NCHRP SYNTHESIS 344

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Winter Highway Operations

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis focuses on the changes that occurred between 1994 and 2004 to practices and strategies being used to control the impacts of winter weather on the safe and efficient movement of traffic. Winter highway operations integrates snow and ice control strategies and activities, traveler information, traffic operations, weather effects, environmental impacts, incident management, and customer information. Winter weather is experienced as snow and ice accumulation on pavement, fog and reduced visibility, rockslides, and high winds throughout North America. This synthesis reports that experienced and well-trained highway maintenance personnel are the most valuable resource in transportation agencies' winter programs and targets as the intended audience frontline and mid-level supervisory winter maintenance decision makers and planners in the United States.

Survey responses were received from 13 state departments of transportation, 6 Canadian provinces, and 3 Canadian municipalities. The state of the practice was developed based on these responses, capturing changes that have occurred at the planning, managing, and operations levels of winter highway operations.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write the report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

WINTER HIGHWAY OPERATIONS

SUMMARY

Winter highway operations now integrate snow and ice control strategies and activities, traveler information, traffic operations, weather effects, environmental impacts, incident management, and customer satisfaction. Winter weather is experienced as snow and ice accumulation on the pavement, fog and reduced visibility, rockslides, flooding, and high winds throughout North America. This synthesis focuses on the changes as reported by a representation of U.S. state and Canadian provincial agencies between 1994 and 2004 to practices and strategies being used to control the impacts of winter weather on the safe and efficient movement of traffic.

Government agencies tasked with maintaining levels of service on the vast system of highways affected by winter weather resort to a variety of approaches. They use various technologies to forecast winter storms and the degree of impact to highways. Such agencies maintain travel way functionality armed with both information technologies and advanced snow fighting equipment and materials. Maintenance trucks are equipped with plows, ice-controlling chemical reserves and associated spreading machinery, deployment optimizing communications systems, and advanced control systems for all of these devices. All of this represents a significant expenditure of public funds aimed at keeping vital highways operational throughout inclement winter weather.

The FHWA Road Weather Management website, "Welcome to Road Weather Management" (http://ops.fhwa.dot.gov/weather) reports that state and local agencies spend more than $2 billion annually on snow and ice control operations and more than $5 billion annually for infrastructure repair as the result of snow and ice damage.

Some of this significant infrastructure damage has been attributed to winter operations policies and practices, such as Oregon's experience with studded tire use by the public. This represents a significant expenditure for highway agencies and therefore deserves attention and effort toward optimizing winter maintenance techniques and practices. The variety of practices currently in use represents both expected differences in the evolution of winter highway control from agency to agency and the necessary variability owing to unique weather conditions experienced in some regions.

States, provinces, and local governments operate their own maintenance equipment or hire contract services. There is no uniform measure or standard for winter road maintenance in North America. Local and regional operations are guided by multiple levels of service developed to meet customer expectations, budgets, and standards of care concerns. In general, higher classifications of highways receive more attention. In the United States, routes on the 160,000-mi (256,000-km) National Highway System network, primarily Interstate expressways and primary roads, are typically cleared more quickly and completely. Similar conditions exist for the approximately 15,000-mi (24,023-km) Canadian National Highway System. Specialized policies exist for critical areas such as mountain passes that have traction device requirements for vehicles, snow emergency routes that will be cleared of parked cars, and avalanche hazard zones.

Treatment to prevent bonding of snow and ice to the road surface (anti-icing) is increasingly used; however, classic methodologies such as snow removal by plowing, with chemical and abrasive application, remain the mainstay of winter operations. These strategies have changed in the 10 years from 1994 to 2004 and will undoubtedly continue to evolve, integrating new technological advances as they emerge and prove their worth. Of note are the recent advancements that have been developed through intelligent transportation systems initiatives. These components represent the overlap between highway and transportation needs and the use of advanced or emerging technology applications. Trends toward greater use of anti-icing techniques have increased reliance on roadside weather and surface pavement condition observations as well as task-specific weather forecasts.

Although having been in use before 1994, Road Weather Information Systems (RWIS) have gained tremendous application throughout the United States and Canada. RWIS generally continue to be part of maintenance divisions. Although state responsibilities vary, active deployments of new RWIS are under the purview of intelligent transportation systems divisions within many agencies. Increased use of RWIS is particularly true for agencies with remote highway segments that are prone to severe winter weather. Advances in the technologies used by roadside RWIS Environmental Sensor Stations (RWIS–ESS) and the associated communications have expanded the utility of remote weather stations. The use of cameras in conjunction with the more traditional RWIS–ESS components has demonstrated the value of visual confirmation of near-real-time weather data.

Maintenance managers have been required to further stretch finite resources to address greater public demand for better and more consistent levels of service. The benefits of the continuing move in this direction are found in the increasingly innovative approaches to the management of personnel, equipment, and materials. Experienced and well-trained highway maintenance personnel are the most valuable resource in transportation agencies' winter programs.

Deicing and anti-icing chemical use is an area of change, with many chemical and chemical combinations available. Emphasis on the protection of the natural environment and minimizing impacts to the delicate balances found there have been significantly felt at the winter maintenance level. Responses to a questionnaire indicated that the use of abrasives such as sand appears to have diminished, in part, as the result of the environmental impacts associated with airborne particles generated indirectly through their use. Many agencies are experiencing more stringent storage, clean-up, and disposal requirements for both chemicals and abrasives. Efforts to cost-effectively minimize the use of deicing and anti-icing chemicals are both less detrimental to the environment and a prudent use of public resources. Costs resulting from corrosion to public and agency vehicles, corrosion of the infrastructure, and infrastructure damage that results from not maintaining travel way traction levels compound these efforts.

