natural sand, or crushed stone aggregate are available and as effective.
- If sand mixed with salt is used, it should consist of 20-50 kg of salt per m³ of sand (17-42 lb of salt/yd³).
- Snow-clearing equipment should be adapted to the prevailing snow and temperature conditions.
- Snow should be cleared from the roads quickly. If possible, salting should be delayed until snowfall has stopped.

FIGURE 1 Swedish guidelines for minimizing salt use (*25*).

ESTIMATING WINTER MAINTENANCE BENEFITS AND COSTS

The following discussion of the benefits and costs of highway winter maintenance is based on a review of the literature. More attention has been paid to winter maintenance benefits and costs in recent years because of the large expenditure for winter maintenance and concerns about the indirect effect of chemical deicing on the environment, infrastructure, and motor vehicles. Demands that highway agencies reduce salt use to control adverse environmental effects have raised concerns about the potential effects on service levels, safety, and operations. Because a thorough discussion of the issues concerning winter maintenance benefits and costs cannot be provided in this synthesis, efforts are made to summarize information provided by the agencies that responded to the questionnaire and to identify major studies on the topic that can be referenced for futher information.

Agency Estimates

Agencies were asked to provide documentation of the effects of winter maintenance on accidents, travel times, local economies, and other areas of potential impact. The response was limited. The City of Milwaukee furnished a study of the economic benefits estimated from snow clearance during a major winter storm (*26*). Columbus, Ohio reported that in 1989, Ohio DOT calculated that highway snow and ice control efforts in the city and surrounding region provided daily savings of $784,000 in accident costs, $651,000 in delay costs, and $975,000 in lost wages and productivity costs (personal communication, L. Gomer, City of Columbus, Public Works Department, 1993).

Estimates from the Literature

Few studies have attempted to estimate both the beneficial and adverse effects of highway snow and ice control programs; instead, most have examined specific impacts, including effects on safety, local economies, and the environment.

Safety Effects

Several studies have tried to estimate the effects of winter maintenance on accident rates, although the many confounding factors affecting accident rates (e.g., changing traffic levels and weather conditions) make validation of these estimates difficult. Most of the studies have been conducted in Europe and focused on the safety effects from deicing.

A 1983 study from Sweden found that the use of special overnight deicing equipment patrols in several districts resulted in a 30 percent decline in early morning accidents compared to districts without the special patrols (*27*). A 1988 German study reported substantial reductions in accident rates after the application of salt for deicing (*28,29*). A recent study by Kuemmel for the Salt Institute, patterned after the German study, used accident and traffic data to calculate hourly accident rates before and after salt treatments on 832 km (520 mi) of two-lane highways and 80 km (50 mi) of four-lane freeways in four states. It was found that accident rates were substantially lower following salt treatments, although many potentially confounding factors such as temperature changes and the effect of plowing operations could not be assessed (*30,31*).

Other studies have attempted to show how snow and ice conditions affect highway safety. Again, most of these studies have been conducted abroad. Japan developed a model that can be used to predict the effect of snow and ice control on accident rates (*32*). The model, which correlates skid resistance with accident rates, predicts that 30 percent of winter accidents in Hokkaido, Japan are caused by snow and ice conditions. Finnish studies have concluded that the risk of accidents on main roads is 25 to 35 times greater under icy conditions than under dry conditions (*33*). A Swedish study showed a rapid increase in accident risk for small and moderate amounts of snowfall, and concluded that snowfall of more than 5 to 10 mm (approximately 0.33 in.) results in accident rates that are 3 to 5 times higher than under drier conditions (*34*).

Impacts on Local Economies and Services

In a study by Brenner and Moshman for the Salt Institute, a methodology was developed for estimating the local economic benefits of highway deicing (*35*). The 1976 study pointed to various effects that should be considered in valuing the benefits of highway snow and ice control, including reduced disruptions in emergency services, decreased worker absenteeism and tardiness, and increased business productivity. The City of Milwaukee conducted a study in 1980 that estimated the effect of a single immobilizing snowstorm on the city's economy (*26*). The impact was measured in terms of the value of irretrievably lost sales and production, lost wages, and the cost of snow-induced accidents. An estimate from the model, adjusted to 1986 dollars, indicated lost revenue to businesses of $26 million and lost wages to workers of $33 million from a snowstorm that resulted in a 5-day shutdown. It was reported that such a complete shutdown occurred in Milwaukee in 1947, resulting in estimated losses of $38 million (reported at the time) (*36*).

Kuemmel's study for the Salt Institute also estimated travel-time savings to motorists as well as other benefits, including fuel savings, from chemical deicing compared with the program expenditures for the chemical treatments and plowing (*30*). This report showed that chemical treatments were cost-beneficial after 71 vehicles used treated two-lane highways, and after 280 vehicles used treated freeways. The major benefits identified in the study, however, consisted of safety related savings that are difficult to quantify monetarily.

Effects on the Environment, Infrastructure, and Motor Vehicles

Most of the adverse effects reported from winter maintenance operations stem from the use of salt and other chloride-based materials for deicing. The literature in this area was reviewed and evaluated by a special TRB study committee in 1991 (*3*). The committee reported that the main side effects, or indirect costs of salting, are motor vehicle and infrastructure damage, degradation of the natural environment along the roadside, and sodium infiltration of drinking water. For each of these side effects the committee reached the conclusions that follow.

- Salt damages motor vehicles and infrastructure primarily because of the corrosive effects of chloride on metals. By far the most costly damage is to motor vehicles, followed by bridges and parking structures. Less obvious side effects that collectively may be significant include damage to concrete pavements, underground utilities, and roadside objects. Motor vehicle corrosion damage and protection measures related to road salting cost motorists approximately $3 to $6 billion per year. The cost of treating and preventing damage by road salt to concrete bridge decks and parking garages, caused primarily by corrosion of imbedded reinforcing steel and other bridge and highway components, totals between approximately $400 and $900 million per year.
- The most damaging effects of road salt on the natural environment are chloride injury to roadside trees and other vegetation (browning leaves, sometimes dying limbs, and dying plants) caused by salt runoff and spray; long-term sodium accumulation in soils, which can degrade soil structure and fertility (affecting erosion and plant growth); and increased salinity of surface waters. The magnitude of these effects is highly site-specific, depending on vegetation species and cover, drainage, topography, salt use, traffic levels, precipitation, and numerous other local conditions. Some highway agencies report that 5 to 10 percent of roadside trees (within 30 m (100 ft) of pavement) on heavily salted highways suffer from salt-induced damage. Soil damage usually occurs only

within the first 2 to 3 m (6.5 to 10 ft) of roadside soil, and salinity in surface water is most significant for small streams and receiving ponds near heavily salted roads. Dollar costs were not estimated for these effects.

- Road salt can enter drinking water supplies by soil into groundwater or by runoff and drainage into surface water. In general, only wells and reservoirs close to salt-treated highways or salt storage facilities are susceptible. Susceptibility depends on many factors, including salt intensity, drainage, soil type, and water volume and dilution. Salt migration to drinking water raises concerns about public health effects. Salt has been negatively associated with health primarily because of concerns about the effect of sodium on hypertension, or high blood pressure. Road salt has been found to more than double the concentrations of sodium in some wells and water supplies, usually because of poor storage practices. However, because drinking water and all other beverages account for less than 5 percent of daily sodium consumed by most people, no federal standards have been developed to aid in assessing the magnitude and potential cost of these side effects. State highway agencies spend an estimated $10 million per year mitigating complaints of road salt infiltration into water supplies.

In the questionnaire for this synthesis, several highway agencies reported corrosion and environmental costs related to snow and ice control. Five state agencies reported corrosion of winter maintenance equipment. Agencies in 4 states and 2 provinces documented vegetation effects, while agencies in 11 states and 2 provinces documented the effects of salt on groundwater or surface water. Fifteen states and all six of the responding provinces indicated they had paid for either monitoring or replacement of wells because of contamination of groundwater in wells. The most common source of contamination was runoff from salt storage facilities. Dane County in Wisconsin reported runoff problems because of salt storage facilities.

In 1992, Nevada sponsored an economic analysis of five alternatives for removal of snow and ice from approximately 120 km (75 mi) of highway in the Lake Tahoe basin (*37*). The report considered 25-year costs of various snow and ice control methods and materials, including use of state-of-the-art RWIS and anti-icing technologies. Among the costs considered were adverse impacts on the environment and motorists and effects on winter maintenance program expenditures (manpower, equipment, and materials). A summary of the cost estimates is provided in Table 4.

TABLE 4
NEVADA SUMMARY OF ALTERNATIVE SNOW AND ICE REMOVAL COSTS (*37*)

Alternative	Manpower, Materials, and Equipment	Environmental	Motorist	25 Year Total
No Change (932 tons NaCl)	$11,135,166	$20,781,788	$0	$31,916,954
	This alternative does not address the environmental concerns associated with the use of salt			
No Chemicals (0 tons chloride)	$13,785,037	0	69,010,849	82,795,886
	This alternative will produce winter road conditions worse than with traditional practice. Longer periods of snow/ice pack will increase the risk of accidents. This alternative is not recommended at this time.			
CMA (0 tons chloride)	46,975,018	0	0	46,975,018
	This alternative will produce winter road conditions similar to traditional practice. Construction of storage facilities would require a five (5) to seven (7) year implementation plan.			
NaCl with State of the Art Technology (556 tons NaCl)	13,041,150	14,538,397	0	27,579,547
	This alternative will produce winter road conditions similar to traditional practice. With state of the art technology, salt use could be reduced a minimum of 30 percent through micro-management. Implementation could be completed through a three (3) to five (5) year plan			
Alternative Chlorides with State of the Art Technology (479 tons NaCl & $MgCl_2$)	16,992,770	10,680,738	0	27,673,513
	This alternative would likely produce improved winter road conditions over those obtained with traditional practice. With state of the art technology and techniques, chloride use could be reduced approximately 50 percent. Some of the anti-icing techniques are not sufficiently refined to the point that they could be utilized on two (2) lane mountainous highways. Coupled with the need to construct liquid de-icing chemical storage facilities, implementation could be completed through a five (5) to seven (7) year plan.			

Agency Expenditures for Winter Maintenance

The most direct cost of winter maintenance is the expenditures required of state and local governments to conduct snow and ice control operations. For many local communities, winter maintenance operations account for a substantial portion of annual operating budgets. The 1991 TRB special report surveyed state highway agencies to determine expenditures on snow and ice control operations (*3*). The survey indicated that states spend about $750 million annually on manpower (40 percent of total maintenance expenditures), equipment (30 percent), and materials (30 percent) used for snow and ice control. The study further estimated that all highway agencies in the United States, including state, city, and county agencies, spend about $1.5 billion on highway winter maintenance per year. Operating costs of highway agencies are presented in Chapter 3.

CHAPTER THREE

PERSONNEL AND OTHER MANAGEMENT ISSUES

OPERATIONS MANUAL

Because advance preparation for winter maintenance is essential, most agencies have developed detailed lists of winter maintenance procedures contained in operations or procedures manuals for use by management as well as equipment operators.

An example of a highly prescriptive manual is Illinois DOT's operations manual for the Chicago area. The 150-page manual describes the duties of all personnel from the central maintenance office to equipment operators, including overtime equalization procedures, pre-season planning steps, communications practices, equipment inspection methods, and operational procedures for specific circumstances, such as driveways, mail boxes, and railroad crossings (*5*). The manual also contains details of reporting forms and provides the names and telephone numbers of personnel on call-out lists, as well as maps of jurisdiction limits on freeway ramps and frontage roads.

A more complete listing of the various types of information that are often contained in procedures manuals is provided in Figure 2.

PERSONNEL

Management Tiers

Agencies were asked to list the tiers of management from head maintenance engineer (or equivalent) to first-line supervisors. The tiers that were reported generally reflect the size of the organization. Most highway agencies at the state and province levels reported four or more tiers, whereas none of the county agencies reported more than four (Table 5). Wisconsin DOT reported eight tiers, which includes three in the central and district DOT offices and five in county agencies that are responsible for maintenance of state highways by contract with their counties.

TABLE 5
LEVELS OF MANAGEMENT*

Number of Levels	States	Provinces	Counties	Cities
2	0	0	1	0
3	3	2	1	1
4	13	12	2	2
5	1	3	0	2
6	2	0	0	3
7	2	0	0	0
8	1	0	0	0

*From state maintenance engineer or equivalent through first line supervisor.

- Summary of winter maintenance policies
- Annual calendar of key dates and events
- Procedures for assessing equipment and material needs
- Chain of command during storm mobilization
- Detailed description of service priorities
- Area maps of route and their priorities
- Summary of interagency agreements
- Weather forecast arrangements and procedures
- Personnel staff assignment and alert procedures
- Contract arrangements and procedures
- Plans for disaster events
- Personnel training schedule
- Reporting procedures
- Equipment preparation procedures
- Public relations activities
- Parking enforcement preparations and procedures
- Storm mobilization procedures
  - —Progress reporting
  - —Continuous staffing plans
  - —Overtime provisions
  - —Record keeping
- Cleanup procedures

FIGURE 2 Items found in winter maintenance operations (procedures) manuals.

Staffing Levels and Patterns

Agencies were asked to describe how they determine the number of employees needed for winter maintenance. Responses varied considerably, although 11 of the state agencies indicated that staffing is determined by the number of workers needed to operate winter maintenance equipment, and 6 agencies indicated that staffing is the same year round. When snow and ice control equipment are idle, most agencies reported that personnel are used for other tasks such as litter patrol, shop maintenance, equipment repair, or highway facility repair maintenance.

Most agencies assign one operator to each piece of equipment. Forty-three of the 51 responding agencies reported use of a single operator on spreaders, while 8 reported using two operators. Forty-two agencies reported a single operator on snow plows, while 6 reported two-person teams. Other agencies reported using combinations. Nine agencies reported using two-person teams for snowblower operations. With regard to length of shifts, an 8-hour shift limit for equipment operators was reported by 22 agencies, while 23 reported a 12-hour limit and 6 reported longer limits or none at all.

The agencies were also asked to identify their source of relief drivers when 24-hour operations are required. Several agencies provided more than one response. Twenty-three reported use of other agency employees for this purpose—10 use contractors, 15 employ part-time drivers, 3 use overtime workers, and 7 have no provisions for relief. During especially long and severe storms that tax the capacity of their personnel, 30 agencies, of which some provided more than one response, employ contractors on an emergency basis, 15 hire temporary employees, 9 rely on the National Guard, and 7 depend on resources available from other governments through mutual-aid agreements (again, multiple responses were received from some agencies). Arkansas reported splitting crews to expand the work force, while Texas calls on agency personnel and equipment from unaffected areas of the state.

Mobilization

Highway agencies usually include workforce and equipment mobilization procedures in their operations or procedures manuals. Most agencies rely on a telephone contact to initiate mobilization, although 22 agencies also reported use of paging systems. Vermont and Milwaukee reported use of computerized telephone call-out systems. The Milwaukee system, known as the Voice Response Unit (VRU), is linked with a computerized dispatch system that assigns drivers to individual pieces of equipment. The VRU communicates the assignment to drivers, therefore automating the mobilization of 350 operators used for a full-scale plowing operation (personal communication, W. Kappel, City of Milwaukee, 1992).

Tracking the Progress of Operations

Agencies were asked to indicate whether data on the progress of snow and ice control operations are routinely and formally collected. Several agencies reported that they have developed forms for reporting the progress of operations that are collected and monitored by agency supervisory personnel in most cases (Table 6). Denver has a form that is used to track the lane miles of highway serviced, including the number that have been plowed, the number that have not yet been plowed, and the number that require replowing. Milwaukee's computerized progress report form is shown in Figure 3. The form provides information on operational progress on a district and citywide basis by type of equipment operated by the city as well as contractors.

Staff Training Aids

Periodic retraining of winter maintenance personnel is often necessary because winter maintenance assignments are not full-time responsibilities. Effective training is essential to ensure efficient, economical, and safe operations.

In many cases, the agency's operations manual serves as a valuable document for instruction and training. MinnDOT's operations manual contains detailed chapters on topics ranging from the fundamentals of salt and alternatives to safety procedures (*8*). Maine DOT has prepared a special training guide for use by local government (*38*), which provides information on a number of topics, including the following:

- Types of equipment and materials used for snow and ice control;
- Handling and storage of salt, including types of storage facilities;
- Sanding techniques;
- Cleanup operations;
- Post-season activities, such as equipment storage;
- Preparation required for unexpected or extraordinary storms; and
- Calibration procedures for spreaders.

Michigan DOT also has developed a training guide (*39*) that includes similar information. The City of Milwaukee has a "Snow Plow Drivers Manual" (*40*) with diagrams and instructions for proper plowing at intersections, driveways, cul-de-sacs, dead ends, and other residential street configurations and features common to urban areas. Several of the diagrams are shown in Figures 4, 5-a, and 5-b.

Another useful aid for training workers is through demonstration shows. Snow plow "roadeos," for example, provide an opportunity for operators to refine their skills and knowledge. In these events, plow operators from several agencies compete in contests that may include written tests on traffic and safety regulations, safety inspections of vehicles, and obstacle courses of situations that can occur during operations. Information needed to organize "roadeo" events can be found in the trade literature (*41*).

A variety of videotapes are also available for training purposes. The tapes, produced by both government and industry, are available at many state technology transfer (T^2) centers. The *Snowfighters' Handbook* produced by the Salt Institute is also a valuable resource for determining spreader calibration and for making other winter maintenance equipment preparations (*42*).

BUDGETING

Twelve agencies (7 states, 4 Canadian provinces, and 1 city) reported that they are under increased pressure to reduce winter maintenance budgets. Twenty-eight agencies (20 states, 2 provinces, 3 counties, and 3 cities) reported that they are continuously under budgetary pressure or under minimal pressure partly as a result of recent mild winters (at the time of the survey).

Most highway agencies formulate their winter maintenance budgets by adjusting historic expenditure data. The agencies reported

TABLE 6
PERSONNEL INVOLVED IN REPORTING PROGRESS

Maintenance Unit	States	Provinces	Counties	Cities
Dispatcher	5	1	1	4
Supervisor	27	4	2	6
Maintenance Engineer	10	2	2	0
Other	4	1	1	2

DEPARTMENT OF PUBLIC WORKS
BUREAU OF SANITATION
PLOW EQUIPMENT/PROGRESS REPORT

2/13/93
09:16 AM

SNOWFALL __5.7"
INITIAL PLOWING REPORT

PLOWING PROGRESS		TOTAL EQUIPMENT		CITY EQUIPMENT										CONTRACT EQUIPMENT		
					SENSORS		PACKERS			OTHER	END	UNI	HOLDER			END
				TOTAL	SALT	PLOW	ME	D/L	REC	TRUCK	LOADER	MOG	/BOMB	TOTAL	PLOWS	LDR
N-1		AUTH	62	42	0	15	0	14	1	6	6	0	0	20	17	3
MAINS	100%	REPT'D*	66	41		14		17	1	5	4			25	18	7
DISTS	8%	B/D	2	2		0		2						0	0	
N-2		AUTH	60	49	0	13	9	15	0	7	3	1	1	11	9	2
MAINS	93%	REPT'D*	67	53		15	3	21		12	2		0	14	8	6
DISTS	9%	B/D	2	2		0		2						0	0	
SUB-TOTAL		AUTH	122	91	0	28	9	29	1	13	9	1	1	31	26	5
MAINS	97%	REPT'D*	133	94	0	29	3	38	1	17	6	0	0	39	26	13
DISTS	9%	B/D	4	4	0	0	0	4	0	0	0	0	0	0	0	0
C-1		AUTH	51	36	0	13	0	16	1	1	2	1	2	15	11	4
MAINS	100%	REPT'D*	61	44		17	1	21	1	1	2		1	17	9	8
DISTS	12%	B/D	0	0		0		0			0		0	0	0	
C-2		AUTH	67	50	0	17	0	14	0	8	2	3	6	17	10	7
MAINS	100%	REPT'D*	71	49		12	0	19	0	10	2		6	22	13	9
DISTS	21%	B/D	0	0		0		0			0			0	0	
SUB-TOTAL		AUTH	118	86	0	30	0	30	1	9	4	4	8	32	21	11
MAINS	100%	REPT'D*	132	93	0	29	1	40	1	11	4	0	7	39	22	17
DISTS	17%	B/D	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S-1		AUTH	57	39	0	10	3	16	1	5	4	0	0	18	16	2
MAINS	100%	REPT'D*	31	17	7	3	0	4		2	0		1	14	8	6
DISTS	12%	B/D	0	0				0		0				0		
S-2		AUTH	65	46	0	16	3	16	0	3	5	1	2	19	17	2
MAINS	95%	REPT'D*	47	25		18	0	4	.	1	0		2	22	16	6
DISTS	7%	B/D	0	0		0		0						0	0	
SUB-TOTAL		AUTH	122	85	0	26	6	32	1	8	9	1	2	37	33	4
MAINS	98%	REPT'D*	78	42	7	21	0	8	0	3	0	0	3	36	24	12
DISTS	10%	B/D	0	0	0	0	0	0	0	0	0	0	0	0	0	0

CITY-WIDE SUMMARY

PLOWING PROGRESS		TOTAL EQUIPMENT		CITY EQUIPMENT										CONTRACT EQUIPMENT		
				CITY	SENSORS		PACKERS			OTHER	END	UNI	HOLDER	CONT		END
				TOT	SALT	PLOW	ME	D/L	REC	TRUCK	LOAD	MOG	/ BOMB	TOT	PLOW	LOAD
CITY-WIDE		AUTH	362	262	0	84	15	91	3	30	22	6	11	100	80	20
MAINS	98%	REPT'D*	343	229	7	79	4	86	2	31	10	0	10	114	72	42
DISTS	12%	B/D	4	4	0	0	0	4	0	0	0	0	0	0	0	0
IN SERVICE			339	225	7	79	4	82	2	31	10	0	10	114	72	42

*** REPT'D = "All" vehicles which have reported. Including those that are currently broke down. Enter all percentages as decimals. EG: 26% = .26.**

FIGURE 3 City of Milwaukee's computerized snow removal operations progress report. Note: The term "sensors" refers to salt spreaders and the term "packers" refers to garbage packers used for snow plowing.

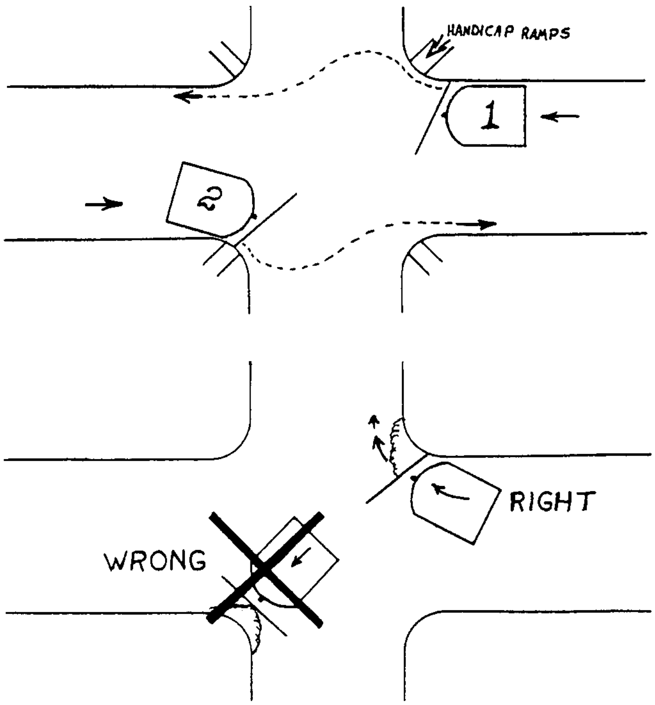

FIGURE 4 Diagrams for plowing residential streets with sidewalks and at intersections, City of Milwaukee (*40*).

a variety of expenditure monitoring capabilities that aid in budget formulation, including methods for monitoring expenditures on a route, district, and storm basis. The majority of states and provinces also reported having methods for monitoring costs on a lane-mile basis at the district level. A variety of other methods for monitoring expenditures were reported, such as per-year and per-work-hour expenditure rates, and expenditures rated by category of labor, material, and equipment used.