CHAPTER ONE

INTRODUCTION

PURPOSE OF THE SYNTHESIS

NCHRP Synthesis of Highway Practice 207: *Managing Roadway Snow and Ice Control Operations* was published in 1994. It described several new innovations and concepts developed in North America, Europe, and Japan for managing snow and ice control operations at that time. Winter operations have changed in the 10 years between 1994 and 2004, as new methods, materials, and equipment have become more readily available. Increasing environmental concerns, limited budgets, and workforce issues must be balanced against mobility and safety demands. These innovations have been adopted in different ways for different conditions provided the purpose for a new synthesis to highlight these advances and how they can be assimilated.

METHODOLOGY AND REPORTING AGENCY STATISTICS

The state of practice of winter operations was sampled through responses to a questionnaire sent to highway agencies. A survey questionnaire was crafted that focused on capturing changes that have occurred over the 10 years since the publication of the 1994 synthesis at the planning, managing, and operation levels of winter highway operations. To capture change, approximately one-third of the questions were similar to those used for the earlier synthesis research. The survey was transmitted to a sample group of transportation agency representatives. A limited number of responses were received and then cataloged and combined in a manner to support the organization of this report.

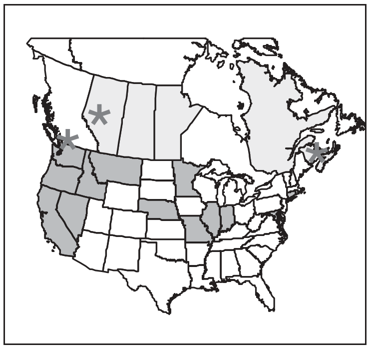
A second survey was then sent to representatives from 71 transportation agencies. (This survey questionnaire can be found in Appendix A.) They included 48 state and the District of Columbia department of transportation (DOT) representatives, educational institute representatives for the remaining 2 states, 10 Canadian provincial DOTs, and 10 Canadian municipalities. Thirty-four percent (22 of 71) responded with completed questionnaires, providing a sample of 22 agencies, 26% (13 of 50) of the state DOTs, 60% (6 of 10) of the provincial DOTs, and 33% (3 of 10) of the Canadian municipalities. (A list of respondents is provided in Appendix B.)

The 22 respondents represent five western states and one province, two western Canadian municipalities, five mid-continent states and two provinces, two northeastern states and three provinces, and one northeastern Canadian municipality. The six northeastern respondents each encompass large coastal regions. In other winter operation-related disciplines, it has been useful to identify characteristic winter climate regions. A broad spectrum of options was presented in one question to provide a possible division of winter highway operators according to the nature of their winter climate and road network. The responses fell into five specific categories: Rural Mountainous, Rural Plains or Plateau, Rural Coastal or Lake Effect, Urban Plains or Plateau, and Urban Costal or Lake Effect. Although these were useful in considering the context of the responses, the simplification of the categories to two agency groups, state or provincial and municipality, afforded clearer explanation and discussion. Figure 1 illustrates this categorization and the geographic relationship of the responding agencies. According to Environment Canada (“Snowiest City” 2003), the greater Moncton area (pop. 111,000) is the 6th snowiest Canadian city (138 in., 350 cm annual average), Edmonton (pop. 937,845) the 73rd snowiest city (49 in., 124 cm), and Vancouver (pop. 1,986,965) is the 98th snowiest city (19 in., 48 cm). The distribution of the responses for this synthesis was biased toward the central mid-west and large western states and provinces.

In addition, a literature review was conducted of the primary recent contributions or research related to winter operations. This limited search drew on articles that provided insight into the direction that research has taken since 1994.

ORGANIZATION

The review of the responses for this synthesis is organized into eight chapters. The first chapter is an overview and introduction to the report, along with a discussion of its limitations. Chapter two describes results of the literature search conducted for this synthesis. The responses covering state of practice are organized and presented in chapter three. An overview of environmental effects that are topical to winter highway operations is presented in chapter four. Responses of the agencies to special issues, such as catastrophic winter weather events, snow avalanches, and appropriate design and construction of winter operations make up chapter five. Institutional issues concerned



State DOTs	Provincial DOTs
California	Alberta
Connecticut	Manitoba
Idaho	Québec
Illinois	New Brunswick
Indiana	Nova Scotia
Maryland	Saskatchewan
Minnesota	
Missouri	
Montana	
Nebraska	**Municipalities**
Nevada	Edmonton, Alberta
Oregon	Moncton, New Brunswick
Washington State	Vancouver, British Columbia

FIGURE 1 Responding agencies and their geographic distribution.

with training and skill levels are described in chapter six. Emerging technologies just beginning to be introduced to winter operations are presented in chapter seven. Conclusions and suggested areas for further research are offered in chapter eight. Appendix A is the survey questionnaire, Appendix B a list of the responding agencies, and Appendix C tabulated results of selected questions.