Agencies were asked to list the direct costs of winter maintenance per season on a lane-mile basis for the most recent budget year (primarily the 1990–91 winter). The range of costs and their averages are shown in Table 7. The wide variation in reported costs results mainly from differences in winter severity experienced by the reporting agencies, as well as differences in service level requirements.

Four agencies (three states and one province) reported using maintenance management systems that aid in budgeting. Although many more agencies are likely to have these systems, the questionnaire did not cover this topic thoroughly. Pennsylvania DOT (PennDOT) uses a winter index system that compares historic maintenance costs controlling for variations in temperature, weather, precipitation, and other winter severity factors (*43*). The indexing system was developed by PennDOT in the early 1980s to compare the impact of weather conditions on winter maintenance costs. Considered in the index are total inches of snowfall and its duration, number of days with snowfall, number of days with high and low temperature above or below 0°C (32°F), and total hours in the period when snow or ice occurs. PennDOT found that the severity index correlated strongly with the number of premium hours paid to maintenance personnel, and this was found useful for budgeting and cost control purposes.

Similar indices have been developed elsewhere and reported in the literature. For example, an application of the Hulme Index in Cheshire County, England is described in *Better Roads* (*44*). This index was developed in 1982 to compare high and low temperatures and snowfall levels over a 50-year period (*45*). The index was used in Cheshire County to determine the expected future benefits of applying road weather information technologies by using historic expenditure data adjusted for winter severity. A winter index, used to compare winter maintenance costs in successive winters, was developed for SHRP (*46*).

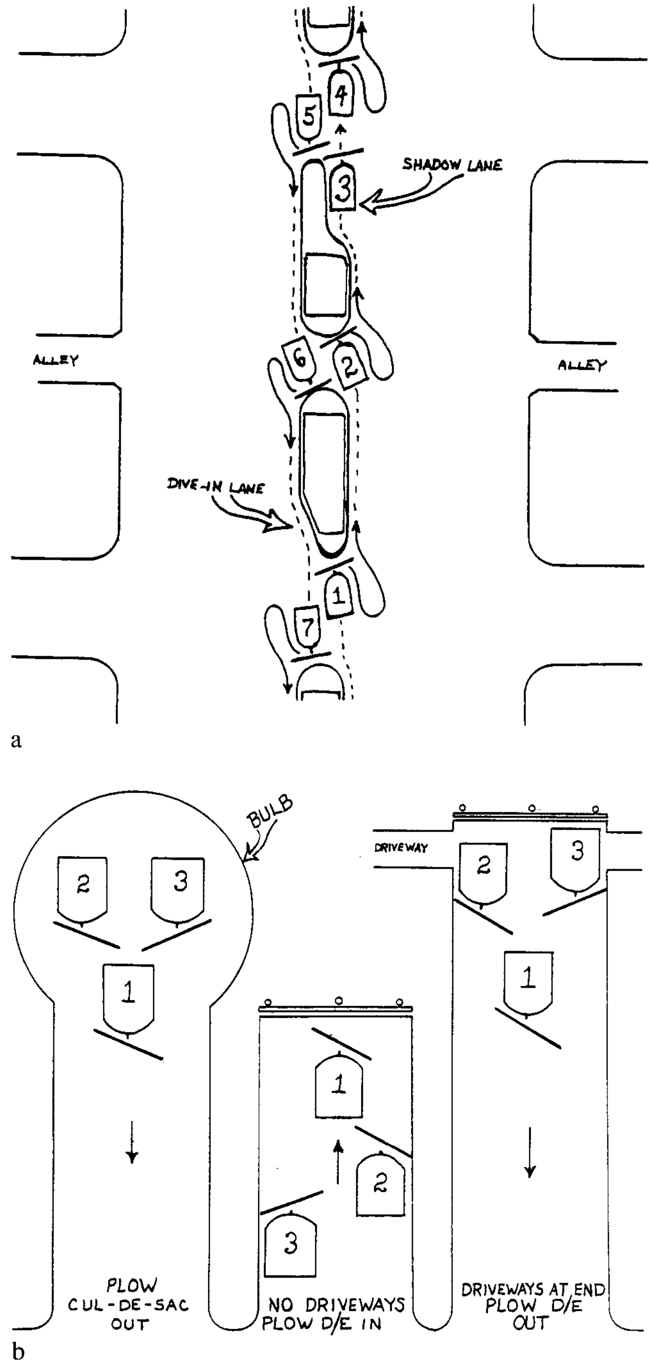

FIGURE 5 Diagrams for plowing from City of Milwaukee's "Snow Plow Drivers Manual" (*40*): (a) residential streets with shadow and dive-in (short left turn) lanes; (b) residential streets with cul-de-sacs and dead ends.

TABLE 7
REPORTED COST OF WINTER MAINTENANCE (1990–91 SEASON OR 1991 CALENDAR YEAR)

Agencies	Number Reporting	Range of Costs $/lane-km	Range of Costs ($/lane-mi)	Average Cost $/lane-km	Average Cost ($/lane-mi)
States	29	$3[1]-1,438[2]	($5-2,300)	$396	($634)
Provinces[3]	6	$500-1,780	($800-2,850)	$1,395	($2,232)
Counties	0	N/A		N/A	
Cities	6	$215-922	($345-1,475)	$624	($998)

[1]A state with a small part of the road system open to traffic under winter conditions.
[2]A state that includes substantial supervisory costs in its direct cost, and has severe winter weather.
[3]In U.S. dollars.

CONTRACTING SERVICES

Twenty-six of the 34 responding state agencies indicated that they almost always use their own personnel and equipment for winter maintenance. Three agencies reported using contract services to meet approximately 10 percent of their needs. New York DOT contracts approximately 25 percent of its needs, Connecticut 28 percent, and Maryland 50 percent. Wisconsin delegates most winter maintenance responsibilities to its 72 counties, providing funding support, management, and training assistance. New Hampshire reports using its own forces, contract services, and local governments to provide winter maintenance.

Four of the responding provinces reported that they perform most of their own winter maintenance, while Ontario and the Northwest Provinces contract for 35 to 43 percent of their winter maintenance needs. All of the counties and five of the cities reported that they seldom or never contract for winter maintenance. Schaumberg, Illinois contracts for about 10 percent of its snow and ice control services, whereas Worcester, Massachusetts contracts for more than three-quarters. Kansas City, Missouri relies substantially on contract service for snow plowing, while Milwaukee has gradually increased contract vehicles for plowing from 30 in 1982 to approximately 100 in 1992 (personal communication, J.C. Kaminski, Director of Public Works, City of Milwaukee, 1992).

Milwaukee reported that, at first, it was difficult to interest the private sector in bidding for plowing contracts. A meeting with local contractors, however, led to changes in contracting procedures, whereby base provisions in long-term (usually 6 years) contracts were added to permit monthly allowances to pay principal and interest on plowing equipment, which was paid as a monthly amount during the winter months. Hourly plowing rates for actual service are bid on in addition to the standby rate, and contractors forfeit the standby for any month in which they do not respond. Because private contractors seldom use radios with the correct frequency, they usually work in tandem with city vehicles.

In calling out contractors, Toledo, Ohio uses a five-stage response plan, only calling out contractors in stages four and five for major storms (*47*). Rochester, New York had problems with contracting for snow removal when it experienced a major snowfall in the early 1980s (*48*). Contractors hourly bid rates were substantially below the market rate during the emergency conditions. As a result, many contractors worked for private concerns during the emergency. Milwaukee reported that it has resolved this problem by permitting bid costs that are higher than the direct costs of government provision of the services to ensure that private sector resources are available to supplement agency fleets, through the above-mentioned forfeit procedure.

Ontario substantially increased its use of private contractors in the early 1980s (*49*). The contractors are used for plowing as well as some sanding and salting operations, including stockpiling, in large urban areas. Government-owned spreaders are mounted on the contractor trucks. In British Columbia, the first phase of an effort to contract for maintenance for all of the province roads and bridges was completed in 1992 (*50*). Many of the province's 2,700 maintenance employees formed corporate groups to bid for the work, and were given special treatment in contracting. Other employees joined private firms that succeeded in obtaining maintenance contracts. The province sold and leased much of its maintenance equipment and facilities to the contractors. The contracts permit significant private sector management, including determination of winter maintenance methods (mechanical, chemical, abrasives), patrol routes, and communications with the public (personal communication, J. Condron, FHWA, 1993).

PREPARING FOR SNOW DISASTERS

Agencies were asked if they are prepared to deal with winter storms that are beyond their immediate resources. Fifteen states reported they have winter disaster plans for dealing with this situation. Six of the 15 states had provisions for emergency hiring of private contractors. Most of the plans also prescribe procedures for closing roads. During especially heavy storms, Missouri withdraws its forces until the storm is over, and then reassigns crews from other parts of the state to help the hardest hit areas. Minnesota has a written policy for closing highways when crews are unable to ensure safe travel conditions (*51*). The state also has a policy guideline on responsibilities for identifying such circumstances and the duties of agency personnel (*52*).

Four of the six responding provinces reported having disaster plans. Newfoundland and Ontario close some roads to concentrate their resources, reopening them only as conditions and resources permit. The Northwest Territories contract with the private plow operators for snow and ice removal assistance during major storms.

Nearly all of the counties and cities reported having written disaster plans, indicating some reliance on the private sector and/or National Guard for severe emergencies. Denver has a statement of understanding in its policy manual with the Colorado Contractors Association, which proclaims that if an emergency is declared, the city and county are provided the equipment, personnel, and know-how of the Colorado construction industry. The implementation of snow disaster plans by local governments is sometimes described in trade publications. One such article from 1992 describes how the city of Moncton, New Brunswick implemented its emergency plans to deal with five feet of unexpected snow (*53*). The article describes how the local highway agency successfully handled the emergency by following a clear and detailed snow emergency plan that identified available sources of relief equipment and prioritized police and medical emergency routes.

CHAPTER FOUR

WEATHER INFORMATION SYSTEMS

Accurate and timely information on current weather conditions and forecasts of emerging conditions are critical to ensuring efficient and effective winter maintenance operations. With access to good weather information, highway agencies can better time chemical treatments and more effectively deploy snow and ice control equipment, which can lead to reducing program expenditures and adverse environmental effects by eliminating unnecessary applications of salt and other chemicals and abrasives. During the past 20 years, many highway agencies have significantly improved their weather monitoring and forecasting capabilities. Three weather information capabilities, (1) weather forecasting services, (2) road weather information systems (RWIS), and (3) thermal mapping, are discussed below.

WEATHER FORECASTING SERVICES

Many agencies reported using personal computers to access weather forecasting information from the National Weather Service (NWS), which is usually done through use of vendor-provided equipment installed at NWS radar tracking stations. The network of NWS radar stations extends throughout the country. Public access is permitted for a fee using leased telephone lines that are capable of dialing any NWS station in the country. Some agencies also use private forecast services that provide 24-hour weather advisory information and alert key agency personnel about incoming storms.

About two-thirds of the state highway agencies and the province of Ontario reported using computers to access NWS information. All three responding counties and four cities reported having computer access to weather forecasting networks.

The NWS is updating its Weather Surveillance Radar System as part of a program known as Next Generation Radar (NEXRAD) by replacing the existing network of stations installed during the 1960s with more than 100 pulsed-Doppler radar stations (*54*). The first of the new stations began operation in 1992 and the conversion is scheduled to be completed in 1995. The $2 billion system is expected to substantially improve weather forecasting accuracy (personal communication, E. Friday, Assistant Administrator for Weather Service, 1992). Enhanced radar is now commercially available from some private forecast services for local areas. The kinds of services and products offered by commercial weather support companies are described in a 1990 TRB report (*55*).

Region-specific weather forecasts are in demand by highway agencies. A computer program developed under the SHRP IDEA project, known as ROADWEATHER PRO, promises to provide improved regional weather forecasts for highway application (*56*). The program contains a model that converts raw surface observations and radiosonde measurements provided by NWS into forecasts for statewide areas at frequent intervals. The program, which can be run on a personal computer, contains detailed geographic and topographic data for computing the effects of terrain on weather development and generating graphic displays of terrain and weather in several levels of geographic detail. The displays can also be juxtaposed on a road network display. The Colorado DOT, which assisted in development of the program for highway use, has reported that the model was more than 90 percent accurate in predicting weather conditions during the winter of 1991–92 (*57*).

ROAD WEATHER INFORMATION SYSTEMS (RWIS)

RWIS have been operating in the United States for several years, although they are far more prevalent in Europe. These systems are used for monitoring and collecting site-specific weather information through a combination of sensing devices, communications equipment, computer networks, and professional meteorologists.

Sensors on highway pavement and bridge decks are used to measure road surface temperatures, monitor levels of moisture and snow on the roadway, and determine whether deicing chemicals are present and needed. Other sensors include devices that measure wind speed, ambient air temperature, dew point, visibility, and precipitation at the site (*58*). Sensors are usually wired to a remote processing unit (RPU) that provides communication by radio, telephone, or microwave to a central processing unit (CPU) accessible to winter maintenance management. In most cases, the CPU is also connected to a private meteorological forecast center where meteorologists interpret the information and advise the agency. A schematic of RWIS is provided in Figure 6 (*59,60*).

Nearly three-quarters of the state highway agencies reported having access to one or more such stations or systems operated by private companies under contract. Twenty-one agencies use a single vendor for the service, while Minnesota reported using the systems of three different companies on an experimental basis. Ten state highway agencies reported that they do not use RWIS.

Ontario is the only province using RWIS, employing the systems of two vendors. Two counties (Dane and Milwaukee Counties in Wisconsin) and four cities (Columbus, Denver, Kansas City, and Milwaukee) have access to systems used by the state highway agency.

An example of a pavement temperature forecast, produced by the RWIS of Wisconsin DOT, is shown in Figure 7. The numbers on the top portion of the figure indicate below-freezing temperatures forecast from 0 hr to 0600 hr. The lower portion of the figure shows snow accumulation forecasts, which indicate the snow will begin to fall at 2200 hr with accumulations increasing from 25 mm (1 in.) at midnight to 150 mm (6 in.) by 0900 hr when the snowfall ends. Additional forecast discussion and details are shown in Figure 8.

RWIS Costs and Benefits

A total of eight RWIS field weather and pavement sensing stations were installed in the Denver area in 1987 (Figure 9). The

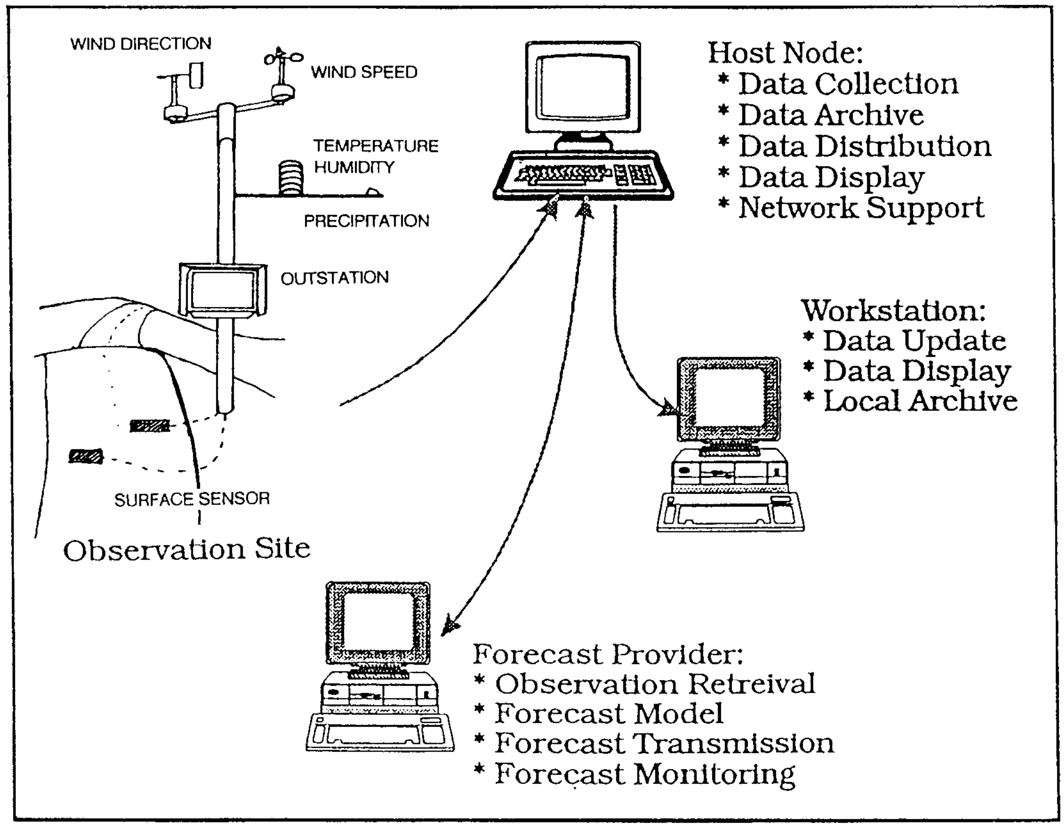

FIGURE 6 Schematic of road weather information system (RWIS) (*59,60*).

stations have been used regularly by maintenance personnel since the winter of 1987–1988 and, according to an assessment report by Colorado DOT, each of the stations costs approximately $35,000 to install, with the central computer and communications equipment needed to access the stations costing an additional $108,000. The total capital cost of the system was $457,000, which included some initial maintenance by the vendor. Operating costs have averaged $6,200 annually, including equipment repair and replacement expenditures (*61*).

The cost effectiveness of RWIS have been examined by SHRP researchers through questionnaires and personal interviews with users and manufacturers of systems (*62*). A cost-benefit analysis was performed that employed a model to compare RWIS costs with winter maintenance program expenditure effects. The researchers found that total benefits from use of RWIS exceeded expenditures by 5 to 1 (*46,63*). The researchers concluded that RWIS, coupled with thermal mapping and access to the services of professional weather forecasters, can lead to accurate guidance on when maintenance crews should be dispatched to specific sites. This advantage results in less patrolling by maintenance crews, more timely chemical treatments, and guidance on when snow and ice control operations can begin to wind down (*63,64*).

The cooperation of highway agencies across jurisdictional levels is essential to ensuring implementation of cost-effective RWIS. Counties and cities may be linked to the same CPUs, thereby avoiding duplicate costs for computer systems and central forecast stations. Wisconsin DOT, the City of Milwaukee, and Dane County in Wisconsin are linked to the same CPU, which is operated by Wisconsin DOT. This cooperation requires use of common equipment, data, and communications standards and protocols, some of which already exist. For example, the World Meteorological Organization has developed a standard data format for weather data transmission known as Binary Universal Format for Data Representations (BUFR) (*59*). A standard communications protocol does not currently exist (*63*).

The three major manufacturers of RWIS in the United States employ different formats for key elements of their systems. MinnDOT is currently pursuing development of an open system specification to help address this problem (*60*).

Use of RWIS Abroad

The use of RWIS around the world is shown in Table 8. Highway agencies in Europe have developed more extensive RWIS networks than highway agencies in the United States. For example, the United Kingdom has 520 RWIS stations, compared to 350 in the United States (*46*). Sweden has 550 stations operated jointly by municipalities and regional offices of the Swedish Road Administration (*65*).

Finland has 150 RWIS field stations (*60*). Some of the stations contain high-quality still-frame video cameras that supplement the data provided by RWIS stations (*66*). The cameras take two or three black and white photos per hour, which are processed on a personal computer for transmission by telephone to the agency and a central weather information center. The images provide agency personnel with visible information about road conditions at key locations, supplementing numerical data provided by sensors and

```
+--------------------------------------------------------------------------+
|                 SCANCAST(sm) _______ PAVEMENT   Forecast                  |
|                SCAN  Highway  &  Runway  Prediction  Model                |
|MONROE CO, I-94 & HWY 12, APPROACH       Issued: Apr 19 12:46 CDT          |
| Valid 24 hours starting at  12pm Apr 19 1993                              |
+--------------------------------------------------------------------------+

+--------------------------------------------------------------------------+
|                      Pavement Temperature Forecast                        |
~--------------------------------------------------------------------------~
|12 13 14 15 16 17 18 19 20 21 22 23  0  1  2  3  4  5  6  7  8  9 10 11 12 |
~--------------------------------------------------------------------------~
|CDT                                                                        |
 .  .  .  .  .  .  .  .  .  .  .  .  . 44 .  .  .  .  .  .  .  .  .  .  .
 .  .****  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  . 43.  .  .  *
****  . ****.  .  .  .  .  .  .  .  .  . 42 .  .  .  .  .  .  .  .  .  *.
 .  .  . 41 ***.  .  .  .  .  .  .  .  .  .  .  .  .  .  . 41.  . **  .
 .  .  .  .  .  **  .  .  .  .  .  .  . 40 .  .  .  .  .  .  .  . .**.  .
 .  .  . 39 .  . **  .  .  .  .  .  .  .  .  .  .  .  .  . 39.  *  .  .
 .  .  .  .  .  .  .  .  .  .  .  .  . 38 .  .  .  .  .  .  .  . *.  .  .
 .  .  . 37 .  .  .**.  .  .  .  .  .  .  .  .  .  .  .  . 37.*  .  .  .
 .  .  .  .  .  .  .  ****  .  .  .  . 36 .  .  .  .  .  .  .  *  .  .  .
 .  .  . 35 .  .  .  .  .****  .  .  .  .  .  .  .  .  .  . .**.  .  .  .
 .  .  .  .  .  .  .  .  .  .  ******  . 34 .  .  .  .  .  .***  .  .  .  .
 .  .  . 33 .  .  .  .  .  .  .  .  **  .  .  .  .  .  .  ** 33.  .  .  .
 =  =  =  =  =  =  =  =  =  =  =  =  =**32***************  =  =  =  =  =  =
 .  .  . 31 .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  . 31.  .  .  .
                                     <<<<<<<<<<<<<<<<<<<
|      < = below freezing temperature                                       |
~--------------------------------------------------------------------------~
|12 13 14 15 16 17 18 19 20 21 22 23  0  1  2  3  4  5  6  7  8  9 10 11 12 |
~--------------------------------------------------------------------------~
|               Precipitation and Pavement Condition Forecast              |
~--------------------------------------------------------------------------~
|                                                                           |
|////////////////////////////////#/#/#/#/##################### ## # # # # #|
| /:Rain           #:Snow                                                   |
+--------------------------------------------------------------------------+

+--------------------------------------------------------------------------+
|                       Snow  Accumulation  Forecast                         |
~--------------------------------------------------------------------------~
|.  .  .  .  .  .  .  .  .  .  .  .  . 10 .  .  .  .  .  .  .  .  .  .  .
|.  .  .  9  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  9.  .  .  .
|.  .  .  .  .  .  .  .  .  .  .  .  . .8 .  .  .  .  .  .  .  .  .  .  .
|.  .  .  7  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  .  7.  .  .  .
|.  .  .  .  .  .  .  .  .  .  .  .  . .6 .  .  .  .  .  .  .  ^  ^  ^  ^
|.  .  .  5  .  .  .  .  .  .  .  .  .  .  .  .  .  .  ^  ^  ^  ^  ^  ^  ^
|.  .  .  .  .  .  .  .  .  .  .  .  . .4 .  .  ^  ^  ^  ^  ^  ^  ^  ^  ^
|.  .  .  3  .  .  .  .  .  .  .  .  .  .  .  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^
|.  .  .  .  .  .  .  .  .  .  .  .  . .2 ^  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^
|.  .  .  1  .  .  .  .  .  .  .  .  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^
|.  .  .  .  .  .  .  .  .  .  ^  ^  ^ ^0 ^  ^  ^  ^  ^  ^  ^  ^  ^  ^  ^
~--------------------------------------------------------------------------~
|12 13 14 15 16 17 18 19 20 21 22 23  0  1  2  3  4  5  6  7  8  9 10 11 12 |
~--------------------------------------------------------------------------~
|         Units:    Inches                                                  |
```