ASSUMPTIONS AND CONVENTIONS

Because this synthesis is uniquely targeted to frontline and mid-level supervisory winter maintenance decision makers and planners in the United States, English units are used primarily with the International System of Units (SI) secondary in parenthesis when appropriate.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews research literature as of 2003 relevant to winter operations to provide a context for understanding advancements in the state of the practice. This limited literature search describes recent articles on key topics related to the report including anti-icing chemicals, Road Weather Information Systems (RWIS), route optimization and automatic vehicle location (AVL), environmental and worker health effects, and emerging technologies. They provide insight to the direction research has taken over the surveyed 10 years. A search using Transportation Research Information Service (TRIS) Online provided hundreds of results, with a limited number of peer-reviewed publications.

The first research results described here include the collaborative efforts between the Colorado DOT and the Colorado auto insurance industry that indicated a shift toward increasing use of deicing chemicals and the decreasing use of sand (Chang et al. 2002). The specification for sand no larger that 3/8 in. has contributed to a less-than-expected increase in windshield damage costs for the traveling public. The cost basis was arrived at by combining the amount paid out by two insurance companies reflecting 32% of the Colorado auto insurance industry, normalized against the growth in number of automobile policies over 8 years.

A study in Iowa concluded that dry abrasives, when applied to the roadway with significant traffic traveling at high speeds, remain in place for approximately 10 to 100 vehicle passages (Nixon 2001).

A study by the Center for Transportation Research and Education at Iowa State University presents the primary challenges to winter highway operations (Knapp et al. 2000). One of the findings of the research was that although traffic volume during the study period significantly decreased, from 16% to 47%, hourly crash frequencies and approximate crash rates increased dramatically, on the order of 942%. It also found that in the case of Iowa highways, the number of crashes per storm increases with an increase of any of three variables: (1) a product of season length and traffic volume in million vehicle miles, (2) snowfall intensity, and (3) maximum wind speed gusts. Also important for winter highway operations is their finding that although the average vehicle speed showed a 16% reduction, the standard deviation for storm speeds was much larger than for nonstorm periods, 7.57 mph versus 1.86 mph.

A method for categorizing and ranking various anti-icing chemicals on the basis of performance in a number of categories was produced by the Iowa Institute of Hydraulic Research Hydroscience and Engineering Department at the University of Iowa (Nixon 2002). It defines and uses the categories freezing point depression, consistency, environmental impact, stability, corrosion, handling, conductivity, and documentation to assist in selecting anti-icing chemicals. In a report for the Ohio DOT, recommendations for a statewide expansion of the state's RWIS network were made based on an extensive literature review, product review, cumulative cost comparison, survey of users and administrators, and site visits (Nixon and Williams 2001). Factors used to determine optimal deployment included distance between existing Environmental Sensor Stations (ESS) in Ohio and surrounding states, number of declared snow days, and annual amounts of Ohio snowfall.

A minimum number of RWIS–ESS sites are determined in addition to already deployed sites to meet basic statewide weather prediction and monitoring needs (Zwahlen et al. 2003). Recommendations were made that (1) installations should be at locations with typical rather than extreme conditions and (2) that each county garage be equipped with a small weather station and simple pavement sensor near the station for the purpose of creating a weather conscious culture at the county garage level.

A study of the Washington State DOT (WSDOT) "rWeather" discontinued website (renamed and incorporated in the larger WSDOT website) and RWIS use among maintenance personnel found that maintenance personnel did not take full advantage of the increased capabilities offered through RWIS in part because it was not necessary in the use of traditional reactive winter maintenance strategies (Boon and Cluett 2003). Recommendations of requirements for the expansion of RWIS included management commitment and continued investment in equipment reliability, demonstration of forecast credibility, targeted training, and implementation planning. This study also identified the strong value to the long-distance traveler of the weather information provided on the website.

A study conducted for the Colorado DOT Research Department evaluated deicers for chemical contaminants, environmental effects, human health effects, corrosion, application rates, performance, cost, and advantages and disadvantages (Fischel 2001). It identified information gaps in the knowledge base and conducted a preliminary, qualitative worker health effects study.

In a study sponsored by the U.S.DOT, geographic information systems (GIS) and artificial intelligence techniques were used to develop an intelligent snow removal asset management system (Salim et al. 2002). The system was evaluated with a case study on snow removal from state roads in Black Hawk County, Iowa. It used the logical rules and expertise of the Iowa DOT's snow removal experts with a GIS to access and manage road data. The system was used to generate prioritized snowplowing routes in visual format, to optimize the allocation of assets for plowing, and to track materials (e.g., salt and sand). The case study of the system produced an improvement in snowplowing time by 1.9% for moderate snowfall.

A pilot study of AVL technology by Virginia concluded that the technology could be used to track winter maintenance operations in a satisfactorily and timely manner (Roosevelt et al. 2002). It cautioned future projects in the importance of good background mapping, such as orthorectified aerial photographs, that lane location determination is impractical, that there exists a limit to the amount of data the system can process, and that repeated installation and removal of the AVL units results in an unacceptable rate of connection and unit breakages. The study found that although two-way messaging is important, other methods of communications with the operators would be better, and two-way messaging should only be used in case of an emergency. As with most technology, the importance of logistical support was highlighted. The following common themes associated with successful field implementation of technology were also supported by this study:

- Existence of a project champion with desire and resources;
- Available and supportive information technology personnel;
- Field personnel with ownership in the system, an understanding of it, and who are supportive of it; and
- Identified and developed preventative maintenance procedures and assigned personnel.

One of the prominent issues identified was the need for efficient procedures to assign identification numbers to the vehicles and update the computer system as assignments were made or changed.

NCHRP Project 6-12 provided a review of existing and proposed concepts for improving visibility for snowplowing operations along with the identification and development of potential means for improving these operations (Rea and Thompson 2000). The project included limited field tests to evaluate the potential benefits of these concepts. Conclusions of the research included the following:

- A trap angle of approximately 50° for front plows will reduce the amount of material blown over the plow and onto the windshield.
- Packing flaps at the discharge ends of front plows reduce the size of the snow cloud around and behind the snowplow.
- Closing the gap between the front plow's discharge end and the intake end of the wing plow will reduce the size of the snow cloud around and behind the snowplow when wing plows are used.
- Side vanes with a 20° angle to the snowplow's body, mounted on the rear of the vehicle, will reduce snow and ice accumulation on surfaces and on the rear lighting of the snowplow.
- Switching off the driver-side headlamp and using an auxiliary passenger-side headlamp will reduce the backscattered light seen by the operator during snowfall.
- Shielded headlamps, the louvered or cut-off type, that reduce stray light above the horizontal plane, will also reduce backscattered light.
- Steady-burning light bars, mounted along the rear edges of the snowplow truck, will improve following drivers' ability to detect changes in the snowplow vehicle's speed and will provide an indication of the vehicle's width.

A report for the Virginia DOT indicated potential for heat pipe technology to be used effectively on bridge decks to prevent snow and ice accumulation. However, a reliable deck heating system requires further development, including more robust controls (Hoppe 2000). The report also concluded that an active system requires a substantial effort in terms of time, personnel, and expertise to ensure that all components are functioning safely and effectively. Conclusions and recommendations included:

- It is feasible to apply heat pipe technology to heating bridge decks.
- For effective deck heating, selecting a proper working fluid for heat pipes is critical.
- The surface condition sensor should be placed on the bridge deck.
- The heat pipe system does not pose a construction problem.
- Operating costs for the heat pipe system are lower than for an alternate electrical or hydronic system.
- The heating system does not appear to have any adverse effects on the durability of the bridge deck.
- The use of an infrared camera can be very effective in evaluating heat distribution and intensity across the deck surface.
- The failure of a single sensor can cause the entire heating system to become inoperable, making the control system redundant.
- Place the control sensor on the bridge deck.
- Use infrared scans as a measure of the performance of the heating system before granting final acceptance.

There have been cost–benefit analyses done to enable emerging technologies to become part of the mainstream. One study concluded that limited data collection was adequate for initial justification; however, data collection methods and research studies have not been applied successfully for operational scale performance measures (Meyer 2002).

Many research projects were scheduled to publish their results at approximately the same time this synthesis was under way. There has been significant effort by the AASHTO Snow and Ice Pooled Cooperative Fund Program (SICOP) and the FHWA Road Weather Management Program to keep recently published research relevant to winter highway operations available on the Internet. This effort has resulted in good collections of knowledge-improving papers on their respective websites: http://www.sicop.net/documents.htm (AASHTO) and http://www.ops.fhwa.dot.gov/weather/resources/publications.htm (FHWA). The reader is directed to these to sites for the most current information available.

Other documents relevant to winter highway operations are referenced throughout this synthesis and are also found in the literature reference list at the end of this document.

CHAPTER THREE

STATE OF THE PRACTICE

This chapter provides an inventory and discussion of innovations, improvements, developments, and advancements made in winter highway maintenance during the past 10 years. It presents a comprehensive and descriptive picture of the practices, enhancements, and technologies in use.

In comparing the literature, efforts of leading states and provinces, and agency responses it is clear that there is very little separation between state of the practice and state of the art in winter highway operations. The two levels of technology and research, integration and adoption, exist between the agencies themselves rather than between the agencies and the researchers or developers of the advancements. Many agencies have active participation in applied research programs and frontline practical experimentation. In winter highway operations, every storm, every day, involves adaptation using the same set of methods and materials applied to a new situation that at some levels is very similar to previous ones but never fully the same. Winter maintenance activities take a certain amount of finesse and creativity to accomplish, especially in times of increasing resource constraints.

SURVEY RESPONSES

The responses of the 22 agencies providing the primary content of this synthesis are presented in Appendix C and are described by topic in the next sections of this report.

One question asked respondents was "what tools in their winter operations toolbox are well used?" Several traditional practices, as well as advancements, were described as "well used" tools by the responding agencies. Some of these traditional practices included the use of various equipment, materials, and technologies such as snowplows, sanders, snowblowers, motorgraders, front-end loaders, salt, snow fences, and two-way radios.

Responding agencies cited the following advancements in winter highway operations:

- Anti-icing, all-liquid application, and pre-wetting;
- RWIS weather forecasts, pavement and weather information;
- Camera images available on the Internet;
- Management practices (e.g., salt management plans, storm reports);
- Equipment improvements (wider front plows, wing plows, ground speed control units);
- Training and winter preparation;
- Better communication with the traveling public; and
- Information distribution at the winter operations decision-maker level.