FIGURE 7 Pavement temperature forecast from Wisconsin DOT RWIS.

```
+-------------------------------------------------------------------------------+
|                        Wind Speed/Direction Forecast                          |
~-------------------------------------------------------------------------------~
|E 18     NE18     NE20     N 20     N 20     N 20     N 20     N 18     N 17|
~-------------------------------------------------------------------------------~
|12 13 14 15 16 17 18 19 20 21 22 23  0  1  2  3  4  5  6  7  8  9 10 11 12 |
~-------------------------------------------------------------------------------~
~-------------------------------------------------------------------------------~
|            Air and Wind Chill Factor Temperature Forecast                     |
~-------------------------------------------------------------------------------~
| 38AirT   38       36       34       33       32       32       34       37|
| 14Chill  14       10        7        6        4        4        9       14|
+-------------------------------------------------------------------------------+

+-------------------------------------------------------------------------------+
|                        Forecasters Discussion                                 |
~-------------------------------------------------------------------------------~
|PERIODS OF RAIN THIS AFTERNOON INTO THIS EVENING...SOME THUNDERSTORMS          |
|POSSIBLE.                                                                      |
|                                                                               |
|RAIN MIXING WITH AND TURNING TO HEAVY WET SNOW MID TO LATE EVENING,            |
|THEN PERIODS OF HEAVY WET SNOW OVERNIGHT.                                      |
|                                                                               |
|SNOW DIMINISHING EARLY TUESDAY.                                                |
|                                                                               |
|4-7 INCHES ACCUMULATION POSSIBLE.                                              |
|                                                                               |
|****DISTRICT UPDATE WILL BE ISSUED BY 7PM****                                  |
|                                                                               |
|112                                                                            |
|-------------------------------------------------------------------------------|
|                        Wisconsin Weather Summary                              |
|-------------------------------------------------------------------------------|
|A STORM DEVELOPING OVER SOUTHERN KANSAS AND OKLAHOMA WILL MOVE NORTHEAST       |
|TOWARD THE GREAT LAKES DURING THE NEXT 36 HOURS. AS IT APPROACHES WISCONSIN|
|WILL ONCE AGAIN BE IN THE TRANSITION BETWEEN WINTER AND SPRING AS              |
|THUNDERSTORMS DEVELOP OVER THE SOUTH AND SNOW OVER THE CENTRAL PART OF THE     |
|STATE.                                                                         |
|                                                                               |
|THE LOW WILL PULL PLENTY OF MOISTURE NORTH INTO THE BADGER STATE TODAY AND     |
|INTO TONIGHT, SETTING THE STATE FOR HEAVY RAINS IN THE SOUTH AND POSSIBLY      |
|HEAVY, WET SNOW IN A LINE FROM WEST-CENTRAL TO NORTHEAST WISICONSIN.           |
|                                                                               |
|STRONG NORTHEAST WINDS WILL ALSO DEVELOP AS THE STORM APPROACHES AND           |
|PULLING INCREASING CLODER AIR INTO THE REGION.                                 |
|                                                                               |
|114                                                                            |
+-------------------------------------------------------------------------------&
```

FIGURE 8 Additional forecast details from Wisconsin DOT RWIS.

other RWIS devices. An evaluation of the system has indicated that benefits exceed costs by 5 to 1, and that salt usage has been reduced by one-fifth because of improved anti-icing effectiveness made possible by the RWIS information (*67*).

Several RWIS have been tested in Austria, including the three major systems currently available in the United States (*68*). The tests included measurements of the accuracy of air temperature, humidity, and salinity sensors. The Austrians reported that the salinity sensors showed the greatest variability and that measurements of nighttime temperatures were more accurate than those taken during daylight, when variability in sunlight can effect measurement accuracy.

Various other RWIS technologies have been developed abroad. For example, experiments have been conducted in Austria on road condition radar systems that permit noncontact probing of the road surface, providing information on moisture, film thickness, and chloride levels (*69*). The Japanese have developed a dielectric pavement freezing detector, which provides more accurate measurement of chlorides on the roadway (*70*).

THERMAL MAPPING

With the advent of RWIS and greater emphasis being placed on pavement temperature monitoring and forecasting, several

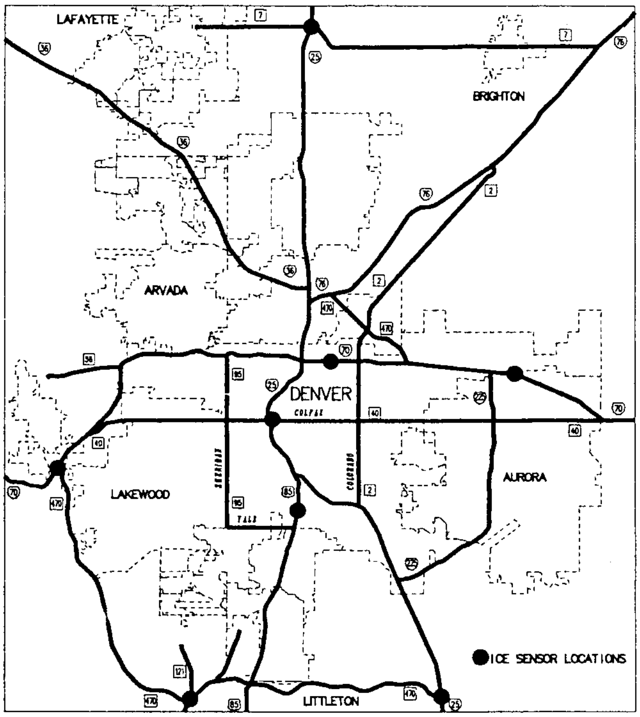

FIGURE 9 Denver area RWIS station locations (*61*).

highway agencies have developed thermal maps of highway segments. Thermal mapping, or road thermography, involves measurement of pavement temperature with an infrared radiometer, which creates profiles of pavement temperatures at periodic points on the highway system (*63*).

The equipment and measurement methods used for thermal mapping can range in sophistication and cost. In a SHRP project, a hand-held device that cost approximately $1,900 was used to develop a thermal map. Readings were taken from a vehicle traveling 32 kmph (20 mph) at 0.16-km (0.1-mi) intervals. The radiometer was linked to a lap-top computer that recorded the measurements. The SHRP researchers estimated the cost was approximately $6.25/km ($10/mi). While the researchers noted that more detailed thermal mapping requires more sophisticated equipment and measuring techniques that can cost $125/km ($200/mi), the low-cost technology was found to be sufficient.

Thermal mapping is often used to select sites for RWIS stations and devices (*46*). When RWIS stations are located far apart, they may not adequately portray system conditions. Thermal mapping can be used to select the best combination of RWIS station sites to ensure the most accurate prediction of system conditions. Minnesota and Virginia reported that they have used thermal mapping for this purpose.

Thermal mapping can also be used to provide information on weather conditions at sites located between RWIS stations (*62*). Vancouver, British Columbia has used thermal mapping to develop temperature profiles for its entire arterial system during storm events (*71*). Researchers in Sweden have developed a model that combines thermal mapping and RWIS to deal with pavement temperature variabilities caused by topography and landscaping (*72*). A specially equipped vehicle is deployed to survey the road system, measuring road and air temperatures every other season for input into the model. The model provides a detailed temperature profile to target ice control strategies for individual highway sections.

TABLE 8
STATUS OF RWIS AROUND THE WORLD, SEPTEMBER 1992 (*46*)

Country	Thermal Mapping Km	Road Weather Stations No.	Computer Weather Network
Austria	0	280	none
Belgium	0	0	none
Denmark	4000	220	yes
Finland	500	150	yes
France	750	200	yes
Germany	200	160	yes
Holland	3000	153	yes
Italy	0	30	none
Luxembourg	200	20	none
Norway	3500	50	yes
Spain	0	0	none
Sweden	12,000	550	yes
Switzerland	100	200	yes
United Kingdom	38,000	520	yes
U S A	1000	350	yes
Canada	400	10	yes
Japan	70	2	none
TOTALS	63,720	2,895	

CHAPTER FIVE

MATERIALS FOR SNOW AND ICE CONTROL

Ice control chemicals and abrasives are the primary materials used for highway winter maintenance, representing a major expenditure area by highway agencies. It has been estimated that application of ice control chemicals (including material, labor, and equipment costs) accounts for about one-third of highway winter maintenance expenditures in the United States, totaling $500 million per year (*3*). Expenditures on sand and other abrasives account for more than 10 percent of winter maintenance budgets, excluding application costs (*3*). As discussed earlier, use of these materials has also been shown to be costly in terms of damage to infrastructure and motor vehicles, harmful effects on the natural environment along the roadway, and the need for additional highway cleanup operations. Yet, because use of these materials facilitates and enhances the effectiveness of snow and ice control operations, it provides benefits that are extremely valuable to the public.

Many developments have taken place in recent years to help control the total costs associated with snow and ice control materials, while enhancing their effectiveness. Many of these developments, which include the use of pre-wetted deicers, anti-icing techniques, and alternative deicing chemicals, are discussed next.

USE OF SALT AND OTHER DEICING CHEMICALS

Ice may be removed from pavement through a combination of plowing, chemical treatment, natural melting, and traffic action. However, because ice adherence to pavement is often quite strong, removal by plowing alone may not be possible. While cohesive forces bond the ice molecules together, the molecules are also adhesively bonded to the pavement surface by intermolecular forces that develop between the ice and pavement and the mechanical interlocking of ice particles frozen in pavement pores (*73*). Deicing chemicals help break this adhesive bond by melting into the ice, spreading under the ice layer, and weakening the pavement-ice bond. The resulting ice sheets can then be removed mechanically by plowing or traffic action (*73*). The growing use of ice control chemicals in advance of precipitation to prevent the formation of the pavement-ice bond, which is known as anti-icing, is discussed later in this chapter.

Chemicals have been used for highway deicing since the turn of the century, although extensive use did not occur until the 1950s following introduction of the Interstate highway system and growing dependence by suburban residents on the motor vehicle for transportation. By far the most commonly used deicing chemical has been and still is sodium chloride (NaCl), often referred to as road salt. Currently, about 10 million tons of road salt are used each winter in the United States (*3*).

Sodium chloride is widely used because of its proven deicing effectiveness, its relatively low price, and its easy application procedures. Environmental concerns, however, have created demands for more controlled salt use in some states and communities, leading to experimentation with alternative deicing treatments that promise to be less harmful to highway facilities and the natural environment. Some of these alternatives are presented following the discussion of sodium chloride use.

Sodium Chloride Use

Sodium chloride, used straight or mixed with abrasives, is by far the most common deicing chemical used by agencies that responded to the questionnaire. Although application of other chemicals is often reported in the literature, most of the reporting agencies indicated that they mainly use salt for chemical deicing. All of the Canadian provinces reported using straight salt for deicing on a regular or periodic basis and, at times, mixing salt with abrasives. Four of the county and city agencies reported using road salt exclusively for chemical deicing, while the remainder of agencies reported using road salt straight and sometimes mixed with abrasives. Eight of the states reported that they sometimes use abrasives with minimal salt mixed in, while Oregon reported using abrasives exclusively. Many agencies reported using road salt pre-wetted with liquid calcium chloride ($CaCl_2$) for low-temperature deicing.

Application Rates

Application rates for salt reported by many of the agencies varied largely because of differences in weather conditions, service levels, and demands of highway users. The state highway agencies reported application rates per treatment ranging between 8 and 46 g/m^2 (100 and 600 lb/12-ft lane-mi). Provinces reported application rates ranging from 13 to 68 g/m^2 (170 to 890 lb/12-ft lane-mi). Application rates reported by the counties ranged from 8 to 31 g/m^2 (100 to 400 lb/12-ft lane-mi), while cities reported rates ranging from 17 to 67 g/m^2 (200 to 800 lb/11-ft lane-mi). Reported temperatures for salt applications ranged from –10° to 1°C (14° to 34°F).

Salt Use Policies

Nearly all of the agencies, including 27 of the 34 responding states, 5 of the 6 provinces, and all counties and cities, reported having salt use policies. Illinois' policy manual for districts outside Chicago provides guidance on the effective temperature for use of salt, liquid calcium chloride, and mixtures of the two chemicals. New York's policy manual states that "if the conditions are favorable, salt should be the first choice in ice control material" (*74*). New York State maintenance crews are instructed to use calcium chloride when temperatures are especially low and abrasives, to provide traction, when salt and calcium chloride are deemed ineffective. Some districts use salt/abrasive mixtures depending on weather and traffic conditions. Because of salt mines located in the state, New York has a relatively low cost supply of salt.

Kansas City's policy manual notes that road salt is used to achieve bare pavement on downtown and arterial streets, while salt and abrasive mixtures are used in outlying areas where traffic is lighter (*75*). Residential streets are plowed with selected salting and abrasive treatments at intersections and other areas where conditions require treatment.

Highway agencies often mix salt with sand and other abrasives in small quantities of less than 5 percent salt to prevent freezing of abrasive stockpiles. Higher salt ratios, however, may be used to provide deicing. Minnesota's policy manual states that deicing chemicals are to be used in variable combinations with abrasives (*7*). As discussed previously, legislation in Minnesota requires highway agencies in the state to limit salt applications to special sites such as hills, intersections, and high-speed roadways, and only if other means such as plowing, abrasives, or natural elements are not likely to be effective in a reasonable amount of time. In practice, mixtures of salt and abrasives are used on most highways in Minnesota, with the salt ratios varying according to conditions and highway priority.

In the winters of 1982–1983 and 1983–1984, Ontario tested the effectiveness of salt versus salt/abrasive mixtures by applying straight salt on several freeway sections that in previous winters had been treated with salt/sand mixtures containing 13 percent salt. The research found that "in areas where salt only was used, the pavement surface became bare and dry within several hours of the final salt application. The slush produced by the salt was rapidly peeled off the driving surface by traffic action. However, in sections where sand was used extensively, the pavement remained moist for a considerably longer period of time. This often resulted in refreezing of the pavement surface and hence further application of either sand mix or salt was often required" (*76*). Results from the study caused the agency to expand straight salt use to other major highways.

Three agencies reported using salt brines to pre-wet dry salt at the rate of 25 l/m^3 (6 gal/ton) for use on compacted snow and ice at temperatures below –9°C (15°F). Mixing or wetting salt with brine or plain water (or calcium chloride as discussed in the next section) is intended to improve the application characteristics, including speed of application by spreaders and the melting effectiveness of salt. *The 1993 Public Works Manual* states that "when applied dry, salt shows some segregation; large particles tend to spread wide; and there is some dust. Applied salt stays in place on loose slush, but tends to slide wide on thick ice. Salt is dormant when initially applied, taking 3 to 5 minutes to imbed into accumulations at 30°F (–1°C); 19 minutes at 25°F (–4°C); and longer for temperatures below 20°F (–7°C). When applied at high temperatures, there is minimal loss because of traffic; however, at low temperatures, traffic may cause considerable loss" (*77*).

Brines produced from oil and gas well brines tested in West Virginia were deemed economical if brine shipment charges could be substantially reduced (*78*). The effectiveness of salt brines for highway deicing has also been tested in Norway, where researchers found the applications very effective when used as an anti-icer (*79*). By comparison, the researchers found that use of dry (solid) salt as an anti-icer resulted in 80 percent or more of the salt particles being blown or bounced off the roadway.

Highway agencies in Sweden have also experimented with methods to reduce salt usage by using aqueous sodium chloride and by pre-wetting salt with plain water (*25*). Both treatments, which required minimal capital investments, were deemed effective in improving the adhesion of salt to pavement. Finland also reported in 1992 that pre-wetting salt with water significantly improved adhesion characteristics (*66*).

Calcium Chloride Use

Calcium chloride is a commonly used deicer available in pellet, flake, or liquid form. Compared to sodium chloride, it has a lower eutectic point (freezing point), is more deliquescent (absorbs moisture from the air to dissolve readily), and adheres better to the road during colder temperatures (*73*). Because of these properties, calcium chloride is sometimes used in combination with sodium chloride to provide low-temperature deicing. Calcium chloride is also used to pre-wet salt to improve the melting and application characteristics of the salt treatment, and thereby reduce salt usage.

Calcium chloride is priced higher than salt and has some adverse side effects. In Canadian tests, the use of straight calcium chloride resulted in costs 4.5 times higher than salt to melt ice layers under usual storm conditions, and 6 times higher to disbond the layers (*73*). Calcium chloride use also caused several adverse side effects related to its deliquescence. Residual calcium chloride remained wet on the road surface, increasing pavement slickness and causing melting of fallen snow that had a tendency to refreeze into ice when the temperature dropped. Because of these test results and other cost and use considerations, including high corrosivity, straight calcium chloride is seldom used in the United States.

Fifteen state highway agencies reported mixing salt with liquid calcium chloride at rates ranging from 21 to 50 l/m^3 (5 to 12 gal/ton) of salt used. Two provinces use liquid calcium chloride at rates of approximately 40 to 50 l/m^3 (8 to 10 gal/ton) of salt used. Two counties reported using it at the rate of 42 l/m^3 (10 gal/ton) salt, while cities reported using it at the rate of approximately 17 to 33 l/m^3 (4 to 8 gal/ton) salt. State agencies reported that they apply calcium chloride mixes at temperatures ranging from –17° to 0°C (0° to 32°F) for liquid calcium chloride. Provinces reported using it at temperatures ranging from –13° to 0°C (9° to 32°F), while cities reported application temperatures between –9° and –2°C (15° and 28°F). Saskatchewan's policy is to use straight liquid calcium chloride in a spray application at temperatures as low as –25°C (–13°F).

Pre-wetting of salt with liquid calcium chloride is achieved using on-board tanks that feed the liquid onto the spinner. Pre-wetted salt adheres better to the roadway, melts into the ice at a faster rate, and increases the effectiveness of salt treatment in lower temperatures. Michigan DOT produced a report in 1979 to assess the experiences of several agencies that used salt pre-wetted with calcium chloride. It was found that use of 33 to 50 liters of calcium chloride liquid per metric ton (8 to 12 gallons per ton) of salt lowered the quantity of salt required by up to 50 percent and extended the temperatures at which salt was effective to –18°C (0°F). Similarly, the use of liquid calcium chloride, sprayed at the point of salt discharge from the spreader, was reported in England to have reduced salt use by 50 percent (*80*).

The 1993 Public Works Manual states that "pre-wetting with liquid calcium chloride is not the total solution for snow and ice control." The manual recommends that "for the most accelerated deicing action at lower temperatures, dry calcium chloride alone or in mixtures with salt must be applied. At lower temperatures, dry calcium chloride is much more effective than salt or salt pre-wetted with liquid calcium chloride." The manual also notes that "if speed of action is critical under low temperature conditions, then dry calcium chloride is the answer to the problem. The use of pre-wetting or dry calcium chloride must be tailored to the user's operations, concerns, and weather conditions" (*77*).

A report by Carr from Massachusetts DOT ("Calcium Chloride Dry Mix for Winter Salt Reduction," presented at the Committee on Winter Maintenance, TRB, January 12, 1993) summarizes the satisfactory experiences of the agency in targeted use of dry calcium chloride mixed with salt to reduce total salt (especially sodium) usage near water supplies. In highway sections treated with 4:1 mixes of salt and calcium chloride, and consistent use at a rate of 23 g/m^2 (300 lb/12-ft lane-mi), total salt use in the targeted area was reduced by 40 to 75 percent annually. In the 1991–1992 season, the ratio increased to 3:1, causing further reductions in salt use accompanied by satisfactory deicing. The overall material cost of the calcium chloride/salt mix, which was premixed by the supplier, was believed to be fairly close to the material cost of straight salt because fewer treatments were required.

Calcium Magnesium Acetate (CMA)

In searching for a more environmentally acceptable deicing chemical, the FHWA, industry, and state and local highway agencies have been experimenting for several years with a number of alternatives. One of the most frequently considered is CMA, which was developed with support by the FHWA during the 1970s and has been the subject of numerous laboratory and field tests during the past 15 years. Some highway agencies use it regularly, although on a very limited basis, primarily on corrosion-prone structures and environmentally sensitive areas.

Experience concerning the application, storage, and handling characteristics of CMA are summarized in TRB's 1991 *Special Report 235: Highway Deicing: Comparing Salt and Calcium Magnesium Acetate* (*3*). The study also reviewed what is known about CMA's effectiveness as a deicer, its application costs, and likely impacts on the environment, motor vehicles, and infrastructure. Major findings from the study, which surveyed users and reviewed virtually all published reports concerning CMA field applications and tests from 1979 to 1991, were as follows.

Deicing Effect and Field Experience

In selective and experimental situations where CMA has been used, it has performed acceptably, although not in the same manner or quite as effectively or consistently as salt. Compared with salt, CMA is slower acting and less effective at lower temperatures and in freezing rain, drier snowstorms, and light traffic conditions. Because of its lower density and greater volume requirements, it requires greater truck capacity and enclosed storage space than salt.

Health and Environmental Effects

Research findings to date (1991) indicate that CMA is likely to have no adverse effects on human health and few negative environmental effects, although the effect of CMA near some poorly flushed or poorly diluted ponds and streams may require further study and monitoring.

Compatibility with Motor Vehicles and Infrastructure

CMA is more compatible with motor vehicle and highway materials than salt. It is less corrosive to reinforcing steel, and is therefore likely to be much less harmful to poorly protected bridge decks that are not already contaminated with chlorides. The effects of CMA in retarding corrosion of salt-contaminated decks and the potential for CMA spray to adhere to windshields, thus creating a safety hazard, require further study.

Production Technologies and Price

CMA is manufactured by reacting dolomitic lime with acetic acid. The acid, usually derived from natural gas, is CMA's chief cost component. The only CMA on the market is priced between \$600 and \$700 per ton delivered. Other lower-cost production technologies that use acetic acid produced from alternative sources are being explored but are uncertain. Therefore, sodium chloride will probably continue to be the predominant highway deicer for many years to come.

Six agencies (five states and one city) responding to the synthesis questionnaire reported targeted use of CMA on highway segments crossing locks and dams, on bridge decks prone to corrosion, and in environmentally sensitive areas. The agencies reported a slightly narrower range of application temperatures for CMA, ranging from –5° to 0°C (22° to 32°F), than for salt, which was applied at temperatures as low as –9°C (15°F). CMA application rates were reported to be slightly higher than for salt, ranging from 15 to 39 g/m^2 (200 to 500 lb/12-ft lane-mi). The highest reported application rate for road salt by the agencies was 46 g/m^2 (600 lb/12-ft lane-mi).