Another question asked what tools no longer were useful or had been discarded in the past 10 years. A few were mentioned, such as the use of the 75mm recoilless rifle in highway avalanche control by the California DOT (Caltrans). Montana has seen the end of cutting snow pack with motorgraders, and California no longer uses liquid deicers directly on snow pack. Indiana, Maryland, and Nevada cited a reduction in the heavy dependence on abrasives. There have been technologies that have been replaced, such as overhead spray systems, mechanically controlled hopper spreader boxes and U-boxes, or gasoline engines (all are diesel now). Quebec included pre-wetting in the not useful category owing to difficulties in integrating it.

The survey asked respondents to describe the most significant changes to winter operations that occurred during the 1994 to 2004 period. New chemicals, all-liquids, and pre-wetting were the most common response with improved equipment; RWIS and weather forecast use were also frequently mentioned.

Respondents reported upgrades to equipment, improved quality of equipment, and better products for anti-icing as the most common changes affecting winter maintenance operations. Specific key changes to winter operations included:

- Addition of pre-wetting,
- All-liquid trucks,
- Cab controls that are easier to use, and
- Ground speed controllers for spreader operation to provide calibrated application.

Larger and more powerful equipment has had a significant impact in reducing the effort required to complete many winter maintenance tasks as compared with 10 years ago. Several key changes cited fall into the information management category, such as centralized storm management, winter operations team (Indiana), RWIS (one of the top three mentioned changes), customer surveys, performance measures, and availability of information on the Internet. Radar access at the decision-maker level was specifically mentioned as an important change. Improved weather forecasts and the use of highway meteorology consultants were singled out as examples of positive change.

In recent years, fog and other warning systems have attracted increasing interest at a national level. Under an FHWA-sponsored research project to develop a low-cost, reliable fog sensor, several sensors were fabricated, and bench and field-tested (*Highway Fog* . . . 1999). Caltrans specifically mentioned the intelligent transportation systems (ITS) technology available through their fog warning system as benefiting winter operations. The Caltrans fog warning system has evolved to include four districts consisting of three main elements: driver education, enforcement, and a system of sensors and dynamic message signs.

Adoption of salt management practices and attention to associated environmental impacts of chemical treatments in general has become increasingly important. This issue has affected operations from 1994 to 2004 as agencies respond to more restrictive environmental constraints such as storm water, storage area, and watershed runoff regulations. For example, the Oregon DOT (ODOT) has implemented best management practices developed specifically for snow and ice removal and sanding in an effort to minimize impacts (*Routine Road Maintenance* . . . 1999). ODOT also makes a concerted effort to recover abrasives in stream sensitive areas at the end of each winter season.

Maintenance funding constraints and changes relating to personnel were referred to as key issues affecting winter operations. Examples of personnel issues included the loss of maintenance workers, increased use of casual or temporary workers, and training. One responding agency, Alberta Transportation, has switched to 100% contract winter maintenance provided by private industry. Alberta also experienced a doubling of network miles for which they are responsible, with the transfer of roads from municipalities. It was reported that difficulties accompanied this transfer of responsibility owing to only a 20% increase in the snowplow fleet. More than one respondent cited an increase in road miles for which they have maintenance responsibility.

Several agencies described the expectations of the public for bare pavement as a factor of increasing importance over recent years.

Meanwhile, Saskatchewan indicated an overall decrease in the severity of winter storms over the past 10 years, noting lower than average precipitation over the period.

Landscaping adjacent to roadways has become increasingly prevalent. Its mere presence is another significant issue agencies are dealing with in their winter operations. There is the extra effort of maintaining the landscaping, as well as the effort of minimizing the negative affects that winter maintenance actives have on the landscaping. These areas are often no longer available for snow storage, require reduction in plow speeds to avoid damage, and are sensitive to concentrations of deicing chemicals or abrasives. The importance of maintainability often arises with the inclusion of culture- and technology-driven trends in the form of context-sensitive design. It is increasingly important for maintenance to review plans and specifications at the design stage to avoid long-term difficulties and the associated extra costs.

Nevada documented maintenance considerations to be included in the design of the I-580 freeway extension between Reno and Carson City (Kashuba 1999). The design recommendations included:

- Incorporation of divided alignments,
- Non-use of undivided alignments with vertical separation,
- Wide shoulders and ditches,
- Sound wall use only with sufficient snow storage area (6 m minimum) and no shadowing of the roadway,
- Design of standard detail for installation of snow poles in proposed barriers,
- Wide medians (15 m minimum) with minimal use of barriers,
- Fills to be 0.74 to 1 m above existing grade (i.e., above the surrounding snow surface throughout a "design winter"), and
- Use of snow fences.

SNOW AND ICE CONTROL STRATEGIES

The organization of snow and ice control or other winter operation activities by the various agencies follows logical outlines based on the local needs and governmental structure. A common thread expressed by the respondents was "doing more with less" under increasing constraints.

Twenty-one (95%) of the responding agencies provide winter maintenance through their own personnel. Alberta uses solely contract personnel. Ten agencies augment their own employees with contract maintenance workers. One of the 10, Minnesota, uses other government employees under contract. Two agencies, Manitoba and Quebec, augment their own employees with both private and other government contract personnel. The specific break out is shown in Table 1. Readers interested in good examples of guidelines for contract operations are referred to Bourdon's *Best Practices of Outsourcing Winter Maintenance Services* (2001).

Snow and ice control as conducted by nearly all of the agencies follow organized strategies in the form of written plans, policies, or plow routes. Two state agencies, Maryland and Nevada, stated they do not have a policy manual; however, both do use plow routes. Four of the surveyed agencies, California, Idaho, Nevada, and Vancouver, do have policies, but do not use plow routes.

TABLE 1
PROVIDING WINTER MAINTENANCE (responses by agency)

Agency	Agency's Own Employees	Improvement District	Contract with Private Sector	Contract with Government Agencies
State/Province				
Alberta Transportation			√	
California DOT	√		√	
Connecticut DOT	√			
Idaho Transportation Department	√			
Illinois DOT	√		√	
Indiana DOT	√		√	
Manitoba Transportation and Government Services	√			√
Maryland State Highway Administration	√			
Ministère des Transports du Québec	√			
Minnesota DOT	√			
Missouri DOT	√			
Montana DOT	√			
Nebraska DOT	√			
Nevada DOT			√	
New Brunswick DOT	√		√	√
Nova Scotia DOT	√			
Oregon DOT	√		√	
Saskatchewan Highways and Transportation	√		√	√
Washington State DOT	√			
Municipality				
City of Edmonton	√		√	
City of Moncton	√		√	
City of Vancouver	√			

A common difficulty experienced by all respondents was obtaining reliable snow and ice control costs. For ODOT, fleet and personnel costs are not easily combined into a single winter maintenance cost report. Another difficulty is the inclusion of shop or repair costs in the overall winter operations cost. It is generally assumed that more shop and repair costs are required for winter operations than any other maintenance activities.

BUDGETING AND PERFORMANCE MEASURES

Several agencies in the survey group provided descriptions of how budgeting for winter operations is accomplished. For many agencies, costs are tracked at the district level. However, Alberta Transportation tracks costs by roadway segment in the management of their contract forces. The metric used by most of the responding agencies for tracking is an activity code, although lane miles, salt usage, and snowplow hours were also identified as cost-tracking methods. Past expenditures are most frequently used for determining budget amounts. Specific historical methods included running 5- and 10-year averages. Maryland sets their snow and ice control budget at a mild-to-average winter level, assuming that overages from severe winters will be reimbursed. Nevada operates under a unique situation where funds are set on a zero base budget, with the legislature allocating funds on a biannual basis. In this scenario, severe winters have a direct impact on the funds available for other maintenance activities. The base year is reestablished every 2 years.

Information collected about costs per lane mile for winter maintenance was sufficient only for summary comparison. The numbers present a picture of dramatic contrast between rural and urban costs. Agencies operating primarily in rural regions are subject to much lower costs per mile than their urban counterparts. The average rural winter maintenance cost per lane mile for 2002/03 was $2,500. Figure 2 graphically represents the cost per mile data provided by the responding agencies.

The majority of the agencies use some form of electronic maintenance management system. Only 50% of the agencies tie the costs and budgets associated with maintenance to specific roadway segments, and only Edmonton and Moncton responded that GIS have been incorporated for snow and ice control budgeting and cost tracking.

Four agencies, Edmonton, Idaho, Saskatchewan, and Washington State, noted that they had documented benefits resulting from winter maintenance activities. Idaho analyzed winter maintenance activities for 5 years of pre-implementation and 3 years of post-implementation of all-liquid anti-icing on a rural mountainous highway. Their findings are an example of what success can be achieved with a well-planned and

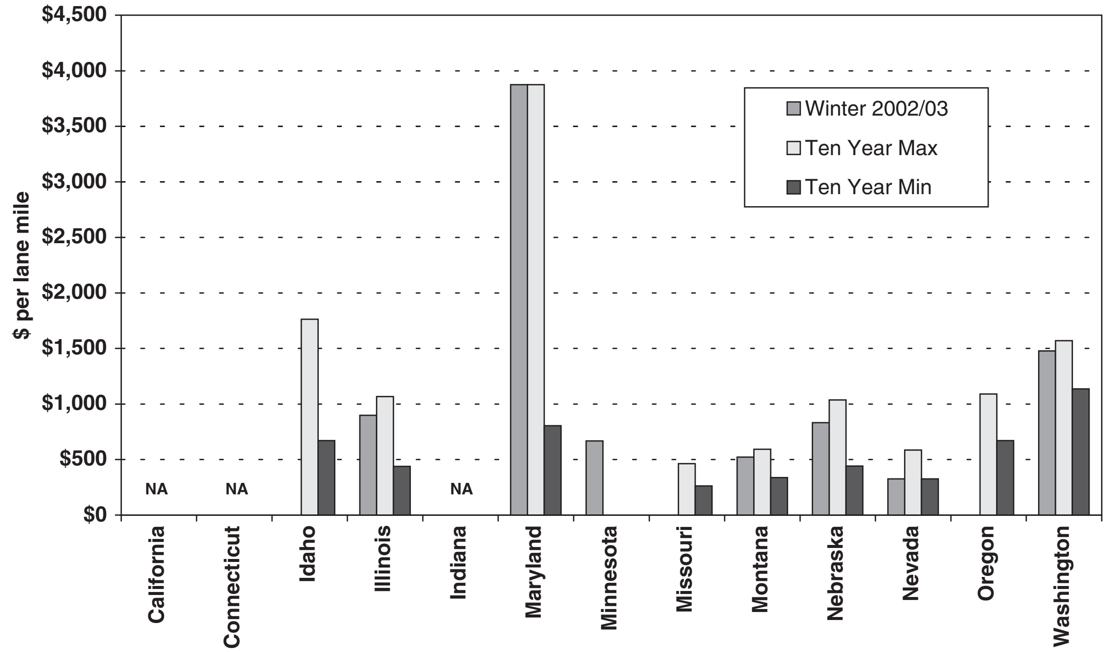


FIGURE 2 Approximate winter operation costs per lane mile as provided by respondents.

championed program. Table 2 presents the efficiencies for a specific regional route attained through use of all-liquid anti-icing. The decreases in the use of resources and number of crashes indicated were attributed by Idaho to these changes.