In a 1993 survey of winter maintenance agencies, 25 percent of the agencies surveyed by *Roads and Bridges* magazine (56 percent of the states) responded that they had tested CMA, while 16 percent said it was somewhat likely or likely that they would use CMA the next winter (*81*).

Other Deicing Chemicals

California reported occasional use of urea on bridges in the San Francisco Bay Area. Urea is a soluble, weakly basic, nitrogenous compound, either organic or synthetically produced. It is commonly used by airports as an ice control chemical because of its low corrosivity. Kansas City reported using urea on sidewalks. Ontario reported that experiments with urea indicated that twice as much of it is needed as salt and it has a tendency to degrade into ammonia that may be harmful to aquatic life in streams and lakes near roadways (*73*). South Dakota DOT has tested the sodium salts of carboxylic acids for deicing, which exhibited properties comparable to sodium chloride (*82*). The agency reported that mixtures of sodium acetate with sodium formate might provide effective deicing; however, field trials were not reported.

Magnesium chloride is sometimes used as a substitute for calcium chloride because it is less expensive and works at similarly low temperatures. Arizona DOT reported using magnesium chloride in its solid form, applied at a rate of 8 to 11 g/m^2 (100 to 150 lb/ 12-ft lane-mi). In field tests conducted during the winter of 1988–1989, Richmond, Ontario found that magnesium chloride is effective in melting dry snow but less effective in melting ice (*73*).

MinnDOT has begun comprehensive tests of several ice control products to investigate environmental impacts, as well as application costs and deicing effectiveness (*83*). MinnDOT has reported (in an exhibit at TRB's Third Annual Symposium in 1992) the following purchase costs for several chemicals used in the experiments:

- CMA: \$738/m^3 (\$670/ton)
- Sodium formate: \$441/m^3 (\$400/ton)
- CMA mixed with potassium acetate: \$771/m^3 (\$700/ton)
- CMA mixed with salt: \$171/m^3 (\$155/ton)
- Salt: \$29/m^3 (\$26/ton)
- Calcium chloride: \$294/m^3 (\$267/ton)
- Salt mixed with calcium chloride: \$108/m^3 (\$98/ton).

SHRP has published a manual for use by agencies in evaluating alternative ice control chemicals (*84*). Twelve laboratory test methods are provided in the report that evaluate physio-chemical characteristics, compatibility with bare and coated metals and metals in concrete, compatibility with concrete and non-metals used in highways, the ecological effects, and health and safety aspects.

Anti-Corrosion Additives

A number of products on the market are advertised as inhibiting corrosion of concrete reinforcing steel if added to chloride deicing chemicals. The products are available in both liquid and granular forms from a number of suppliers. The use of such corrosion inhibitors was reported by 10 of the states responding to the questionnaire. However, none of the provinces, counties, or cities reported using these additives.

Most agencies that reported use of corrosion inhibitors did not report on the effectiveness of the products in inhibiting corrosion. However, Alaska reported that results of corrosion inhibition are not clear, while Idaho reported fair to poor results for three products field tested. Wisconsin reported that it is nearing completion of a 5-year study on corrosion inhibitors.

One product on the market uses lignosulfonates to retard corrosion by causing chemical reactions that purportedly seal the pores in the metal surfaces, thereby limiting corrosion points (*85*). Laboratory tests showed 50 to 80 percent less corrosion for steel treated with the product than untreated steel when both were exposed to chlorides. California DOT has investigated the toxicity of lignin sulfonate and found it detrimental to certain aquatic life (*86*).

Chemical Deicing Procedures

Agencies were asked in the questionnaire to describe their threshold in determining when ice control chemicals should be used. Twenty-two of the 51 agencies (14 states, 1 province, 3 counties, and 4 cities) reported that any snowfall accumulation triggered the need for application of ice control chemicals. Nine agencies (4 states, 2 provinces, and 3 cities) reported waiting until 6 mm (0.25 in.) of snow has accumulated on pavements, while 17 agencies (14 states, 2 provinces, and 1 city) reported waiting for depths of up to 12 mm (0.5 in.) or other conditions as thresholds, which include presence of ice or packed snow, snow accumulation combined with falling temperatures, and snowfall that obscures the centerline (Virginia).

Agencies were also asked to describe how they monitor chemical applications. Of the 51 agencies responding to this question, 19 track the total amount of material used, 8 rely on supervisors to monitor application levels, 12 use field observers, 5 depend on public input (complaints of too much or too little), and 6 employ special maintenance management systems. Milwaukee County reported having a unique indicator light system on the outside of truck cabs where different color lights indicate application rates so that field supervisors can readily observe the rates of individual spreaders.

Agencies reported several rates of salt application, using a number of rate parameters. Some agencies reported the weight of material per lane-km (or lane-mi), while others reported weight per two-lane km (or two-lane-mi) because two-lane highways are often treated with one application that covers the center of the road. In urban areas where lanes are not always clearly defined, rates are often reported on a per-mile basis. Many agencies recommend application rates in their policy or procedure manuals. Connecticut specifies use of a 7:2 mixture of sand and salt applied at a rate of 360 kg of sand and 85 kg of salt per km of two-lane divided highway (1,264 lb of sand and 300 lb/mi salt per two-lane highway).

The Illinois State Toll Highway Authority has a section in its maintenance manual devoted to material usage to aid personnel in selecting chemical application rates for different storm conditions (*87*). The toll roads are maintained in bare pavement condition as much as possible because of the high traffic volumes and speeds. To keep pavement bare, the toll authority's guidelines, which are provided in Figure 10, emphasize the use of salt under most winter storm conditions. Sand and other abrasives are recommended mainly under very low temperature conditions.

Maine DOT has developed a coursebook for training personnel from local highway agencies in maintaining low-volume local roads and streets (*38*). The coursebook includes guidelines for treating various winter conditions, which are summarized in Figure 11. The guidelines suggest applying salt only when mixed with abrasives for most conditions, but recognizing that straight salt may be required at times under certain weather and pavement conditions to prevent snow packing.

The varying procedures employed on Illinois toll highways and Maine local roads represent two different types of strategies. Salting is emphasized and abrasives are used in limited quantities on the Illinois toll roads, whereas Maine recommends mostly abrasives on local roads and limited salting. The strategies differ because of such things as variances in traffic levels, safety demands because of traffic speeds, and environmental concerns.

The examples of Illinois and Maine illustrate a dilemma faced by agencies when determining how to meet service level requirements and prepare a written policy or guide. Connecticut DOT's policy, like that of many other highway agencies, falls in between these two examples, calling for the use of straight salt on freeways and high-speed highways, abrasive/salt mixtures on non-freeways, and mostly sand on low-speed roads (*88*).

ANTI-ICING

Anti-icing involves the application of ice control chemicals in advance of precipitation to prevent ice formation and bonding of

Condition 1
Temperature near -1°C (30°F)
Type precipitation: snow, sleet, or freezing rain
Road surface: wet
Rate of accumulation: moderate to light
Type mix: straight salt
Rate of application: 27 g/m^2 (350 lb/12-ft lane-mi)
Prior to rush hour: 43 g/m^2 (550 lb/12-ft lane-mi)

Condition 2
Temperature below -1°C (30°F) and falling, but not below -5°C (20°F)
Type participation: snow, sleet, or freezing rain
Rate of accumulation: moderate to heavy
Type mix: straight salt
Rate of application: 27 g/m^2 (350 lb/12-ft lane-mi)
Prior to rush hour: 43 g/m^2 (550 lb/12-ft lane-mi)

Condition 3
Temperature: below -5°C (20°F) and falling to -12°C (10°F)
Type of precipitation: wet to dry snow
Wind: 25 kmph (15 mph)
Rate of accumulation: heavy
Type mix: salt and dry and/or liquid calcium chloride or salt, calcium chloride and sand (to assist in drying of pavement and prevent formation of a thin ice layer)
Rate of application: 27 g/m^2 (350 lb/12-ft lane-mi)
Prior to rush hour: 43 g/m^2 (550 lb/12-ft lane-mi)

Condition 4
Temperature: down to -18°C (0°F) to -12°C (10°F)
Precipitation: dry snow
Wind: exceeding 25 kmph (15 mph)
Road surface: tracking
Rate of accumulation: moderate to heavy
Type mix: salt, dry and/or liquid calcium chloride, and sand or sand and calcium chloride, or sand only
Rate of application: 27 g/m^2 (350 lb/12-ft lane-mi)
Prior to rush hour: 43 g/m^2 (550 lb/12-ft lane-mi)

FIGURE 10 Illinois State Toll Authority guidelines for winter maintenance (*87*).

Condition 1
Temperature below -9°C (15°F)
Begin plowing when 25 mm (1 in.) of snow has accumulated. Spot sand as necessary. Salt is not recommended under these conditions.

Condition 2
Temperature between -9° and 0°C (15°F and 32°F) with dry snow
Treat similar to Condition 1, although rising temperatures may form snowpack that requires spot sanding.

Condition 3
Temperature between -9° and 0°C (15°F and 32°F) with wet snow
When snow is packing and temperatures are *dropping*, plowing should begin when 12 to 25 mm (0.5 to 1 in.) of snow has accumulated. Sand/salt mixtures should be applied to break the bond forming between the snow and pavement. Straight salt is not recommended. When the temperature is *rising*, sand and/or salt should be applied as soon as snow begins to fall to prevent packing and bonding. Under these circumstances, plowing should begin as soon as the salt starts to work and the snow has accumulated to a depth of 12 mm (0.5 in.). Straight salt may be applied at approximately 100 kg per centerline-km (350 lb per centerline-mi).

Condition 4
Freezing rain or sleet
This is the most serious condition. If some snow falls before freezing rain, snow should be left on the pavement to absorb some of the rain and provide limited traction, although heavier snowfall should be removed to keep slush from being created and freezing in pavement ruts and potholes. Salt/sand mix should be applied in a ratio of 1:3 at a rate of 0.5 m^3 per centerline-km (1 cubic yard per centerline-mi).

FIGURE 11 Recommendations by Maine DOT for winter maintenance of local roads (*38*).

snow and ice to the pavement surface. The theory behind anti-icing is that less salt is ultimately needed to prevent ice than to melt it once it has formed, and that less plowing is required to remove snow that has not frozen and bonded to the road surface.

Finland has reported extensive activities with anti-icing, first in the 1970s using dry salt applications and more recently using pre-wetted and aqueous sodium chloride. Based on experiences under many weather conditions and using various application rates and times, the Finnish researchers reported that anti-icing (using brines and pre-wetted materials before initial snowfall) led to less salt use, but that liquid salt was not especially effective once storms had begun (*89*).

Anti-icing practices have also been applied in Sweden (*90*). Following anti-icing experiments (referred to as preventive salting) during the mid 1980s, the Swedish researchers concluded that preventive salting must be done just prior to expected frost or snow; salt should be applied at rates of about 10 g/m^2 (135 lb/12-ft lane-mi) for expectations of normal snow (rates should be increased for higher expected snowfalls), and less than 10 g/m^2 (135 lb/12-ft lane-mi) when hoarfrost (feathery crystals of ice formed when dew freezes) can be expected. Spreaders must be properly calibrated for maximum effect and speed of spreader vehicles must not exceed 30 km/h (18 mph), although speeds can be increased to 50 to 60 kmph (30 to 35 mph) by pre-wetting salt with water or brine.

SHRP has funded research to determine the conditions under which anti-icing is most effective and to develop techniques for enhancing anti-icing under the range of weather conditions experienced in the United States. Preliminary results from SHRP research, which is being continued by the FHWA with some modification, indicate that in certain locations, effective anti-icing can significantly reduce the quantity of materials used during the winter (*91*). The researchers used a friction measuring device (the Swedish-made "Coralba") to indicate anti-icing effectiveness and found that the use of liquid chemicals is more effective than solids for most anti-icing (*92*). The researchers also noted that experiences in Europe indicated that the increased application of new technologies such as RWIS should facilitate anti-icing.

In continuing the SHRP research, FHWA will address some of the uncertainties not fully investigated, such as the optimal time, form, and amount of chemical required to successfully accomplish anti-icing with the least environmental impact and using the required equipment. Fifteen state highway agencies are assisting FHWA with the study, which will also assess the cost-effectiveness of anti-icing and its effect on accident rates (*92*).

USE OF SAND AND OTHER ABRASIVES

Sand and other abrasives are used primarily to improve traction, although they are often mixed with salt and other chemicals for deicing purposes. Abrasives are used routinely for treating snow-packed and icy roads in rural areas. They are also used on medium- and low-priority roads in many non-rural areas, and on all types of roads (for traction) when temperatures are too low for chemical deicing to be effective. In some urban areas, abrasives are not used or are used sparingly because they require cleanup to prevent clogging of storm sewers.

Pros and Cons of Abrasives

According to *The 1993 Public Works Manual* (*77*), abrasives are advantageous in that they are inexpensive, offer some immediate traction on slippery surfaces, and, where cinders or other dark materials are used, provide visible evidence of action by road crews. The manual also notes the disadvantages of abrasives, including low distance of coverage per truckload of material, requiring frequent reloading; adverse effects on cars such as damage to windshields and body finishes; and significant cleanup efforts following storms and the winter season.

In a report discussing alternative snow and ice control materials, Ontario explains that if abrasives are applied without a prior application of chemical deicer to weaken the pavement-ice bond, the snow plow blade is not able to scrape the ice from the road and an uneven driving surface may result (*73*). The report also notes that abrasives can clog catch basins and storm sewers in urban areas, and that disposal of used highway abrasives may be a problem in jurisdictions where used abrasives are classified as waste.

Some jurisdictions are concerned about the effect of abrasives on air quality. According to "Guidelines to Reduce Air Pollution from Street Sanding," published by the Denver Regional Air Quality Council, the grinding action of traffic on abrasive particles can produce a fine, powdery material that can become airborne and contribute to increased particulate matter in the air (*93*). The Denver guidelines recommend ways to reduce the amount of sand used, provide specifications to ensure use of clean sand, and recommend applications of less than 39 g/m^2 (500 lb/12-ft lane-mi). The guidelines also recommend increased plowing before sanding, targeted sanding where accident hazards are greatest, proper training of operators, and accurate calibration of spreading equipment. Guidelines for sweeping procedures and equipment are also included.

Agencies were asked in the questionnaire to judge the effectiveness of abrasives and salt/abrasive mixtures compared to deicing chemicals for snow and ice control. Agencies were asked to rank abrasives as better than, equivalent to, or worse than chemicals for various criteria of effectiveness and impact. The judgments of the agency personnel, which were mixed, are shown in Table 9.

Agency Use of Abrasives

Most states and provinces reported that they use abrasives to increase traction when ice control chemicals do not work, while some reported routine use of abrasives for treating snow-packed roads. Idaho reported routinely using straight sand with minimal salt added to prevent stockpile freezing. North Dakota uses bottom ash and sand mixed with 10 percent salt. Saskatchewan uses straight sand on snowpack at trouble spots during cold conditions and mixes sand with deicing chemicals when temperatures increase, while New Brunswick reported using sand treated with calcium, which is easier to handle under colder conditions.

The majority of cities and counties reported some use of abrasives, either on local roads or when chemicals are ineffective. Several of the cities do not use abrasives because of the impact on storm sewers. Columbus, Ohio uses calcium-treated sand, whereas Glastonbury, Connecticut uses straight sand when temperatures exceed –1°C (30°F) and sand mixed with calcium at lower temperatures. Most agencies mix some road salt with abrasives, if for no other reason than to prevent stockpiles from freezing. The mixes reported ranged from 5 to 10 percent salt to prevent freezing of stockpiles to as high as 50 percent to aid in deicing.

Twenty-six states and two provinces reported using abrasives on all types of roads routinely or occasionally, depending on individual circumstances. Fifteen agencies reported using abrasives under a wide range of temperatures. Ten reported use below –7°C (20°F), although Illinois reported use below –12°C (10°F). Temperatures at which abrasives are used by the provinces ranged from –12° to –6°C (10° to 21°F). Saskatchewan reported that it uses straight sand below –6°C (21°F).

Two cities and two counties reported use of abrasives under temperatures below 0°C (32°F). Denver, Colorado and

TABLE 9
RESPONSE OF STATES ON EFFECTIVENESS OF ABRASIVES WHEN COMPARED TO ICE CONTROL CHEMICALS

Criteria	Better	As Good	Worse	No Answer
Safety	8	6	10	8
Speed deicing	2	3	20	6
Vehicle Corrosion	14	8	1	7
Impact on water	17	5	0	8
Impact on vegetation	18	4	1	7
Impact on drainage	1	2	20	7
Impact on maintenance cost	11	5	8	7

Glastonbury, Connecticut reported using abrasives on all road classes, while other cities reported using them sparingly or not at all.

Application rates vary. For state highway agencies they range from 8 to 92 g/m^2 (100 to 1,200 lb/12-ft lane-mi). Nine states did not indicate rates, while seven indicated that rates vary considerably depending on situations. Three reported using less than 31 g/m^2 (400 lb/12-ft lane-mi), eight reported using 31 to 62 g/m^2 (400 to 800 lb/12-ft lane-mi), and seven reported use of more than 62 g/m^2 (800 lb/12-ft lane-mi). County rates ranged from 8 to 31 g/m^2 (100 to 400 lb/12-ft lane-mi), while city rates varied from 25 to 84 g/m^2 (300 to 1,000 lb/11-ft lane-mi). The general rate of use of abrasives reported in *The 1993 Public Works Manual* is 77 g/m^2 (1 ton/mi of two-lane highway) (*77*).

On the basis of its own research, Ontario concluded that mixing salt in abrasives above the level needed to prevent stockpile freezing improves neither the abrasive qualities of straight sand nor the deicing qualities of straight salt (*73,76*). The agency reported that highway sections treated with straight salt require fewer applications than sections treated with salt/abrasives mixtures, while achieving the same level of service.

Research to Improve Abrasives

Ontario reported that the physical properties desirable for abrasives include the following (*73*):

- Resistance to compression, crushing, impact, and grinding from traffic action;
- An angular particle shape to reduce blow-off and improve skid resistance;
- Dark color to absorb heat to aid in ice melting and reduce blow-off;
- Consistent grain size to provide uniform spread patterns and minimize equipment repair; and
- Maximum grain diameter of 1.3 cm (0.5 in.) to reduce windshield damage, and minimum size of 300 micrometers (50-mesh sieve) for effective skid resistance.

In 1982, Alaska DOT tested several abrasives to compare their effectiveness in providing skid resistance (*94*). The agency reported that coal ash had the most favorable skid resistance properties, while concrete sand was superior to regular sand. Fractured particles were found to be superior to rounded particles for traction, and particles as small as 6 mm (0.25 in.) were found to damage windshields. The researchers recommended that abrasive particles should be able to pass through a 6-mm (0.25-in.) sieve.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) has researched the relative braking traction of various abrasives and concluded that course sands are best suited for warm ice surfaces, and that good performance can be expected under all temperatures for sands with most grains in the 1 to 2 mm (0.04 to 0.08 in.) range (*95*).

Tests such as those at Pennsylvania State University found that heated sand improved traction characteristics and imbedded in ice more readily than regular sand; however, in field tests of mobile heater-spreaders, the sand could not be heated to the level required (93°C (200°F)) (*96*). Colorado and Alaska's tests of heated sand to improve traction did not produce favorable results because difficulties were encountered in heating the materials (*97,98*). Researchers in Finland reported that when using sand heated in the drying drum of an asphalt plant, sand temperatures must exceed 100°C (212°F) when discharged to ensure ice penetration. When sand heated to 250°C (482°F) was applied, the larger sand particles were found effective in penetrating the ice; however, the smaller particles tended to blow away (*66*).

CHAPTER SIX

EQUIPMENT AND FACILITIES

PLOWING EQUIPMENT

Vehicles

Most of the 51 responding agencies reported that they used the same type of vehicles for plowing as for salt and abrasive application, although there were some exceptions. For example, Milwaukee reported that it sometimes uses garbage trucks, or packers, for plowing. Vehicles for plowing are often outfitted with special features such as modified hydraulics (reported by 37 agencies), added axle/spring capacity (32 agencies), reinforced frame (29 agencies), heavy-duty brakes (21 agencies), automatic transmissions (19 agencies, mostly for vehicles used in urban areas), larger engines (18 agencies), and four-wheel drive (10 agencies, consisting mainly of states and Canadian provinces).

Plow Features

Vehicles used for snow plowing are equipped with a variety of plow designs, including those with the following features.

Mold Board Type

The mold board is the curved portion of the plow that scoops the snow off the pavement. Its shape and angle determine the direction of snow movement (casting). Mold boards are mounted on a frame and usually have a separate cutting edge. Standard mold boards are used for light or moderately heavy snows and are capable of reversing casting direction or designed for one-way casting (right or left). Mold boards may be cylindrical or conical in shape, or with variable geometries.

Urethane-coated steel is the most common material used for mold boards, specified by 26 of the 51 agencies that responded to the questionnaire. Steel-type mold boards are specified by 20 of the agencies, while 8 agencies reported using plastic/urethane mold boards. One agency reported that it specifies more than one type.

Cutting Edge

The cutting edge of the plow consists of a blade made of hardened steel located at the pavement end of the mold board. The blade is replaceable, so that the entire mold board does not need to be replaced when the blade wears down and alternative cutting edges can be used. Agencies report using several types of cutting edges. Twenty-three states use tungsten carbide edges, 16 use high-carbon steel, 15 use steel, and 5 use rubber. Most of the provinces and counties reported using tungsten carbide, while high-carbon steel was predominant in most of the cities.

Plow Tripping Mechanism

Tripping mechanisms reduce the impact when vehicles strike utility access covers, raised pavement joints, or other obstructions. By reducing impact, tripping mechanisms improve safety and help reduce impact damage to plows as well as objects encountered. The trip mechanism may be mounted on the cutting edge or mold board, or it may be a segmented mechanism that trips both. Segmented mechanisms are designed mainly for municipal use, as segments of both the cutting edge and the mold board move upward when obstructions are encountered. Thirty-four states and provinces reported using mold board tripping mechanisms, six reported using cutting edge mechanisms, and Ontario reported using the segmented mechanism. Eight counties and cities use the mold board mechanism, one uses the cutting edge, and two use segmented mechanisms.

Plow Shoes (Runners)

Some agencies use plow shoes to lift the blade slightly off the pavement, particularly to avoid striking utility access frames that protrude above the pavement surface, thereby extending the useful life of the cutting edge. Twenty-three states and provinces reported using shoes constructed of steel, while 12 reported using tungsten carbide-faced steel. Seven reported that they are using or experimenting with wheels or castors. While four of the cities and counties use steel plow shoes, most reported using a variety of runner types.

Wing Plows

Wing plows, which are usually mounted on the middle right side of the plowing vehicle, are generally used for two applications: (1) benching snowpiles and (2) expanding plowing width. Wing plows aid in benching snow by moving snowpiles behind shoulders or onto medians to reduce the height of snow windrows and increase storage capacity. Wings are also used in combination with front-mounted plows to expand plow width (i.e., to plow a driving lane and shoulder or portions of two driving lanes at the same time).

Thirty-four states and provinces reported using or experimenting with wing plows, while six reported not using them at all. Some agencies reported using wing plows on all highways or those with full shoulders only, while others use them only on highway shoulders and median borders. Connecticut reported that it uses wings on ramps and for benching snowpiles after storms, while Utah uses them for clearing mountain passes. Two cities use wings on highway sections prone to blowing and drifting snow. Two counties reported using wings for clearing rural highways, while Milwaukee County uses them on all types of highways.

Ice Scrapers and Cutters

Ice scraping involves the removal of the upper surface of ice with the plow blade tilted forward or at a negative angle, less than 90° from the vertical. Ice cutting involves the removal of the entire ice sheet, accomplished by tilting the blade backward at a positive angle to undercut the ice layer and break the pavement-ice bond. Special cutting edges or teeth fastened to the blade are sometimes used for ice cutting.

Nearly all of the states reported using road graders for ice cutting. Twenty-eight states also reported using standard plow blades, 18 with carbide tips, 3 with steel tips, and others with special tips. Nine use truck underbody blades for ice cutting. Oregon uses a special plow blade with carbide insert and a road grader with a serrated ice blade. All of the provinces reported using road graders, while some also use underbody blades, blades with special tips for cutting, and standard plow blades in some cases. Saskatchewan does not scrape ice on paved roads. Three counties reported using a combination of road graders and standard plow blades for ice scraping. Two of the counties use underbody blades, including Milwaukee County, which uses a triple-edged underbody blade.

Alberta has tested a new product for ice scraping that consists of a set of carbide and steel tools. The tools snap into machined holes on an adaptor plate that can be bolted to a mold board grader in the same manner as regular blades (*99*). As the tools wear out, they can be replaced individually or as a set without disassembling the blade set-up. Alberta has deemed the system cost-effective to operate, and more effective at ice cutting than using straight blades.

Maine DOT uses a "back body" ice cutter that mounts on the back of a "reverse" dump truck. The device, which is raised when transported, can be lowered to contact ice when the dump is in the lowered mode. The extra weight of abrasives or salt carried in the truck adds to the cutter's ability to break through and remove ice. The agency reported excellent performance in scraping snow pack and ice using the device, which cost approximately $6,000. The agency has purchased 46 of the devices, each containing an AASHTO-specification blade punch so that a variety of blades can be attached. While the agency found that a sawtooth grader blade worked well on snow pack, the blade provided only a few hours of use and was damaging to pavements if full weight was applied. As a result, the agency is experimenting with a carbide shoe that will fit into the bit holder at the end of the blade at critical points to prevent pavement damage. A scarifier blade with integral bit holders and a carbide-edged chisel bit was found to work well. The scarifier is often followed by a standard plow and spreader that apply sand into the scarified ice until chemicals facilitate ice removal (personal communication, J. Dority, Maine DOT, 1993).

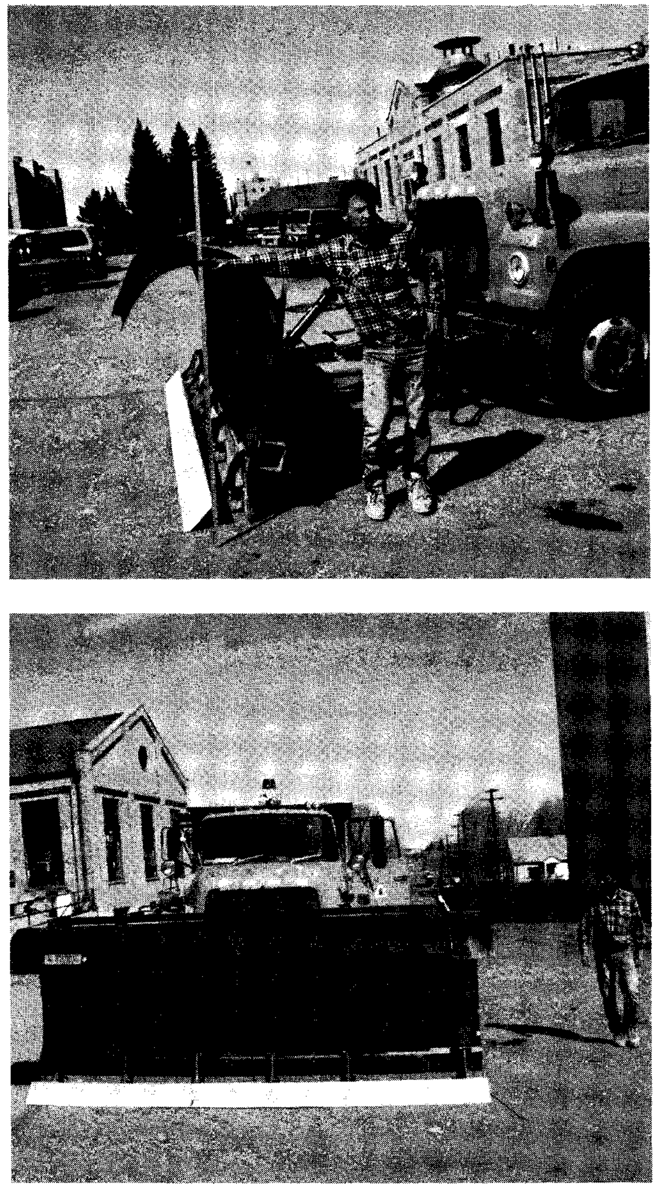

FIGURE 12 Ultra-high polyethylene deflector (snow scoop) in front of cutting edge developed by SHRP.

Research to Improve Plow Equipment

SHRP has sponsored research at the University of Wyoming to develop an improved displacement plow, capable of reducing energy consumption and improving casting performance (*100*). The research has explored the use of an ultra-high and molecular-weight polyethylene deflector (or snow scoop) in front of the cutting edge as shown in Figure 12. The deflector was found to improve plowing efficiency by smoothing the flow of snow onto the mold board. Plow control is also improved because of the reduced force on the plow. In addition, the deflector reduces the snow cloud that is formed by plowing, therefore improving visibility for the plow operator and motorists. The cost of the device is approximately $500 (1993) and is commercially available for testing (*101*). As of 1993, it had not been tested in an urban environment. The research will result in a design manual issued by SHRP; the plow design likely to be recommended will consist of a high mold board with shields on the side (personal communication, D. Minsk, SHRP staff, 1993).

A new plow cutting edge for scraping and cutting ice has also been developed by SHRP to improve the efficiency of ice and compact snow scraping operations (*102*). A sketch of the new blade is shown in Figure 13. A standard blade is shown in Figure 13-a (blade 1) along with SHRP experimental blades (blades 2 and 3). An enlarged drawing of the recommended blade (blade 3) is shown in Figure 13-b. Called the "Advanced Cutting Edge," it is mounted on an underbody truck blade, removing ice with significantly less force than regular edges. The specially shaped tungsten

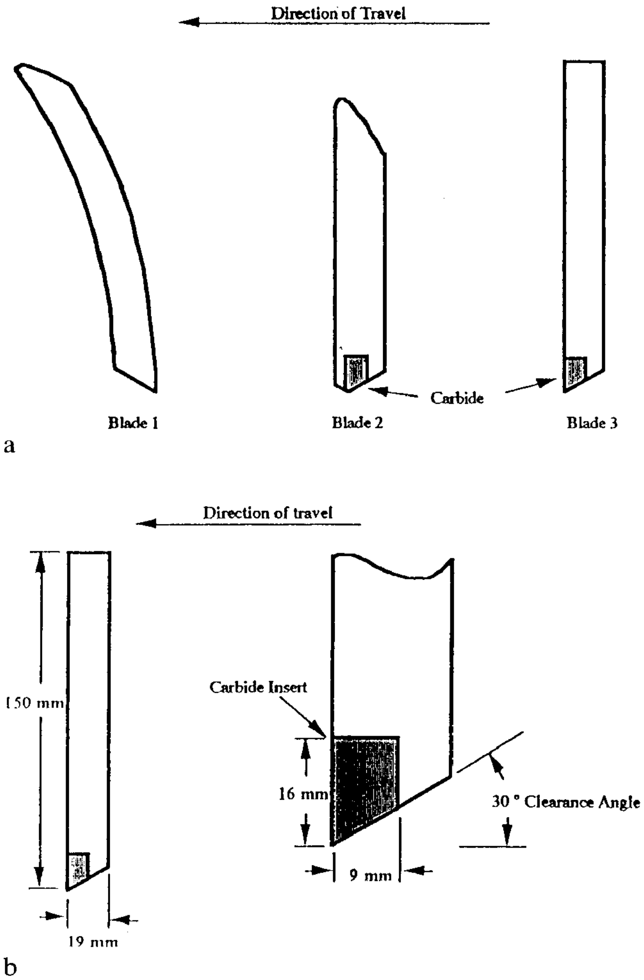

FIGURE 13 Sketches of blades tested in SHRP research. (a) Blade 1—standard; blades 2 and 3—experimental. (b) SHRP recommended blade 3 (advanced cutting edge).

carbide edge incorporates a slight clearance angle between the blade edge and the pavement. The cutting edge is commercially available for agency testing (*101*).

Use of a jet-broom with a front plow and a sweeper-blower unit between the vehicle axles was reported by Switzerland (*103*). Finland reported development of several underbody plows with various cutting edges to level uneven snow pack, and use of a dual blade plow to remove slush from pavement ruts (the cutting edge of the first blade is made of steel, while the edge of the second blade is made of flexible rubber) (*66*). Finland also reported success in using an extendable plow blade with either right or left extensions that can be adjusted by the operator from inside the truck cab (*66*).

Plowing Procedures

Threshold for Plowing

Agencies were asked to describe their thresholds for beginning plowing operations during snowstorms. Twenty-one agencies reported that they plow all accumulated snow, 12 plow snow accumulations exceeding 25 mm (1 in.), 9 plow accumulations greater than 50 mm (2 in.), and 10 wait until depths exceed 75 mm (3 in.). Cities were unique in reporting that they do not plow all snow, whereas some of the states and provinces do. Denver reported that it plows when the snow begins to stick to the pavement.

Plowing Patterns

Agencies employ different plow patterns for two-lane roads and multi-lane highways. When asked to describe how they plow the centerline of two-lane roads, 30 agencies (19 states, 3 provinces, 3 counties, and 5 cities) reported that they extend plows over the centerline on the first pass. Five agencies (3 states and 2 cities) reported that they extend plows over the centerline on the second pass, while 6 state agencies reported that they never encroach on the centerline. Five state agencies reported that they plow the centerline on all passes, while Wyoming reported that it plows centerlines as often as possible without conflicting with traffic. Nova Scotia has no firm rules and relies on operator judgment.

Many states have policy manuals with sketches that show patterns for plowing multi-lane highways using tandem plows in echelon formations. Figure 14 shows Connecticut's echelon patterns for multi-lane highways (with median) and two-lane highways (*88*). New Jersey has similar sketches on echelon plowing, with patterns shown in Figure 15 that vary depending on whether the highway is divided and whether the median is raised (including barriers) or depressed (*104*). One of Minnesota's night formations for echelon plowing on multi-lane highways is shown in Figure 16.

Plow Equipment Allocation and Routing

Agencies were asked to explain their procedures for allocating plow equipment. Most agencies indicated that they allocate plows in much the same manner as spreaders and other snow and ice control equipment, which is covered by procedures defined in their policy and operations manuals.

Illinois' policy manual has an equipment allocation matrix that

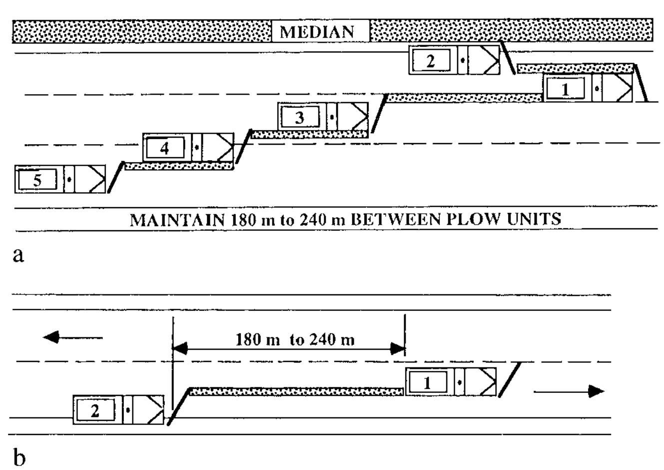

FIGURE 14 Echelon plow patterns recommended by Connecticut DOT (*88*): (a) pattern for multi-lane highway with median; (b) pattern for two-lane highway.

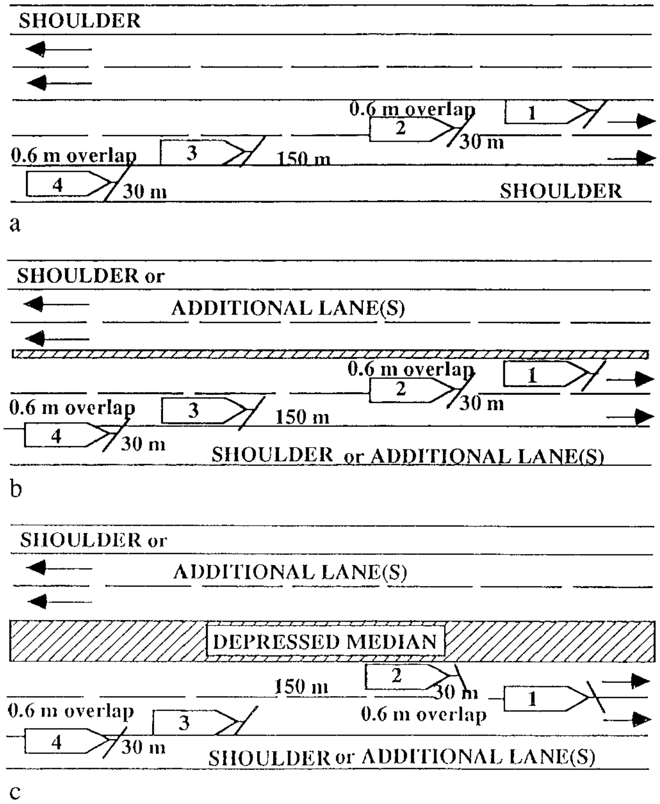

FIGURE 15 Echelon plow patterns recommended by New Jersey DOT (*104*): (a) pattern for undivided multi-lane highway; (b) pattern for highway with raised median (or barrier); (c) pattern for multi-lane highway with depressed median.

shows assignment of one plow/spreader truck per 45 lane-km (28 lane-mi) for freeways and one truck per 64 lane-km (40 lane-mi) for arterials over 3,000 ADT (*6*). For two-lane highways with ADT below 3,000, one truck is assigned per 77 lane-km (48 lane-mi). New York DOT allocates one plow/spreader truck per 32 lane-km (20 lane-mi) for the highest priority highways (i.e., high-volume expressways) and one truck per 48 lane-km (30 lane-mi) for most other highway classes (*74*). Vermont sets standards of accomplishment (productivity) for its plowing crews that result in one plow (with wing) covering 40 to 48 lane-km (25 to 30 lane-mi) on two-lane highways, and tandem plows (one right cast and one left cast) covering the same length of multi-lane highways.

Some agencies are using computer programs and geographic information systems (GIS) to aid in routing plows and other winter maintenance vehicles. A system employed by Indiana DOT uses GIS and computer assisted drafting to improve the routing of plows and spreaders on rural highways (*105*). Digital maps for transportation developed by the U.S. Geological Survey are also used for this purpose. During the 1970s, CRREL reported on the development of a computer model to simulate urban snow removal that assisted in the routing of snow plows using computer graphics (*106*). Applications of commercially available software routing packages have been described in trade magazines. A 1990 article claimed that application of routing software can reduce labor costs, fleet size, and time required to apply deicer to roads by 25 to 40 percent (*107*).

Parking Restrictions to Facilitate Plowing

Seventeen agencies (10 states, 3 provinces, 1 county, and 3 cities) reported that special parking restrictions are put into effect during plowing. Many agencies reported that they ban overnight parking on streets in smaller urban areas during the winter months. Other agencies ban parking on all urban streets during snow emergencies and rely on the media to alert the public to the snow emergency requirements. In large urban areas, more complicated regulations are often necessary. These regulations prescribe alternate side of the street parking during snow emergencies, alternative parking hours, or combinations of the two measures.

In Milwaukee, alternate side parking restrictions are in effect during the winter months on narrow local streets and in high-density districts. Special snow tow-away regulations are in effect for arterial streets. The principal advantage of the winter-long set of restrictions is that plows can quickly begin clearing snow after a storm without encountering delays waiting for a snow emergency declaration and for people to move their vehicles. The disadvantage of this approach is that the winter-long restrictions apply when plowing is not necessary and thus, during mild winters, when plowing is not required as often, the city is under pressure to remove restrictions in areas with high parking demand where people may experience difficulty in locating alternative parking.

By comparison, Minneapolis' restrictions are effective only during a snow emergency. The restrictions prescribe alternate times for parking and prohibit parking on specific sides of streets during

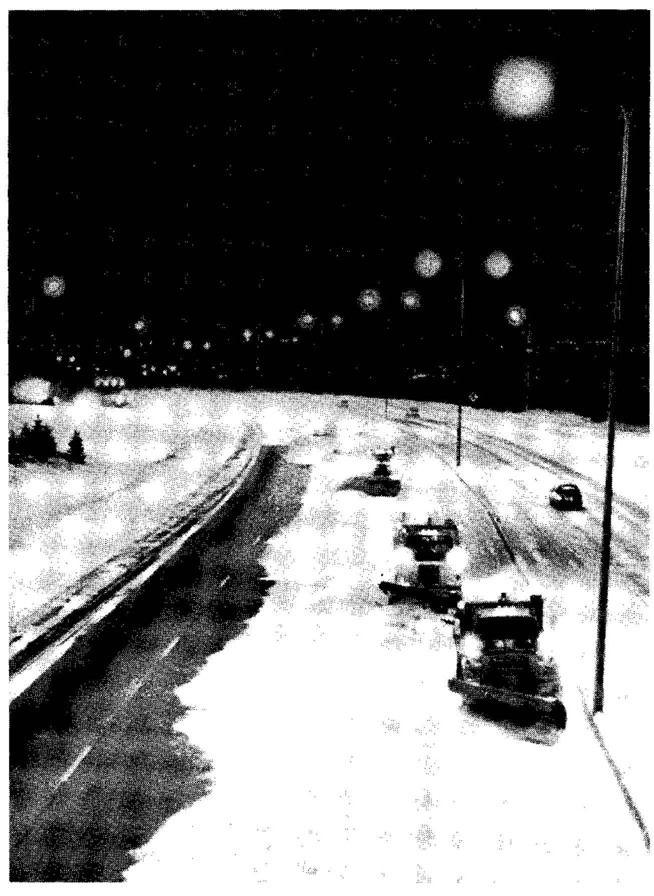

FIGURE 16 Minnesota DOT night echelon plow formation.

declared snow emergencies. An advantage of this system is that the parking restrictions go into effect only when snow removal is required. A disadvantage of this system is that plowing takes longer because parked vehicles must be moved, which may not happen for several hours until the snow emergency is declared and the required restriction is complied with.

SPREADERS

The agencies were asked to describe the types of spreader they specify. Approximately two-thirds reported having specifications for hopper-type spreaders, consisting mostly of conveyor-type designs with some auger designs. More than half of the agencies reported that they use tailgate spreaders, and approximately one-fourth reported using reversible dump/conveyor spreaders. Many indicated that they specify more than one type of spreader.

Spreader Accuracy and Calibration

About one-third of the states and provinces indicated that they have special requirements to ensure spreader accuracy in applying materials. Over half of the counties and cities also reported employing these requirements. The requirements are adhered to by use of ground speed oriented controls or periodic equipment calibration.

When asked if it was difficult to calibrate spreaders at low rates of application (less than 23 g/m^2 (300 lb/12-ft lane-mi)), 14 agencies indicated having difficulty, while 31 indicated having no problems. About 60 percent of the agencies reported that they calibrate manually on the basis of discharge per auger RPM. A number of agencies reported that they tie sacks under the chute to measure discharge, some weigh trucks before and after road runs, and others use the static running-yard method, whereby drive wheels in rollers measure the distance traveled and quantity of material dispensed. Columbus, Ohio reported that it employs a new system that permits continuous calibration. The system consists of a speed-sensing, integrated hydraulics system that contains an electronic console with settings that can be programmed and locked. The system is equipped with an LCD display that reads out information on speed, application amounts, date, and time.

MinnDOT reported that it is working with industry to develop an air-delivered, zero velocity (with respect to ground speed) salt spreader. Plans are for the device to be computer aided in controlling application levels. The agency undertook the project after field testing a representative set of existing equipment used in the United States and finding calibration unsatisfactory at low spreading rates (*108*). To determine if the equipment could provide acceptable spreading patterns, the agency used several measurement methods, including hand sweeping, collection pans, and vacuuming.

European highway agencies were also contacted to find out more about their testing and measurement procedures. Germany and Finland reported that they require equipment manufacturers to demonstrate that their spreaders can control and monitor application rates and spread patterns before the spreaders can be used by highway crews (*108*).

Germany has developed spreader test protocols that consider spread density (g/m^2), spread velocity (km/hr), and spread width (m). According to the protocols, the dosage of spread material must be adjusted so that spread thickness remains constant when the spread velocity is changed in the range between the lowest and highest values; within the adjustment of the spread width, the spread thickness cannot change; within the calculated control valve operating value (testing protocol of the specification), the deviation of the effective spread thickness from the control valve operating value must be within 6 percent; and the limit values of the operating ranges for spread width, spread thickness, and spread velocity must correspond to the predicted application range, spread material, and spread process (varying rates and composition of materials) (from unpublished English translation by R. Blackburn, of "Technical Specifications and Standards for Equipment of the Road Maintenance and Traffic Department," prepared by Research Society for Highway Systems and Transportation, Workgroup on Traffic Management and Safety of Germany, 1991).

Accompanying the German test protocols are various reference points for several materials, such as dry salt, pre-wetted salt, and abrasives. The reference points include various rates of spread width, ranging from 2 to 12 m (6.5 to 39 ft); velocity, ranging from 10 to 60 km/hr (6 to 38 mph); and thickness (rate), ranging from 5 to 40 g/m^2 (65 to 520 lb/12-lane mi) for salt and 80 to 300 g/m^2 (1,040 to 3,900 lb/12-ft lane mi) for abrasives.

The United Kingdom Department of Transportation (UKDpT) is developing standard specifications for spreaders used for road salt anti-icing. Plans are for the spreader to effectively cover three highway lanes with a single truck pass, spreading 10 g/m^2 (135 lb/12-ft lane-mi) across the entire roadway (reported by Ian Lancaster, UKDpT at the open session, TRB's Third International Symposium, September 17, 1992). A prototype of the spreader was constructed in 1992.

Spreader Equipment Allocation

Agencies were asked to estimate the ratio of spreader equipment to lane-km (or lane-mi). Responses varied greatly depending on annual snow and ice exposure. For states that encounter snow regularly, most use 1 vehicle per 48 to 136 lane-km (30 to 85 lane-mi). New York DOT's allocation formula is defined in its policy manual (*74*). The agency allocates 1 spreader truck per 72 lane-km (45 lane-mi). For trucks used for combined plowing and spreading, the agency allocates 1 truck per 32 lane-km (20 lane-mi) of high-volume freeway, and 1 truck per 48 lane-km (30 lane-mi) for other highway classes.

Ratios were higher for provinces, ranging from 1 spreader truck per 80 km (50 lane-mi) to 1 per 160 lane-km (100 lane-mi). Among the counties, the range was 1 truck per 61 to 80 lane-km (38 to 50 lane-mi). For cities, the range was one truck per 32 to 56 lane-km (20 to 35 lane-mi).

BLOWERS

Snow blowers (or rotary snow plows) are used to cut deep snow accumulations, especially in mountainous terrain, or high snow drifts and piles that exceed the height of a plow blade, by blowing snow far off the road in locations where doing so is safe (on rural roads) or into vehicles for hauling (on urban roads) to snow dumps. Blowers are also used for widening shoulders and loading snow in trucks in downtown areas and on long bridges.