Information regarding the use of performance measures is limited. Seven agencies, Alberta, Edmonton, Manitoba, Minnesota, Nova Scotia, Quebec, and Washington State, addressed this situation. Two respondents (Edmonton and Saskatchewan) have documented winter maintenance benefits. More than half of the responding agencies (12) stated that they do not use performance measures. Two (Caltrans and Illinois) did not respond. This would seem to present an area for advancement and the potential for increased efficiency.

Figure 3 shows an example of performance reporting from the Minnesota DOT (Mn/DOT). Through customer surveys the state has determined the expectations of the driving public ("Dashboards Help . . ." 2004). An example of the desired bare lane is shown on the top left. The graph and dashboard examples are from one of the Mn/DOT maintenance districts. The graph on the top right provides the monthly average for the district over the winter of 2002/2003. The dashboard across the bottom of the figure shows the average number of hours to bare lane broken out by functional class and their respective different time expectations. These dashboards are prominent on their website.

For Alberta Transportation, the contractor's target is stated as achieving good driving conditions within a period of time specific to road classifications. These times are shown in Table 3. Good winter driving conditions are defined to "exist when snow and ice have been removed from the driving lanes and excessive snow has been removed from the shoulders and centre line of the highway. Short sections of ice and

TABLE 2
IDAHO TRANSPORTATION DEPARTMENT'S EXAMPLE OF IMPROVEMENTS AS A RESULT OF ALL-LIQUID USE

	1992 to 1997 (without anti-icing)	1997 to 2000 (with anti-icing)	Percent of Change
Abrasive Quantities	1,929 cubic yards (1,475 cubic meters)	323 cubic yards (247 cubic meters)	83
Labor Hours (annual)	650	248	62
No. of Crashes (annual)	16.2	2.7	83

Source: Breen 2001.

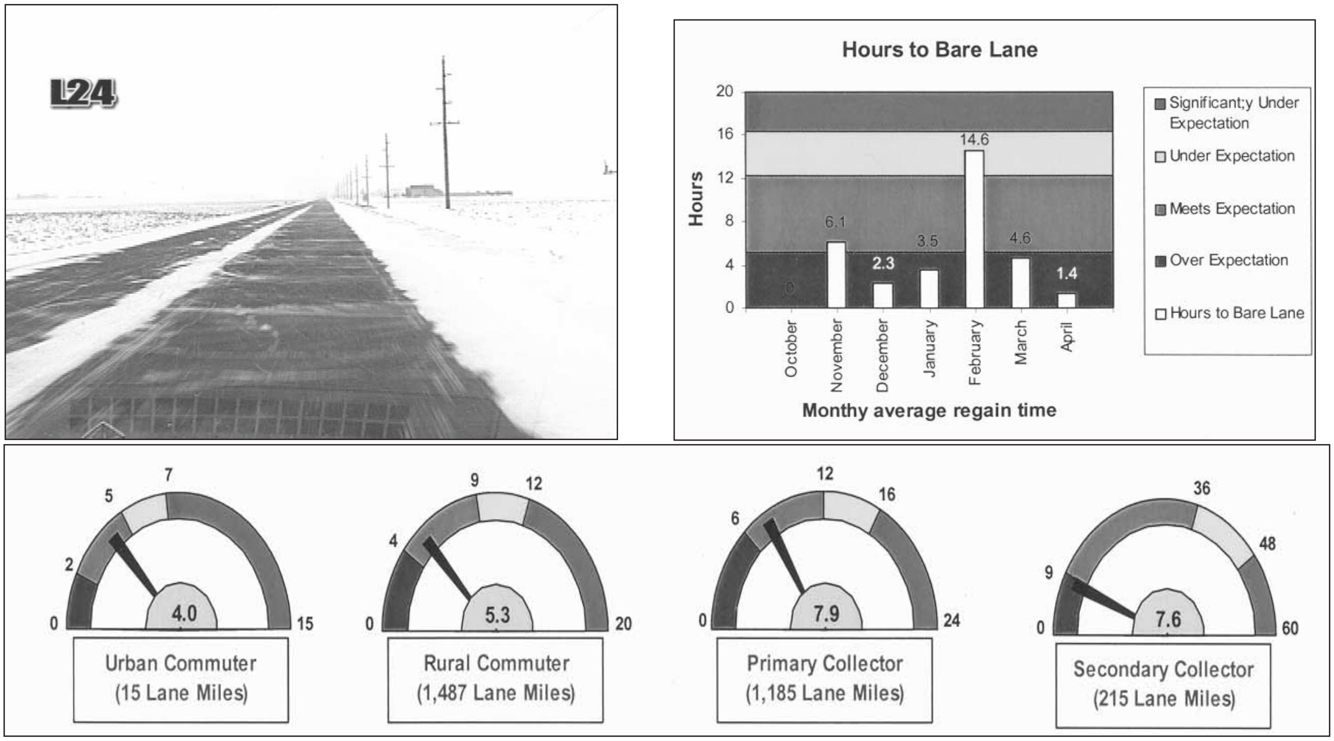


FIGURE 3 An example of graphics that Mn/DOT provides to customers. A bare pavement definition is shown (upper left), along with graphs (upper right) and dashboards (bottom) ("Dashboards Help Drive Mn/DOT Performance," http://www.dot.state.mn.us/dashboards).

packed snow are acceptable and can be expected between the wheel paths, as well as on the centre line."

WSDOT used a single performance measure to report a level of service (LOS) rating for snow and ice control activities. The measure takes into consideration the traction conditions (i.e., presence of traction owing to anti-icing chemical, sand application, or plowing) on the travel lane road surface and is observed and documented during periodic field condition surveys. The traction conditions are determined by returning to the route after a designated period of time has past since the last plowing or sanding and examining all travel lanes between given mileposts. Bare pavement is the condition if at least 95% of the roadway surface is free of ice and/or snow. The roadway is considered sanded if at least 60% of the travel lane has sand on the surface. To allow for simple field analysis, 60% coverage is considered equal to a travel lane with bare tire tracks and sand on the remainder of the lane. This is somewhat time and travel intensive and is in addition to normal storm fighting efforts.

PLOW ROUTES AND MATERIAL APPLICATION DECISIONS

Slightly more than 80% of the respondents stated that they used plow routes. Four of the surveyed agencies, California, Idaho, Nevada, and Vancouver do not use plow routes. The agencies that use plow routes use various methods to determine them including:

- Staffing and performance or LOS targets;
- Functional classification and average daily traffic;
- Emergency service locations and/or transit routes;
- Maintenance shed or garage area;

TABLE 3
ALBERTA TRANSPORTATION CONTRACT ADMINISTRATION REQUIREMENTS FOR SNOW REMOVAL AND ICE CONTROL

Segment Classification	Segment Characteristic	Maximum Time to Good Driving Conditions Following End of Storm
Class A	>7,000 AADT	6 hours
Class B	5,000 to 7,000 AADT	6 hours
Class C	2,000 to 5,000 AADT	8 hours

Note: AADT = average annual daily traffic.

- Lane miles (may cross shed or district boundaries); and
- Combination of climate, geography, and contractor proximity.

The routes are generally changeable once the storm begins, except in cases where they have been determined to coincide with emergency or transit routes or by contractor assignment. Those that are changeable usually adapt to practical constraints such as storm conditions, equipment availability, personnel shortages, or a less than worse case scenario for which the route is designed. A specific example of what happens as a result of route changes is that the segment of lowest LOS drops in priority; for example, is postponed until later. Changes in routes are made by a combination of input from frontline and supervisory levels as based on local institutional guidelines.

The frontline equipment operator has decision-making authority in the application rate of chemical, abrasive, or combinations in slightly more than 50% of the surveyed agencies. This is a subset of localized authority at the maintenance-shed level used by nearly 85% of the responding agencies.

Three of the respondents, Montana, Nevada, and Oregon, set the application rates at a headquarters level and in one case allow the front line operator to adjust the rates for reapplications.

STORM CLEAN-UP

Agencies identified a number of tasks associated with storm clean-up plans. In general, plowing plans based on safety and the importance of routes sets priority. This priority is also frequently dependent on time of day relative to traffic peaks and daylight. The tasks include the following:

- Clearing driving lanes, bridges, and ramps by plowing or blowing;
- Clearing shoulders and approaches;
- Resolving site distance problems by pushing snow back or removing snow piles; and
- Clearing gore areas, signs, and maintaining drainage.

In addition, some agencies must focus on using ice-cutting motor patrols to remove ruts. Some agencies report that they sweep, recover, or recycle abrasive materials, particularly in sensitive areas. These agencies include the city of Edmonton, Nevada DOT, ODOT, and WSDOT. Nevada sweeps in air quality nonattainment areas.

DECISION SUPPORT

The increasing use and reliance on RWIS data and road weather forecasts was cited as one of the primary changes to winter highway operations. Responding agencies did not single out pavement temperature forecasts in their replies. All state and provincial agencies provide access to weather forecasts for winter operations decision makers. Of those, approximately 16% use a private contracted forecast service exclusively, whereas 37% use a government agency forecast service such as Environment Canada or the National Weather Service, and the remaining 47% use a combination of contracted and government-provided forecasting services. The agencies typically access the forecasts from the Internet or facsimile and frequently use more than one method to obtain this information. Other methods used include telephone, e-mail, radio, and satellite transmission. Most agencies receive updated forecasts between two and six times daily in the regular course of operations and increase this frequency as needed during winter storms.

INFORMATION MANAGEMENT

This area represents the greatest advancement during recent years. There is a far greater number and more extensive utilization of information sources and mechanisms in use at the time of the synthesis than 10 years ago. These sources include print, electronic, and interactive. One particular published source of information providing extremely valuable and useful information, printed within the past 10 years, is the 1999 *AASHTO Guide for Snow and Ice Control*.

The FHWA *Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel*, provided a valuable and needed basis for incorporation of the methods and technology (Ketcham et al. 1996). This was followed by Test and Evaluation Project No. 28, which culminated in the *Anti-Icing Technology, Field Report* (Ketcham et al. 1998). This report included results and interpretations, cost analysis, recommendations for practice, and conclusions regarding the state of the