Blowers come in a variety of sizes and designs to accommodate urban and rural uses and differences in desired capacity. They may be dedicated to specific vehicles or specially mounted on road graders, end loaders, trucks, tractors, or other multi-purpose vehicles having sufficient power.

Blower Mounts

Thirty-six states and provinces reported using blowers in various mount combinations. Twenty-three states have vehicles dedicated to snowblowing, while 22 use end-loader mounts, four use road grader mounts, and three have other mounts. Five of the provinces reported using end-loader mounts and four have dedicated vehicles. Only one county in Milwaukee reported using the end-loader mount. Seven cities use blowers, four with end-loader mounts and two with dedicated vehicles.

Blower Types and Width of Cut

Agencies were asked to report whether they used single- or two-stage snowblowers and the width of cut they provide. A single-stage blower is generally most efficient in conditions consisting of fresh, light snow because all of its power is used to throw the snow. Single-stage blowers are designed for mounting on equipment with a power takeoff, but also may be equipped with their own engines. These blowers are usually used for smaller jobs. Two-stage blowers have more powerful integrated engines that use about 20 percent of their power to break up the snow using auger or ribbon sections that feed the snow to the impeller. These blowers are best suited for use in conditions consisting of heavy, wet snow or slush, but can be used in any application (personal communication, J. Tews, City of Milwaukee, 1994).

Thirty-one agencies reported using two-stage units, while 11 use single-stage units. Blower cut widths exceeding 2.4 m (8 ft) were reported by 16 agencies, while 18 used widths of 8 ft or less. Width of cut is important if blowers are expected to open a single lane of traffic with one pass, which requires cuts wider than 2.4 m (8 ft). In practice, blowers are generally followed by plows, because spillage needs to be cleaned up following the blowers.

The majority of states reported having blowers with capacities of 1,360 m^3 (1,500 ton) per hour, whereas most cities reported lower capacities. California uses blowers with capacities exceeding 4,500 m^3 (5,000 ton) per hour, which was the highest capacity reported.

RADIO EQUIPMENT

Radio communications are an integral part of winter maintenance for monitoring operations progress and alerting agency personnel about emergency situations, including equipment breakdowns. Thirty-one agencies reported that virtually all of their vehicles are equipped with radios, while 12 reported that at least 75 percent are equipped. Only 8 agencies reported that less than 75 percent of their vehicles have radios.

Nineteen states and provinces reported that they seldom encounter problems with radio communications, while 13 reported occasional difficulties, including overlap of frequency between districts, interference in mountainous terrain, and obsolescence of equipment. Seven of the counties and cities reported no problems, while three reported difficulties. The lack of repeater stations, dual frequencies that are cross-patched, and old equipment were identified most often as creating problems.

SAFETY EQUIPMENT

Agencies were asked to identify safety devices used in winter maintenance, and a number of devices were reported.

Equipment to Enhance Plow Blade Visibility

Because it is difficult for some drivers to view the plow blade when it is positioned for plowing, therefore making it vulnerable to striking roadside objects and parked vehicles, agencies use several devices to make the blade more visible. Nineteen states and provinces reported using flags or plow markers to improve the visibility of the plow. Thirteen reported using lights mounted to the plow, and two use reflective tape. Indiana paints the blade black for contrast with snow, and New Mexico uses mirrors angled to reflect the plow blade. Ontario uses mirrors equipped with fans for defrosting. Seven of the cities and counties reported using flags, while four counties and cities use plow lights.

A snow plow marker was developed and tested by SHRP to enable passing motorists to see the blade edge and to provide plow, operators with a visual cue about the position of the blade. The marker consists of a set of lights mounted on the ends of the plow.

Equipment to Enhance Truck Visibility

Thirty highway agencies reported using yellow, red, or blue strobe lights on the backs of plow and spreader trucks to make them more visible to motorists and other plow operators. Twenty agencies use rotating beacons, while several other agencies reported using four-way flashers, reflectors, and signs alone or in combination with lighting systems. Arkansas reported use of a lead/follow vehicle.

Because MinnDOT averaged more than 50 accidents per year involving its plows, often because of the effects of snow plumes created by the plowing, the agency conducted research to improve plow lighting. The agency compared several different truck lighting configurations, which were videotaped during their use in the winter of 1988–1989. The agency concluded that the plow trucks equipped with lights mounted on both sides of the cab shield, as well as in other configurations, were much more visible, although they were sometimes obscured by snow pluming from the plow (*109*). The agency recommended new lighting systems for plow trucks, but noted that snow plumes can obscure all types of lighting systems at times, and that redesign of the plow blade should be explored to reduce the plume. The recommended system consisted of adjustable and rotatable yellow and blue strobe lights mounted back to back and horizontally above each side of the cab shield, a yellow strobe light mounted on each rear corner of the truck, and cab shields painted black.

Truck-Mounted Attenuators (TMAs)

TMAs are designed to provide a crash cushion if the truck is hit from behind. Few agencies reported using TMAs on winter maintenance trucks. Researchers for SHRP have developed a specially designed TMA for spreader trucks, which mounts on the rear of the

FIGURE 17 Truck-mounted impact attenuator for spreaders, developed by SHRP.

truck along with the spreader attachments (Figure 17). The TMA permits normal distribution of material while providing a crash cushion in the event of a rear-end collision. The device pivots up and out of the way when not needed, enabling the spreader to operate with it in the up or down position. The cost of the SHRP-developed TMA, which is commercially available, is approximately $8,000 (1992).

SNOW FENCES

Snow fences can be an economical way to control blowing snow. Twenty-eight states reported using snow fences. Fourteen use them for drift control in a variety of locations including mountain passes (Alaska), plains (Texas), and farming areas (Indiana). Six provinces reported using snow fences, primarily in drift areas and mountain regions. One-half of the cities and counties use fences for drift control.

SHRP has been active in snow fence research. According to SHRP's "Blowing Snow Control Design Guide" (*110*), 12 m-(4-ft) high slatted fencing is inadequate for areas with substantial drifting. However, new, lightweight plastics allow fence construction to a 2.4 m (8 ft) height. The guide advises that fence height must take into account the prevailing wind direction and the distance (or fetch) and that fences should have sections on each end with a length of 20 times the fence height and a gap at the bottom equalling 10 to 15 percent of the height. The distance between the fence and the area to be protected should be 35 times the height.

Some highway agencies have experimented with snow fences. Alberta reported positive findings from using a square-patterned, polypropylene material to replace standard wood-slatted fence, because the material was much lighter and required less labor to install (offsetting its higher price) (*111*). Wyoming DOT reported using hedges, or living snow fences, instead of wooden ones (*112*). With adequate maintenance, the hedges survived, although growth was slow. After 8 years, however, the hedges were still insufficient to function as a replacement for large board fences. It is expected that with future growth, hedges will provide suitable replacement for the board snow fence.

Other states have also developed natural snow fences. Iowa has had a cornrow snow fence program since 1986. A press release is sent to farmers each year in April encouraging planting of cornrows parallel to state highways, leaving four to eight rows of corn standing at harvest time (about 30 m or 100 ft), and farmers are compensated for the lost crop. Farmers also benefit from not having their fields damaged by workers and equipment during fence installation (*112*).

A series of sketches in Maine DOT's guide for snow and ice control on local roads illustrates how weed and brush growth on highway slopes can contribute to snow drifting, and how well-placed slopes can help mitigate this effect (shown in Figure 18) (*38*). Guidelines with step-by-step design procedures have been developed for snow fences used in eastern Canada (*113*). Ontario is developing design guidelines for spacing snow hedges and selecting compatible species of hedges (discussed at open session, TRB's Third International Symposium, September 17, 1992). The province is reviewing the necessary administrative changes to allow planting on private lands.

SPECIALIZED EQUIPMENT

Bridge Snow Removal Equipment

Four states use specific equipment for removing snow from bridges. Connecticut and Kansas reported using small loaders, Maryland uses front-end loaders with blowers and belt loaders, and New Hampshire uses small, reversible plows on bridges with weight restrictions. Nova Scotia uses blowers on tractors, and Ontario uses bucket-end loaders. Milwaukee County reported use of snowblowers on bridges. Denver was the only city that reported using special equipment for bridges, such as lightweight pick-up trucks with plows and spreaders on load-restricted bridges.

Avalanche Equipment

Four states reported using several devices for avalanche protection. Colorado uses snow sheds to reduce avalanche hazards, while Alaska uses a jet roof structure for a snow shed (*114*). The structure, located in a notch shaped cut at the top of Thompson Pass in

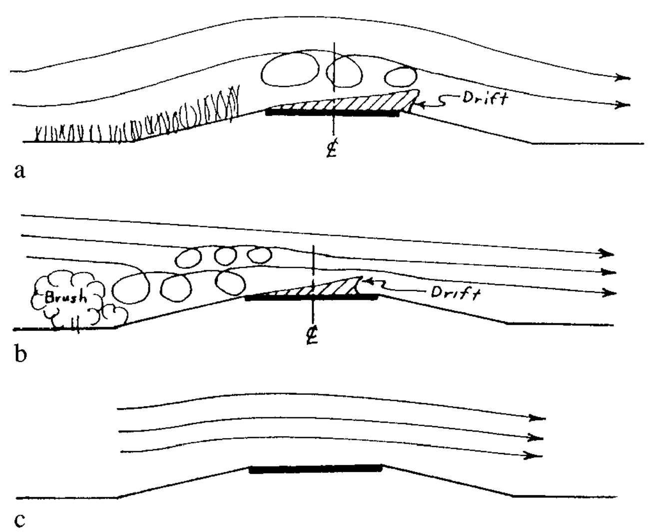

FIGURE 18 Maine DOT's illustrations of weed and brush growth effect on snow drifting (*38*). (a) Effect of weed growth on highway snow drifting. (b) Effect of brush growth on highway snow drifting. (c) Consequence of brush and weed clearance effect on drifting.

the Chugach Mountains, is designed to boost wind velocities, therefore increasing snow movement to eliminate cornice buildup in the notched shape highway cut.

Wyoming uses surplus military artillery to trigger controlled avalanches. California uses several trigger devices, including Gazex, Locat, rifles, and land charges. Gazex is a patented French system that consists of one or more permanently mounted chambers that direct the pressure wave from ignited propane down on the snow cover to precipitate an avalanche. A charge consisting of oxygen and propane is loaded and the explosion chambers are triggered by a radio signal. One such installation is located near where US Highway 50 passes through the Sierra Nevada Mountains (personal communication, R. Watkins, Caltrans, 1993). Locat is a low-cost artillery training device used by the British that has been adapted for avalanche purposes. It consists of an 80-mm high-pressure, air-propelled projectile with low shrapnel. The system is commercially available in the United States (personal communication, J. Tonkin, Caltrans, 1993).

Caltrans has recently developed a buried cable technology for locating roads under heavy snow cover. A cable is buried in the center of the roadway, and a cable fault locator is used to determine location (*115*). The device was developed for locating roads that have been closed all winter, as well as those under avalanche cover.

WINTER MAINTENANCE FACILITIES

A number of different facilities are needed for winter maintenance, including salt storage facilities, equipment repair locations, and snow disposal sites.

Salt Storage

Agencies were asked to categorize their salt storage facilities by type and to indicate the share in each category. Most agencies use more than one kind of storage. Forty-two agencies reported using shelter buildings or other enclosed structures, such as beehive-type buildings. Twenty-four states also reported storing salt on a concrete slab under covering.

Agencies that store salt on the ground, or at other locations where runoff can occur following rain, risk contamination of local groundwater. In 1989, MinnDOT created a task force that developed 25 recommendations for the elimination or proper handling of salt runoff from storage sites such as preventing formation of salt brine, collecting and disposing of brine, storing salt and sand in covered structures, disposing of truck wash water in sanitary sewers, and either spraying the wash on sand piles or hauling it to an approved disposal site (*116*).

The Salt Institute has developed a handbook that explains all aspects of storage, including site selection, sizing facilities, land required, construction details, roof requirements, and ventilation needs (*117*). The Swiss federal highway office reported that it stores salt in silos. The silos enable faster filling of spreaders because they permit several trucks to be filled simultaneously and drivers can load without additional help or equipment (*103*).

Equipment Repair Facilities

Highway agencies were asked to describe how their equipment repair facilities operate during storm events. Thirty-four reported that their facilities are staffed 24 hours per day during emergencies, while 15 agencies reported that they staff normal hours. Twenty-seven agencies reported having remote repair facilities, while 25 reported having capabilities for timely field repairs.

Snow Disposal Sites

An extensive study of snow disposal alternatives was conducted by Ottawa in 1991 (*118*). The study, which was initiated in response to concerns about the environmental consequences of chemical constituents in highway runoff, recommended a series of land disposal sites that would minimize salt runoff into receiving streams.

Several innovative snow removal and transport alternatives were explored in Finland in 1983 (*119*). Among the measures examined were integrating dumps in town plans, using waste heat from power plants to melt snow, dumping snow into main sewers, and using snow melting machines.

HIGHWAY MODIFICATIONS TO FACILITATE WINTER MAINTENANCE

Design Changes

Agencies were asked in the questionnaire if they have made changes in highway design to facilitate winter maintenance. Eight reported changes to medians, 11 to highway profiles, 15 to typical sections, and 15 to drainage systems.

Saskatchewan has flattened back-slopes, while Ontario has widened some shoulders and also flattened back-slopes. Milwaukee has reduced the use of narrow full sidewalks for snow storage by storing snow windrows in the roadway. Worcester, Massachusetts requires cul-de-sacs at all dead ends and has set a 10 percent maximum grade for new streets with a minimum width of 9.1 m (30 ft). The Maine local road snow guide has several sketches shown in Figure 19 that illustrate how changes to highway profile and typical section can help control drifting (Figure 19-a) (*38*). Flat side slopes (4:1 or flatter, shown in Figure 19-b) help prevent drifting onto the pavement, whereas steeper slopes increase drifting (Figure 19-c). Use of cut sections on windward sides also reduces drifting (Figure 19-d).

In 1979, New Hampshire DOT identified a variety of design changes to facilitate winter maintenance (*120*). These include the following: design the left side of bridge decks on super-elevated curves with a small section sloping away from the pavement, as a shoulder would slope away from super-elevated driving lanes (this change will keep snow melt from running off the parapet and onto travel lanes, thereby reducing icing, caused by refreezing of the runoff, and salting needs); minimize use of channelizing islands because they create snow storage and melting problems; install median crossovers for use by maintenance crews; and provide drainage in medians and gore areas so that snow melt does not run onto the pavement.

Pavement and Bridge Heating Systems

Two agencies reported using heated pavements for preventing or melting snow and ice. Wyoming has an electrically heated pavement on a down-grade bridge approach. Arizona uses heated pavements on some super elevations, bridge decks, and ramps.

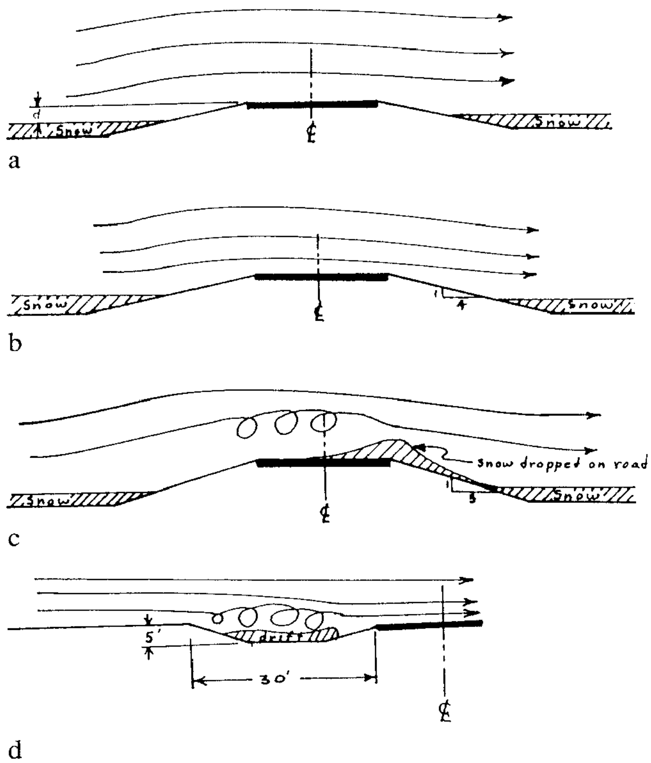

FIGURE 19 Maine DOT's illustrations of the effect on highway profile and typical section on snow drifting (*38*). (a) Profile and typical section. (b) Flat side slopes reduce drifting. (c) Steeper slopes increase drifting. (d) Cut side sections on windward sides reduce drifting.

In a 1978 contract study, the FHWA researched pavement heating systems that use heat generated from the earth (*121*). An installation in West Virginia was used as a model. The West Virginia system uses pipes heated by geothermal energy, a detailed description of which is provided in a 1986 article in *Better Roads* (*122*). The application of heated bridge technologies is being explored further by the FHWA. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) included provisions for several heated bridge demonstration projects. The federal government will pay 80 percent of the installation cost for a minimum of 10 bridges annually (*123*).

Holland, Michigan installed a snow melting system during renovation of its downtown area in 1988 (*124*). The system circulates hot water at 32°C (90°F) from the city's power plant in polyethylene tubing to keep five blocks of sidewalks and the main street free of snow. Operating costs are $30,000 annually (based on the winter of 1989–1990). The city has expanded the system into two adjacent parking lots and is considering further expansion.

In 1992, Japanese researchers reported high costs for heated pavements using a variety of heat sources, including warm groundwater (*125*).

Asphalt Additives

A number of states have experimented with different asphalt mixes, some of which are intended to improve traction during winter conditions. Nine states, one province, and one city reported having experimented with the asphalt admixture Verglimit for anti-icing, mostly on bridge approaches and decks. Several others reported using rubber-modified asphalt partly because of potential traction improvements following winter storms.

Verglimit is a proprietary product that was developed to slow icing of highway pavements until maintenance is provided. The admixture, which is blended into the asphaltic cement surface of pavement, contains encapsulated calcium chloride pellets, which keep the calcium chloride inactive until the pavement surface wears under the action of traffic. Once exposed, the pellets are crushed by traffic and the calcium chloride absorbs moisture in the air to form an anti-icing solution that reduces or eliminates the need for ice control treatments. According to a 1986 report by the Ontario Ministry of Transportation, the Verglimit increased the cost of paving by about 170 percent when added to asphalt in the range of 5 to 7 percent by mass (*73*).

California, Oregon, and Virginia reported poor results with the admixture, while two states reported that experiences were too limited to make a judgment. In 10 test installations of Verglimit in Ontario, 5 were found to retard ice formation on the surface, 4 did not have an affect, and 1 was deemed more prone to icing than comparable regular asphalt. In some cases where the product was found effective in retarding ice formation, Verglimit caused blowing and drifting snow to stick to the pavement (*73*). In some cases, product effectiveness was found to be reduced after 5 years.

There are numerous reports documenting use of Verglimit in the literature. In 1991, the FHWA summarized the results with Verglimit in several states as follows (*126*):

- A Verglimit project in New York performed well in light snowfalls, but was less effective in heavy snowfalls. The pavement performance was deemed satisfactory, and New York reported a reduction in winter accidents of 86 percent on one of the two routes used in the project (*127*).
- In a project in Colorado, anti-icing was reported to be slow, requiring the use of salting and sanding operations that masked the ultimate effect of the Verglimit. The pavement was found to be slick shortly after paving because some of the calcium chloride particles were crushed by the roller. This effect was controlled by sanding of the pavement following construction.
- In Pennsylvania, slickness was controlled by first sanding and then flushing the surface several times with water, which is a practice now recommended by the supplier.
- The experience with Verglimit in Minnesota was unsatisfactory. Minimal deicing benefits were found, and the pavement had to be replaced because of poor performance (e.g., shoving). Laboratory tests of the Verglimit indicated that the pavement was prone to swelling during the first month after application, causing ravelling and moisture infiltration.

In summarizing the construction requirements for Verglimit, the FHWA emphasized the need for careful control of the void content of the asphalt mix and the rollering temperature, which are much more critical than for conventional asphalt mixes (*126*).

Another paving system that is purported to have ice control benefits is rubber-modified asphalt. Rubber-modified pavement systems, which were introduced in Sweden in the late 1960s (*128*), consist of large rubber particles mixed into the asphalt to increase skid resistance and durability. The protruding rubber is supposed to improve friction on icy pavements. These systems are distributed under the names Skega Asphalt or Rubit in Northern Europe and PlusRide in the United States.

Alaska has reported on five experimental test sections of rubber-modified pavement that were installed between 1979 and 1981 (*128*). Major changes in pavement mix design were required to achieve durable, non-ravelling pavements. Measurements of skid resistance showed that significant reductions in icy road stopping distances resulted from use of the rubber-modified paving system. Reductions in stopping distance averaged 25 percent, and ranged from 3 to 50 percent.

Minnesota tested rubber-modified pavements in the late 1980s but found no significant deicing benefit (*129*). In 1991, the FHWA summarized the experience of the PlusRide rubber-modified paving system in three other states (*126*):

(1) New Jersey DOT found improved skid resistance in its test section and determined that the product performed satisfactorily, although some initial rutting developed in 1982 tests.

(2) The state of Washington evaluated the product for 5 years, concluding that it did not show enhanced frictional properties.

(3) Rhode Island reported no differences in friction characteristics in its rubber-modified pavement test section compared to sections consisting of standard paving systems.

The FHWA concluded that rubber-modified pavements have several properties that differ from standard mix design principles, including lower resistance to cracking and rutting, and therefore has recommended certain mix design practices for these paving systems (*126*).

Maintenance Research

MinnDot began allocating one-half percent of its annual maintenance budget in 1990 to improve all areas of maintenance and operations. The money has been used to purchase experimental materials and equipment in the winter maintenance area. This ensures a regular source of funds to support the evaluation of new ideas and has resulted in a substantial source of operating improvements (R. Pletan, Chief Maintenance Engineer, MinnDOT, presentation at TRB's Third International Symposium).

CHAPTER SEVEN

FINDINGS AND RECOMMENDATIONS

This chapter summarizes some of the key points from topics covered in the preceding chapters and identifies opportunities for further research and evaluation.

POLICIES AND MANAGEMENT

Most agencies have developed written policies to guide their winter maintenance practices. These policies are often contained in a policy manual or section of the agency's procedural manual. A number of agencies have publicized their winter maintenance policies through pamphlets, demonstrations, media contact, and other means.

Most policies define level of service for classes of highway based on their priority. Level of service policies tend to be results-oriented (e.g., bare pavement), resource-oriented (e.g., 24-hour equipment coverage), or a combination of both. In most cases, the policies are intended to guide practice, while providing agency personnel with the flexibility to handle specific circumstances. This guidance is also important to ensure that practices conform to policies that reduce agency risk and exposure to liability.

Winter maintenance policies are increasingly influenced by legislative requirements. Agencies in some states and local jurisdictions are required by law to curtail use of deicing chemicals, which has led to experimentation with reduced salting programs and alternative ice control chemicals and methods, including anti-icing. About one-third of the agencies reported having experimented with or implemented reduced salting programs. Road salt use has been linked with adverse effects on the environment as well as infrastructure and motor vehicles. Benefits provided by chemical deicing and other aspects of snow and ice control are also generally regarded as significant, although they are difficult to quantify and are not extensively documented.

Further research to identify and better define the various benefits and costs of snow and ice control programs is needed and quantification in monetary terms, although desirable, may not always be practical. Pressure on agencies to reduce winter maintenance expenditures and demands for the use of alternative ice control materials and techniques that have fewer adverse environmental effects, including curtailed salt use, can have multiple implications—such as affecting congestion, safety, commerce, the environment, and infrastructure—that must be well understood by decision makers. During the past two decades, many agencies have adopted or experimented with new winter maintenance policies and techniques for snow and ice control, including different deicing treatments and methods. A thorough catalogue of these efforts, including an assessment of their objectives, successes, and failures, would be extremely valuable for highway agencies responsible for snow and ice control at all levels of government.

SNOW AND ICE CONTROL METHODS, MATERIALS, AND EQUIPMENT

New technologies in the application of RWIS and weather forecasting services are being implemented in many snowbelt states. These technologies are likely to have major repercussions on the operations of snow and ice control programs.

The use of chemicals and other materials for snow and ice control, which currently account for approximately 25 percent of winter maintenance expenditures, has already been impacted by new technologies in many jurisdictions. Developments in weather information systems are facilitating the use of new techniques for chemical treatment of highway snow and ice that promise to be more efficient and effective, including anti-icing and pre-wetting techniques. The continued development of technologies that improve the timeliness and accuracy of weather information at the regional and road network levels may make the use of salt alternatives such as CMA more feasible for many highway agencies by permitting targeted applications in salt sensitive areas.

To fully achieve the benefits promised by these new technologies, further developments are required in certain other complementary areas of winter maintenance operations. For example, for anti-icing and pre-wetting to be effective, agencies need access to spreaders that are capable of accurate calibration at low rates of chemical discharge (e.g., 8 g/m^2 or 100 lb/12-ft lane-mi) at a variety of speeds and that can accommodate solid or liquid material. This will likely require the development of refined spreader protocols that can be employed by agencies to ensure that their equipment is capable of performing these techniques. While standard methods for testing spread patterns, thickness, and rates of discharge have not been developed in the United States, many European highway agencies have found them practical and beneficial.

Several additional measures would also help facilitate the implementation of new snow and ice control technologies and methods. The development of more uniform data communications and format protocols for RWIS would likely reduce the cost of these systems to agencies by enabling jurisdictions to share key system components such as CPUs, particularly across agency and state boundaries. Many of the promising and innovative products developed by SHRP will require some additional field testing before they can be applied widely. Past experience indicates, however, that these new techniques, once proven effective, may not be applied by all agencies for many years.

If the timing of state-of-the-art advances and their field implementation is too close, agencies will need resources for experimentation and evaluation. Some highway agencies have established strong links between researchers and operational staff that have led to successful field trials and eased the implementation of new products.

GLOSSARY

abrasives—Sand, stone chips, ground slag, bottom ash, or cinders used to provide traction on iced surfaces.

anti-icing—The application of ice control chemicals before or at the onset of precipitation to prevent the formation of strong ice-pavement bonds.

aqueous—A solution made with water.

benching (also called shelving and high winging)—Reducing the height of roadside snowpiles (mounds or windrows) by pushing back the top portion of the windrow, thereby leaving a bench (or shelf) that permits further snowpiling during subsequent storms.

CMA (calcium magnesium acetate)—A man-made deicing chemical developed by the Federal Highway Administration that is being used by some highway agencies because it has fewer adverse effects than salt (sodium chloride) on the roadside environment and highway facilities.

corrosion inhibitor—Usually an additive to an ice control chemical that is provided to prevent or retard the corrosion effects of the chemical on steel components in pavements and bridges and other metal highway objects.

CPU (central processing unit)—A component of a road weather information system that receives and processes data from pavement and atmospheric sensors passed through remote processing units (RPU). The CPU is the final link in the processing chain and has the capability for two-way communication with users.

deicing—The application of an ice control chemical (deicer) after an ice-pavement bond has developed to assist breaking the bond.

echelon plowing—Two or more snow plows proceeding in stepwise formation in different paths.

GIS (geographic information systems)—Systems to automate, store, and display information of a wide variety that has a geographic reference source. The systems include hardware, software, data, and people who operate the systems.

hoarfrost—White, feathery crystals of ice formed when dew freezes.

ice control chemical—Chemical used for deicing or anti-icing.

ice cutting—Removal of the entire ice layer by tilting snow plow blade backward to get under the layer to mechanically break the bond with the pavement.

ice scraping—Removal of the upper surface of ice by tilting the snow plow blade forward.

LOS (level of service)—A policy statement or practice by a highway agency describing either the condition of pavement to be achieved (results desired), equipment deployed, materials used, and/or hours of application (amount of resources used), or a combination of the two. LOS policies usually vary by highway class priority.

NEXRAD (Next Generation Radar)—A new system of pulsed-Doppler radar stations being constructed across the United States by the National Weather Service, with completion scheduled for 1995 (*58*).

NWS (National Weather Service)—Part of the U.S. National Oceanic and Atmospheric Administration.

policy manual—A document describing an agency's practices to achieve winter maintenance requirements for the benefit of the public, elected officials, and agency personnel. Details for policy implementation are usually found in a maintenance procedures manual.

procedures manual—A document detailing an agency's practices and procedures regarding personnel, equipment, and materials used for winter maintenance, including pre-storm preparations, mobilization, operations, and cleanup.

provinces—The Canadian provinces.

relief drivers—Operators of equipment or vehicles who relieve regular personnel during prolonged snow and ice control operations.

road salt—Sodium chloride (NaCl) commonly used as an ice control chemical, sometimes referred to as rock salt. When salt dissolves in water, the freezing point is depressed in proportion to the concentration of ions in solution. Because sodium chloride is very soluble in water and yields a large number of ions per unit weight, it is especially effective as a freezing point depressant, or ice melter (*3*).

RPU (remote processing unit in an RWIS)—The unit is located adjacent to a highway site for which specific weather and pavement information is collected and transmitted to a central processing unit (CPU).

RWIS (road weather information systems)—Systems consisting of field sensing equipment, processing software, and communications equipment that are linked to central computers and weather forecasting services to provide timely and road-specific weather information and forecasts to highway agencies.

shelving—See benching.

SHRP (Strategic Highway Research Program)—Administered by the National Research Council. SHRP was a 5-year (1988–1993), large-scale research program authorized by the U.S. Congress to yield new products and technologies to improve highway construction and maintenance. Although the funding was programmed for a 5-year period, reports continue to be published from the program results and seven long-term activities are continuing under separate support. One of SHRP's program areas addressed winter maintenance.

spreader—Vehicle equipped for the manual or automatic discharge of ice control chemicals, abrasives, or mixtures.

thermal mapping—The collection of pavement surface temperature data by remote infrared scanning and other techniques under a range of weather and temperature conditions. The data are plotted on a map to indicate temperature variations in the highway system that are related to geographic position. Thermal mapping is sometimes used to suit RWIS stations and to locate cold spots on the highway system.

TMA (truck-mounted attenuator)—A mobile crash cushion custom mounted on the back of an ice control spreader or snow plow to minimize the impact of a rear-end collision by motorists caused by the slow-moving vehicle or blowing snow that limits driver visibility.

ton—A short ton, consisting of 2,000 U.S. lb.

tonne—A metric ton, consisting of 2,204.6 U.S. lb.

windrow—A snow mound left parallel to the path of the snow plow blade following the pass of a snow plow.

REFERENCES

1. *NCHRP Synthesis of Highway Practice 24: Minimizing Deicing Chemical Use*, Transportation Research Board, National Research Council, Washington, D.C., 1974.
2. Boselly, S.E., and D.L. Jonas, "Staff Weather Advisor: A Person for All Seasons (and Many Reasons)," presented at the TRB 3rd International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
3. *Special Report 235: Highway Deicing: Comparing Salt and Calcium Magnesium Acetate,* Transportation Research Board, National Research Council, Washington, D.C., 1991.
4. "AASHTO Maintenance Manual," American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1987.
5. "District 1 Snow Control Manual," Division of Highways, Illinois Department of Transportation, Springfield, October 1989.
6. "Snow and Ice Control Manual—District 2-9," Illinois Department of Transportation, Springfield, January 1991.
7. "Minnesota DOT Maintenance Manual—Snow and Ice Control," Minnesota Department of Transportation, St. Paul, June 1986.
8. "Ice and Snow Removal Manual," Minnesota Department of Transportation, St. Paul, February 1991.
9. Heinz, T., "Snow and Ice Control Program Operations Manual," Department of Public Works, Barrington, Illinois, November 1991.
10. "Snow Control Plan," Denver Public Works Department, City and County of Denver, Colorado, undated.
11. "Chapter 15—Snow and Ice Control," in "Maintenance Manual," Colorado Department of Transportation, Denver, January 1990.
12. "Chapter R—Snow and Ice Control," in "Maintenance Manual," California Department of Transportation, Sacramento, December 1989.
13. "Maintenance Manual-Section 13—Snow and Ice Removal," Wyoming Department of Transportation, Cheyenne, September 1989.
14. Teppo, M., "Highway Winter Maintenance and Cost Efficiency," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
15. "Fight Winter and Win—A Survival Guide for Public Officials," American Public Works Association, Kansas City, Missouri, 1992.
16. Kuennen, T., "Snow Budgets Stable, PR Efforts Up, Survey Shows," *Roads and Bridges*, Vol. 27, No. 6, June 1989, pp. 40-46.
17. "Liability of State and Local Governments for Snow and Ice Control—Vol. 4," in *Select Studies in Highway Law*, Transportation Research Board, National Research Council, Washington, D.C., 1976, pp. 1869-1888.
18. "Supplement to Liability of State and Local Governments for Snow and Ice Control," in *Legal Research Digest*, No. 9, Transportation Research Board, National Research Council, Washington, D.C., February 1990, pp. 1-10.
19. "Written Policies to Avoid Litigation," Rural Technical Assistance Program Quarterly Newsletter (unnumbered), Montana State University, December 1991, pp. 2-3.
20. Bryer, T., "Risk Management Analysis: Highway Maintenance Operations," in *Transportation Research Record 979*, Transportation Research Board, National Research Council, Washington, D.C., 1984, pp. 20-24.
21. Migletz, M., J. Graham, and R. Blackburn, "Safety Restoration During Snow Removal—Guidelines," Report No. FHWA-TS-90-036, Office of Implementation, Federal Highway Administration, McLean, Virginia, February 1991.
22. Hill, A., R. Sinn, R. Nibbe, and G. Korphage, "Grygla Snow and Ice Service Level for Low Volume Highways," in *Transportation Research Record 1127*, Transportation Research Board, National Research Council, Washington, D.C., 1987, pp. 27-33.
23. Öberg, G., P. Arnberg, G. Carlsson, G. Helmers, K. Jutengren, and P.G. Land, "Experiments with Unsalted Roads—Final Report," Report 282A, Swedish Road and Traffic Research Institute VTI, Linköping, Sweden, 1985.
24. Öberg, G., K. Gustafson, and L. Axelson, "More Effective De-icing with Less Salt," Report 369SA, Swedish Road and Traffic Research Institute, Linköping, Sweden, 1991.
25. Axelson, L., "Proposal for New Winter Road Maintenance Strategy—MINSALT," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 12-16.
26. "The Economic Impact of a Snow Storm which 'Shuts down' the Milwaukee Economy," Division of Economic Development, Department of City Development, Milwaukee, Wisconsin, revised February 1980.
27. Björketun, U., "Experiments with Improved Winter Preparedness—Traffic Accident Analysis," Swedish Road and Traffic Research Institute, Linköping, Sweden, 1983.
28. Durth, W., H. Hanke, and C. Levin, "Influence of Winter Maintenance on Traffic Safety and Transport Efficiency" (in German), Research Report, Darmstadt Technical University, Darmstadt, Germany, 1988.
29. "Winter Maintenance and Road Safety," in *Curtailing Usage of Highway De-icing agents in Winter Maintenance,* Organization for Economic Cooperation and Development (OECD), Paris, France, 1989, pp. 107-113.
30. Kuemmel, D., and R. Hanbali, "Accident Analysis of Ice Control Operations," presented at the TRB 3rd International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
31. Hanbali, R., and D. Kuemmel, "Traffic Volume Reductions Due to Winter Storm Conditions," in *Transportation*

Research Record 1387, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 159-164.

32. Hagiwara, T., Y. Onodera, T. Fujiwara, T. Nakatsuji, and T. Kaku, "Road Conditions and Accidents in Winter," *Surface Characteristics of Roadways: International Research and Technologies*, ASTM STP 1031, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1990, pp. 442-453.
33. "Traffic Accident Risks in Winter II," Finnish National Road Administration, Helsinki, Finland, 1987.
34. Schandersson, R., "Relationships Between Traffic Accidents, Road Surface Conditions and Winter Maintenance Measures—Accident Risks for Different Quantities of Snow Fall," Swedish Road and Traffic Institute, Fack S-581 01, Linköping, Sweden, 1988.
35. Brenner, R., and J. Moshman, "Benefits and Costs in the Use of Salt to Deice Highways," The Institute for Safety Analysis, Washington, D.C., November 1976.
36. Neuman, D., "When the Trolleys Were Stopped Cold—The Great Storm of '47—Anecdotes and photographs compiled by Donald Neuman from the files of the Milwaukee Journal," April 1983.
37. Nevada State Assembly Advisory Committee on Bill 482, "Report on Methods for Removal of Snow and Ice from Roads in the Lake Tahoe Basin," State of Nevada, Carson City, Nevada, September 1, 1992.
38. Coughlin, P., and G. Greenwood, "Snow and Ice Control on Local Roads" (unnumbered), Maine Department of Transportation, Augusta, February 1990.
39. "Trainers Guide—Winter Operations," Methods Unit, Maintenance Division, Michigan Department of Transportation, Lansing, October 1984.
40. Lorbeske, D., "Snow Plow Drivers Manual," Bureau of Sanitation, Department of Public Works, Milwaukee, Wisconsin, December 1986.
41. Pryzby, S., "So You Want to Have A Snow Plow Roadeo," *Public Works*, Vol. 119, No. 8, July 1989, pp. 70-71.
42. *Snowfighters' Handbook*, Salt Institute, Alexandria, Virginia, 1982.
43. Rissel, N., "Cost Effective Staffing of Crews During Winter," *Public Works*, Vol. 116, No. 9, August 1985, pp. 91-94 and 122.
44. "How Ice Prediction Systems Cut Agency Costs," *Better Roads*, Vol. 61, No. 4, April 1991, pp. 34 and 36.
45. Hulme, M., "A New Winter Index and Geographical Variations in Winter Weather," *Journal of Meteorology*, Vol. 7, No. 73, England, 1982, pp. 294-300.
46. Thornes, J., "Cost Effective Snow and Ice Control for the Nineties," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 185-190.
47. Government Information Services, "Privatization: Snow Removal Contracting," *Financing Local Government*, Vol. 3, No. 12, December 15, 1990, pp. 1 and 5.
48. Doherty, E. "Private Contracting in Municipal Operations," *Urban Resources*, Vol. 2, No. 4, Summer 1985, pp. 29-36.
49. Blaine, J., "Contract Maintenance in Ontario," in *Transportation Research Record 951*, Transportation Research Board, National Research Council, Washington, D.C., 1984, pp. 101-106.
50. "Different Road to the Same Place," *Engineering News Record*, Vol. 229, No. 14, October 5, 1992, pp. 32, 33, 36, and 39.
51. "Policy Position Statement-Closure of State Highways—Severe Winter Storms or Natural Disasters," No. 83-2, Minnesota Department of Transportation, St. Paul, September 1983.
52. "Policy Guideline—Closure of State Highways, Severe Winter Storms or Natural Disasters—Responsibilities," No. 83-2-G-1, Minnesota Department of Transportation, St. Paul, September 1983.
53. Roper, J., "Moncton's Snow Plan Stands Up to Monster Storm," *APWA Reporter*, Vol. 59, No. 5, May 1992, pp. 20-22.
54. Block, J., "NEXRAD—An Overview and Product Description," *On the Front Newsletter* (no volume), Kavoris, Inc., Minneapolis, Minnesota, November-December 1991, p. 3.
55. Kelly, J., "Solutions to Improve Ice and Snow Control Management on Road, Bridge and Runway Surfaces," in *Transportation Research Record 1276*, Transportation Research Board, National Research Council, Washington, D.C., 1990, pp. 48-51.
56. Reiter, E., and L. Teixeira, "Detailed Weather Prediction System for Snow and Ice Control," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 223-230.
57. Reiter, E., "SHRP Train the Trainer Session," Chicago, Illinois, September 29, 1992.
58. Kelly, J., "Pavement Weather Sensing for the Transportation Industry," *Sensors*, Vol. 10, No. 2, February 1993, pp. 14-20.
59. Lister, P., A. McDonald, and K. Goss, "Open Systems for Ice Prediction Systems," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
60. Yrjö, P.-J., K. Toivonen, and J. Kantonen, "Road Weather Service System in Finland and Savings in Driving Costs," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
61. Woodham, D., "Ice-Detection System Evaluation," Report No. CDOT-DTR-R-91-10, Colorado Department of Transportation, Denver, August 1991.
62. Boselly, S.E., "Road Weather Information Systems: What Are They and What Can They Do for You?" in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 191-195.
63. Boselly, S.E., G.S. Doore, J. Thornes, C. Ulberg, and D. Ernst, "Road Weather Information Systems—Vol. 1," Report No. SHRP-H-351, Strategic Highway Research Program, National Research Council, Washington, D.C., 1993, 219 pp.
64. Boselly, S.E., "Benefit-Cost Assessment of the Utility of Road Weather Information Systems for Snow and Ice Control," in *Transportation Research Record 1352*, Transportation Research Board, National Research Council, Washington, D.C., 1992, pp. 75-82.
65. Axelson, L., "Weather Forecasts and Information on Road Conditions—MINSALT Project," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.

66. Kuusela, R., T. Raukola, H. Lappalainen, and A. Piirainen, "New Ideas and Equipment for Winter Maintenance in Finland," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 124-129.
67. "How Ice Prediction Systems Cut Agency Costs," *Better Roads,* Vol. 61, No. 4, April 1991, pp. 34-36.
68. Scharsching, H., "Results of a Field Test of Seven Different Commercial Ice Warning Systems," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
69. Katz, D., "Frengor: A New Smart Pavement Sensor," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 147-150.
70. Ninomiya, H., K. Takeichi, and K. Kawamura, "Performance Evaluation of Pavement with Deicing Materials," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 151-158.
71. McClean, A., "Thermal Mapping," *APWA Reporter*, Vol. 58, No. 2, February 1991, pp. 6-8.
72. Bogren, J., and T. Gustavsson, "Description of a Local Climatological Model for Improvement of Winter Road Surveys," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
73. Perchanok, M., D. Manning, and J. Armstrong, "Highway Deicers: Standards, Practice, and Research in the Province of Ontario," Research and Development Branch, Ontario Ministry of Transportation, Downsview, Ontario, Canada, November 1991.
74. "Highway Maintenance Guidelines—Snow and Ice Control," New York Department of Transportation, Albany, December 1993.
75. "Snow and Ice Control Manual," Kansas City Department of Public Works, Missouri, 1991-92.
76. Aspinwall, D., and D. Wilson, "The Preferred Salt Option Study," Research and Development Branch, Ontario Ministry of Transportation, Downsview, Ontario, Canada, 1984.
77. Public Works Journal Corporation, *Public Works—The 1993 Public Works Manual,* Vol. 124, No. 5, April 15, 1992, p. B85.
78. Eck, R., and W. Sack, "Quality, Quantity and Availability of West Virginia Oil and Gas Well Brines for Highway Deicing Purposes," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 40-47.
79. Stotterud, R., and K. Reitan, "Deicing of Roads in Norway with Brine," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 23-28.
80. Byles, R., "Salt Economies," *New Civil Engineer* (England) No. 803, August 1988, pp. 24-25.
81. Kuennen, T., "Enhanced Salt, CMA show rise in Survey," *Roads and Bridges*, Vol. 31, No. 6, June 1993, pp. 34-37.
82. Johnston, D., and D. Huft, "Sodium Salts of Carboxylic Acids as Alternative Deicers," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 71-78.
83. Fleege, E., "Minnesota DOT Tests Deicing Alternatives," *Public Works*, Vol. 121, No. 8, July 1990, pp. 58-59.
84. Chappelow, C., A.D. McElroy, R. Blackburn, D. Darwin, F. de Noyelles, and C. Locke, "Handbook of Test Methods for Evaluating Chemical Deicers," SHRP-H-332, Strategic Highway Research Program, National Research Council, Washington, D.C., 1992.
85. Buchholz, R., "Effects of Lignosulfonates in Deicing Salts on the Penetration of Chloride Ions into Concrete," in *Transportation Research Record 1268*, Transportation Research Board, National Research Council, Washington, D.C., 1990, pp. 186-192.
86. Ton, T., "The Toxicity of Lignin Sulfonate," Report No. F89TL01, Transportation Laboratory, California Department of Transportation, April 1990.
87. "Snow and Ice Control Manual," Engineering Department, Illinois State Toll Highway Authority, Downers Grove, 1988.
88. "1991-92 Snow and Ice Policy Manual," Office of Maintenance, Bureau of Highways, Connecticut Department of Transportation, Wethersfield, 1991.
89. Raukola, T., R. Kuusela, H. Lappalainen, and A. Piirainen, "Anti-icing Activities in Finland: Field Tests with Liquid and Prewetted Chemicals," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
90. Karlsson, J., and B. Nilsson, "Preventative Salting," Vägverket Report No. N1985-06-19, Vägverket Borlänge, Sweden, 1985.
91. Blackburn, R., E. McGrane, K. Bauer, and E. Fleege, "SHRP H-208: Development of Anti-Technology," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 29-39.
92. Mergenmeier, A., "On the Way: Anti-icing Instead of Deicing," *Better Roads*, Vol. 64, No. 1, January 1994, pp. 29-30.
93. "Guidelines to Reduce Air Pollution from Street Sanding," Regional Air Quality Council, Denver, Colorado, November 1991.
94. Connor, B., "Optimum Sand Specifications for Roadway Ice Control," Report No. FHWA-AK-RD-82-26, Research Section, Alaska Department of Transportation and Public Facilities, Fairbanks, June 1982.
95. Blaisdell, G., and S. Borland, "Braking Traction on Sanded Ice," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 79-88.
96. Reckard, M., "Hot Sand Field Trial-Final Report," Report No. FHWA-AK-RD-87-28, Federal Highway Administration, Washington, D.C., August 1987.
97. Swanson, H., "Heated Abrasives on Snow and Ice Covered Roads," Report No. FHWA-CO-R-82-4, Federal Highway Administration, Washington, D.C., August 1982.
98. Reckard, M., "Hot Sand for Improved Traction on Icy Roads: Estimation of Costs and Benefits," Report No. AK-RD-85-25, Alaska Department of Transportation and Public Facilities, Fairbanks, March 1985.
99. Dewald, C., and B. Petzold, "Report on the Evaluation of the Sandvik 2000 Grader Blade System Used for Ice Control on Gravel Road Surfaces," Alberta Transportation and Utilities, Edmonton, Canada, April 1987.

100. Crane, R., M. Damson, and K. Pell, "Goal-Oriented Design of an Improved Displacement Snowplow," in *Transportation Research Record 1304*, Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 188-192.
101. "SHRP Product Catalog," Strategic Highway Research Program, National Research Council, Washington, D.C., 1993, p. 8.
102. Nixon, W., T. Frisbie, and C. Chung, "Field Testing of a New Cutting Edges for Ice Removal from Pavements," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 138-146.
103. Schlup, U., "Snow Removal and Ice Control Technology on Swiss Highways," in *Transportation Research Record 1387*, Transportation Research Board, National Research Council, Washington, D.C., 1993, pp. 3-7.
104. "Snow and Ice Control Manual," Division of Construction and Maintenance, Bureau of Maintenance, New Jersey Department of Transportation, Trenton, October 1986.
105. Haslam, E., and J. Wright, "Application of Routing Technologies to Rural Snow and Ice Control," in *Transportation Research Record 1304*, Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 202-211.
106. Tucker, W., and G. Clohan, "Computer Simulation of Urban Snow Removal," in *Special Report 185*, Transportation Research Board, National Research Council, Washington, D.C., 1979, pp. 293-302.
107. Evans, J., and M. Weant, "Strategic Planning for Snow and Ice Control Using Computer-based Routing System," *Public Works*, Vol. 121, No. 4, April 1990, pp. 60-64.
108. Fleege, E., and R. Blackburn, "Spreader Equipment for Anti-icing," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
109. "Snowplow Lighting Study—Final Report," Report No. MN/RD-89/03, Minnesota Department of Transportation, St. Paul, September 1989.
110. *Report 320: Blowing Snow Control Design Guide*, Strategic Highway Research Program, National Research Council, Washington, D.C., 1991.
111. "Polymer Tenser Offers Advantages over Conventional Snow Fence—Light Weight Reduces Handling Needs," *Transportation* (Canada), Vol. 6, No. 1, March 1983, p. 6.
112. "Effective Drift Control Helps Win the Battle Against Winter," *Better Roads*, Vol. 54, No. 6, June 1984, pp. 20-22.
113. Baker, H., and C. Williams, "Guidelines for Controlling Snowdrifting on Canadian Highways," *Transport Canada*, Montreal, Quebec, March 1990.
114. Esch, D., "Snow Control Structures," *Research Notes*, Vol. 4, No. 2, Alaska Department of Transportation and Public Facilities, Fairbanks, August 1984, pp. 1-2.
115. Winter, W., and R. Caudle, "Electronic Detection of Roadway Under Heavy Snow Cover," Report No. FHWA/CA/TL- 92/01, Division of New Technology, Materials and Research, California Department of Transportation, Sacramento, 1992.
116. "Salt Brine Runoff Control at Truck Stations and Bulk Storage Sites," Salt Handling Task Force Committee, Minnesota Department of Transportation, St. Paul, December 1989.
117. "The Salt Storage Handbook," Salt Institute, Alexandria, Virginia, 1987, pp. 187.
118. Tumock, G., "Foresight in Snow Planning," *APWA Reporter*, Vol. 58, No. 9, September 1991, pp. 14-15.
119. Kareoja, T., "Snow Dumping Places and Snow Transport" (Finnish), Finnish Road Administration, Helsinki, Finland, 1983.
120. Hogan, R., "The Effects of Highway Design Standards on Snow and Ice Control Operations," in *Special Report 185*, Transportation Research Board, National Research Council, Washington, D.C., 1979, pp. 74-78.
121. Pravda, M., W. Bienert, D. Wolf, J. Nydahl, and K. Pell, "Augmentation of Earth Heating for Purposes of Roadway Deicing—Executive Summary and Report," Report Nos. FHWA/RD-79, 80, and 81, Federal Highway Administration, Washington, D.C., December 1978.
122. "Pavement Heating System Still Works," *Better Roads*, Vol. 56, No. 12, December 1986, pp. 38-39.
123. "Congress Warms Up to Heated Bridge Projects," *Engineering Times*, March 1992, p. 8.
124. "System Melts Away Snow and Doubt," *Public Works*, Vol. 121, No. 8, July 1990, pp. 46-47.
125. Konagai, N., M. Asano, N. Horita, and S. Miyamoto, "Law Prohibiting Use of Studded Tires in Japan, Results of Chemical Deicing Agents Test and Investigation on Efficient Operation of Road Heating Facilities," presented at the TRB Third International Symposium on Snow and Ice Control Technology, Minneapolis, Minnesota, September 1992.
126. Stuart, K., and W. Mogawer, "Laboratory Evaluation of Verglimit and Plusride," *Public Roads*, Vol. 55, No. 3, December 1991, pp. 79-86.
127. Tanski, J., "Performance of Two Ice Retardant Overlays," Research Report No. 132, Engineering Research and Development Bureau, New York State Department of Transportation, Albany, May 1986.
128. Esch, D., "Construction and Benefits of Rubber-Modified Asphalt Pavements," in *Transportation Research Record 860*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 5-13.
129. Allen, H., and C. Turgion, "Evaluation of 'Plus Ride' (Trademark)," Report No. 90-1, Minnesota Department of Transportation, St. Paul, January 1990.

APPENDIX A

QUESTIONNAIRE

Please route this questionnaire to the person responsible for all snow and ice control maintenance in your jurisdiction. (State or agency chief, road maintenance engineer)

Agency ____________ Person answering ____________ Tel ______

TITLE ____________________

1. Do you have a strategy or policy manual governing snow and ice control maintenance? Yes ____ No ____
   If yes, please attach.

2. Is level of service described in the policy manual? Yes ____ No ____
   If no, do you have any policies relating level of service to highway Classification? Yes ____ No ____
   - Traffic volume? Yes ____ No ____
   - Amount snowfall? Yes ____ No ____
   - Temperature? Yes ____ No ____

   If so, please provide.

3. Are snow and ice costs accumulated in your state by
   - per season, per lane mi.? Yes ____ No ____
   - per maintenance district, per lane mi.? Yes ____ No ____
   - per storm per lane mi.? Yes ____ No ____
   - per route per lane mi.? Yes ____ No ____

   Other ________________________________

   ____

   How are maintenance budgets formulated in your agency? Briefly explain.

   ____

   ____

   ____

   Are you under pressure to substantially decrease snow and ice control costs? Briefly explain.

   ____

   ____

   What were your last winter's snow and ice control maintenance cost? List as $/lane mi./

   Total cost for a winter season, $ per lane mile ____________

   List time period (dates or budget year) for cost data ____________

4. Do you provide winter maintenance by
   - a) own forces? ____%
   - b) contract - private sector? ____%
   - c) contract - other government? ____%
   - d) combination of above? ____%

5. Have you documented any benefits from winter maintenance such as:
   - a) accident reduction Yes ____ No ____
   - b) travel time Yes ____ No ____
   - c) economic Yes ____ No ____
   - d) other (list) Yes ____ No ____

   If yes, briefly describe. Contact (if different) ____________ Tel ______

   ____

   ____

   ____

6. Have you documented any of the effects or damages from winter maintenance such as:
   - a) salt in ground/surface water Yes ____ No ____
   - b) vegetation Yes ____ No ____
   - c) corrosion of your equipment Yes ____ No ____
   - d) corrosion of private vehicles Yes ____ No ____
   - e) bridge or pavement reinf. Yes ____ No ____

   If yes, briefly describe. Contact (if different) ____________ Tel ______

   ____

   ____

   ____

7. Have you conducted any experiments with "no salt" or salt levels below your normal levels? Yes ____ No ____

   If yes, briefly describe. Contact (if different) ____________ Tel ______

   ____

   ____

   ____

8. Does your agency conduct a public relations program to either inform public in

advance to prepare the public or during the progress of operations?
a) regularly Yes ____ No ____
b) occasionally Yes ____ No ____

Is it before or during operations? Before ____ During ____

9. Are you currently under a legislative mandate to reduce any component of winter maintenance?
Component ______________

____

____

____

Attach copy of legislation

Contact (if different) ______________________ Tel ______________

10. Is your state contemplating legislation or policy eliminating, reducing or changing deicers? Yes ____ No ____ Date ________

If yes, describe briefly.

____

____

____

Contact (if different) ______________________ Tel ______________

11. Has your agency been sued in the last ten years and lost (or paid) for liability for winter maintenance?
a) level of service Yes ____ No ____
b) timeliness of service Yes ____ No ____
c) equipment accidents Yes ____ No ____
d) damage to private property Yes ____ No ____
e) other Yes ____ No ____

If yes on a) or b), briefly describe.

____

____

Contact (if different) ______________________ Tel ______________

12. Have you had to monitor or replace wells, surface water sources, etc. because of contamination from deicers? Yes ____ No ____

If yes, explain.

____

____

13. Does your strategy plan include dealing with winter storms categorized as a disaster, i.e., beyond capability of your agency? Yes ____ No ____

If yes, briefly describe.

____

____

____

Contact (if different) ______________________ Tel ______________

14. Does your agency have first hand information and access to road weather information systems such as pavement sensors, remote weather stations?
Yes ____ No ____

a) If yes, what make or system? ______________________

b) How many years? ______________________

c) Have you documentation on cost benefit data? Yes ____ No ____

Attach if available.

Contact (if different) ______________________ Tel ______________

15. Do you use a computer access to a weather forecast network of the National Weather Service? Yes ____ No ____

How is it used? ______________________

____

____

Contact (if different) ______________________ Tel ______________

16. Is thermal mapping used for planning your road weather information system?
Yes ____ No ____

17. Is thermal mapping used regularly for operations? Yes ____ No ____

Describe briefly ____

____

____

Contact (if different) ______________________ Tel ______________

18. Please attach a copy of your ice control or de-icer policy if not already provided.
Available? Yes ____ No ____

a) Indicate which deicers are used (place x):
General (Check all applicable)
Use deicers only ____
Use deicers only sometimes and deicer/abrasive mix sometimes ____
Use abrasives only sometimes ____
Use abrasives only always ____

b) When deicers only are used, indicate which ones and their temperature and weather or other conditions controlling use.

Deicer	Temp. °F	Comment	Normal data per Application
Solid sodium chloride	below ____	Straight __ Prewet__	Rate ____
Liquid calcium chloride	below ____	Straight __ Mixed __	Rate ____
Salt brines ____	________	When ________	Rate ____
CMA ____	________	Where ________	Rate ____
Ethylene Glycol ____	________	Where ________	Rate ____
Glycopeptides ____	________	Where ________	Rate ____
Menthanol ____	________	Where ________	Rate ____
Urea ____	________	Where ________	Rate ____
Other ____	________	Where ________	Rate ____

c) Is this usage covered in your winter maintenance policy manual?
Yes ____ No ____

d) Have you performed any cost benefit analysis of the use of any deicers?
Yes ____ No ____

If yes, please provide.

19. Experience with anti-icer products (check).
Verglimit ____
Other ____ List ________________________________

Extent of use ____

____

Willing to share cost/benefit data? Yes ____ No ____

Contact (if different) ______________________ Tel ______________

20. Does your agency have any experience with any corrosion inhibitor as an additive to de-icers? Yes ____ No ____

Extent of use (list and and comment) ________________________

Willing to share on any studies or cost benefit analysis? Yes ____ No ____

Contact (if different) ______________________ Tel ______________

21. When abrasives are used, please indicate the conditions under which they are used.

a) General
Covered in winter maintenance policy? Yes ____ No ____
Part of legislative mandate? Yes ____ No ____

b) Road classification and conditions of use

Classification	Conditions for Abrasive Usage	Temp. °F	Mix (% of Deicer)	Normal Rate of Applic
Princ arterial	________	______	________	____
	________	______	________	____
Minor arterial	________	______	________	____
	________	______	________	____
Collector	________	______	________	____
	________	______	________	____
Local	________	______	________	____
	________	______	________	____

c) What is your opinion of its effectiveness when compared to using only chemical deicers? (Mark with x)

Item	Better	As Good	Worse
Safety	____	______	____
Speed deicing	____	______	____
Vehicle corrosion	____	______	____
Impact on ground surface water	____	______	____
Impact on vegetation	____	______	____
Impact on drainage	____	______	____
Impact on overall maintenance cost	____	______	____

22. a) What type of spreader is current specified for applying deicer? (Check-off)
Tailgate ____
Hopper type, with auger ____
Hopper type, conveyor ____
Reversible dump boyd/conveyor ____
Other ____

List any special requirements for spreaders to ensure accuracy. __________

____

b) About how many lane lines of highway can be covered by one truck (what is the ratio of equipment to lane miles of highway? ______________ (disregard spares)

c) About what percent "spares" do you provide in fleet size for truck breakdown, accidents, etc. ____________ %

d) Is the same spreader used for abrasives or mixtures of abrasives and deicers?

Yes ____ No ____

If no, what is used for abrasives and why? ____________________

____

____

e) Do you have trouble calibrating spreaders, particularly at lower amounts of deicer per lane mile (below 300# salt/lane mile for example)
Yes ____ No ____

f) How are spreaders calibrated? (Mark with x)
Manually
1) output per auger RPM ____
2) static running yard ____
3) weight loads in and out ____
4) actual road runs ____
5) tie sack under chute ____
In vehicle calibration. Describe ______________________

____

If other, describe ______________________________

23. What type of ice scraper is used, if any?
none ____
standard plow blade ____ Describe tip ________________
special plow blade ____ Describe ________________
underbody blade ____
road grader ____

24. What type and size of truck is used currently specified for ice control? (Note snow plowing is covered in next question.)
Same for ice control and snow plowing? Yes ____ No ____
Ice control trucks (correct hp if necessary):

30,000 - 34,000 # GVW, 210 hp ____
35,000 - 39,000 # GVW, 210 hp ____
40,000 - 44,000 # GVW, 210 hp ____
45,000 - 49,000 # GVW, 230 hp ____
50,000 - 54,000 # GVW, 230 hp ____
55,000 - 59,000 # GVW, 250 hp ____
60,000 - 64,000 # GVW, 270 hp ____

Other: ________ # GVW _______ hp

25. a) What type and size of truck is currently specified for snow plowing? (If same as ice control answer under question 24)

30,000 - 34,000 # GVW, 210 hp ____
35,000 - 39,000 # GVW, 210 hp ____

40,000 - 44,000 # GVW, 210 hp ____
45,000 - 49,000 # GVW, 230 hp ____
50,000 - 54,000 # GVW, 230 hp ____
55,000 - 59,000 # GVW, 250 hp ____
60,000 - 64,000 # GVW, 270 hp ____

Other: ________ # GVW ________ hp

b) What special features are currently specified for plowing vehicles (other than safety equipment)?

4-wheel drive ____
Reinforced frame ____
Larger engine ____
Automatic transmission ____
Added axle/spring capacity ____
Heavy duty brakes ____
Modified hydraulic systems ____
Other ____
Describe: ____

____

____

c) What kind of plow blades are currently specified and for what appliction (answer all applicable).

Type of Plow	Applications
Road grader	__________
V plows	__________
Hydraulic raising	__________
Other	__________

Type of Tripping Mechanism
Mold board trip ____
Cutting edge trip ____
Segmented plow trip ____

Mold Board Type
Steel, urethane coating __________
Plastic/Urethane __________
Other ________ (describe)______________________________

____

Snowplow shoes/runner
Steel ____
Tungsten carbide ____
Rollers ____
Urethane runner ____
Other ________ (describe)______________________________

____

Cutting Edge
Steel ____
High carbon steel ____
Tungsten carbide ____
Rubber ____
Other ________ (describe)______________________________

____

26. Do you use wing plows? Yes ____ No ____
Check uses:
Routinely, all rural highways ____
Routinely, median borders ____
Routinely, rural highways with full shoulder only ____
Routinely, shoulders only ____
Routinely, locations with blowing, drifting only ____

Other ____ Describe______________________________

27. Do you use snow blowers? Yes ____ No ____

Mounting

Dedicated vehicle (non-removable) ____
End loader ____
Grader ____

Other ____ Describe______________________________

Type specified (check all) Application

Single stage ____ ______________________________

Two stage ____ ______________________________

Width of Cut (check all applicable)

< 8' ____
8' ____
> 8' ____

Capacity (tons per hour)

500 - 999 ____
1000 - 1499 ____
1500 - 1999 ____
2000 - 2499 ____
2500 - 3000 ____

Applications (check all applicable)

Deep snow ____ Min depth ____
Mountainous terrain ____
Locations where plowing not possible ____
Drifting locations ____
Other (describe) ______________________________

28. a) What percentage of snow and ice control vehicles are radio equipped? (Check)

99% or more ____
75-99% ____
50-74% ____
25-49% ____
0-24% ____

b) Any problems with inadequate radio frequency or capacity? ____________

____

____

29. Do you use any of the following:
a) Snow fences? Yes ____ No ____ Where ____________

____

b) Sidewalk plows? Yes ____ No ____ What kind ____________

c) Special bridge snow removal equipment? Yes ____ No ____ Type ____________

d) Pavement or bridge snow or ice melting equipment?
Yes ____ No ____ Where ____________

____

____

____

e) Heated pavements? Yes ____ No ____

What heat source? ______________________________

Where? ______________________________

f) Avalanche protection? Yes ____ No ____

What kind? ______________________________

Willing to share cost/benefit data on any of above? Yes ____ No ____

Which? ______________________________

Contact (if different) ____________ Tel ____________

30. Any unique winter maintenance facilities you would like to share with the synthesis? Yes ____ No ____

Describe ______________________________

____

31. What facilities have been provided for salt storage? (Check, indicate % of storage facilities)

stored on pavement slab ____ ____ %
stored on ground ____ ____ %
stored unprotected (uncovered) ____ ____ %
plastic canvas covering only ____ ____ %

shelter building ____ ____ %
behive building ____ ____ %
other enclosed building (describe) ______________________________

32. Operation of ice and snow removal equipment repair crews during snow emergency operations (Mark x to all that apply):
    - staffed "round the clock" ____
    - normal work hours only ____
    - located centrally at main repair facility ____
    - located centrally and at remote sites ____
    - located centrally, at remote sites, and with field repair on location where practical ____

33. Describe mobilization procedure. (Check)
    - Initiated by responsible person ____
    - Telephone call out ____
    - Pagers used ____
    - Automated telephone call out system, computer controlled ____
    - Computerized dispatching (assignments) ____
    - Any special mobilization procedure to share with synthesis

    ____

    ____

34. Cold weather starting procedures. (Check all applicable)
    - Equipment inside ____ ____ %
    - Equipment stored outside ____ ____ %
    - Electric block heaters ____ ____ %
    - Special diesel fuel additive ____ ____ %
    - Other (describe)______________________________

35. <u>Application of deicers</u>

    a) Who decides the applications rate for chemical deicers or abrasive/deicer mixtures in a given storm? (Check one only or explain if more than one checked)
    - unit or subunit supervisor in charge ____
    - field supervisor ____
    - field foreman ____
    - truck operator ____
    - other (describe)______________________________

    ____

    ____

    b) How is this monitored by management? ____________________

    ____

    c) Reporting system for salt usage. (Check all applicable)
    - Records kept and reported to management
    - by route in #/lane mi, each storm ____
    - by route in #/lane mi./maintenance unit, each storm ____
    - by route in #/lane mi/season ____
    - by maintenance district in #/lane mi/season ____
    - total salt in tons/district/storm ____
    - total salt in tons/district/season ____
    - total salt in tons/political unit (city,state)/season ____

    d) Equipment allocation for ice control. (Check only one)
    - by lane miles only ____
    - by lane miles, by highway classification ____
    - by lane miles with congenstion factored ____
    - by curb miles ____
    - by lane or curb miles with street parking factored ____
    - other (describe) ______________________________

    ____

    Is allocation for plowing the same? Yes ____ No ____

    If difference, describe ______________________________

    ____

    e) Spreading procedure for deicers or abrasive deicer mixes when used. (Check most typical application)
    - Pretreatment (before snow or freezing rain) ____
    - After onset of precipitation, before plowing ____
    - During plowing ____
    - After plowing (separate pass) ____

    On a two lane rural highway check typical procedure:
    - Plow one side on first pass, plow second side and salt entire road on return
    - Plow and salt or salt first side, then plow, salt second side on return ____
    - other (describe) ______________________________

    ____

36. How is safety during plowing or ice control operations addressed? Describe any special lighting or protective devices to prevent accidents or improve plow driver visibility.

Increased visibility of plow blade to driver.

____

Increased visibility of plow truck to other motorists

____

Use of TMA's ____________________________________

37. Snow Plowing

a) What is threshold for plowing snow (in what range of snow density or depth are just deicers and/or abrasives used? (Check only one)

All snow plowed first ____
Snow > 1" ____
Snow > 2" ____
Snow > 3" ____
Snow > 4" ____
Other (describe) ______________________________

____

____

b) What is the threshold for using deicers or abrasives?

Any snow ____
Snow > 1/4" ____
Other (describe) ______________________________

____

____

c) How is the centerline of a two lane highway covered by snow plows? (Check one only)

Plows extend over centerline on first pass ____
Plows extend over centerline on second pass ____
Plow never encroach on centerline ____
Other (describe) ______________________________

____

d) When round-the-clock ice or snow removal operations are required, where do relief drivers come from? (Answer all applicable)

Other agency employees ____ ____ %
Contractors ____ ____ %
Temporary or part-time ____ ____ %
No relief available ____

Other (describe)______________________________

____

____

e) What is the normal shift length? (Check)

8 hours ____
12 hours ____
18 hours ____
24 hours ____
unlimited ____

Any maximum limit for safety? ____

38. Any special parking regulations during plowing? Describe or attach law or regulation, or furnish any brochure distributed to public.

____

____

39. Have you initiated or suggested any changes in highway design to reduce winter maintenance costs?

Median design ____
Profile changes ____
Typical section ____
Pavement drainage ____
Highway drainage ____
Explain above answers ______________________

____

____

____

40. Personnel

a) How do you decide how many personnel are employed full time for winter maintenance?

____

____

b) Show personnel assignments for each piece of equipment (one or two persons vehicle) Salt or abrasive spreaders ____

Snow plow (reg) ____
Wing plow ____
Snow blower ____

c) Are employees unionized? (Check) Yes ____ No ____
If yes, list union
Union: AFSCME ____
Teamsters ____
Other (list) ____________________

d) What are their winter assignments when it does not snow? (Check all that apply)
Patrol for defects ____
Litter patrol ____
Highway repair ____
Shop repairs ____
Equipment repair/painting ____
Other (describe) ____________________

____

e) What are their job assignments in seasons other than winter? (Check all that apply)
Pavement maintenance and repair ____
Truck driver ____
Other functions (describe) ____________________

41. How do you expand your workforce or equipment if a storm beyond your capacity is encountered?

Source	Added Manpower (x)	Added Equipment (x)	% from Source
Other governments	____	____	____
Contractors	____	____	____
National Guard	____	____	____
Temporary employees only	____		____

42. Management
a) How many levels of management are there for winter maintenance? Describe all management levels from State Maintenance Engineer down to 1 line supervisor, and number each level starting with #1 at the highest.

____

____

b) Who is reponsible for collecting data on progress of snow plowing and ice control for management reports? (Check all that are applicable)
dispatcher in maintenance unit ____
supervisor in maintenance unit ____
maintenance engineer in unit ____
Other (describe) ____________________

____

c) How is this summarized for management? Describe or attach example.

____

43. Risk management techniques utilized in snow plowing and ice control. (Check all applicable)
Preparation of plan with maintenance policies and service levels ____
Weather log each storm ____
Record of treatment ordered and time log ____
Record of treatment carried out, each route ____
Record of time of treatment, each route ____
Accident report review by management ____
Ongoing safety training of operators ____
Periodic equipment inspections for safety ____
Winter maintenance operations procedural manual ____ (Please attach copy)
Others (describe) ____________________

____

44. Any special management techniques you want to share with synthesis?

____

____

____

45. Please comment on your greatest and least problems relative to snow and ice control maintenance.

____

____

____

____

____

____

DATE DUE

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED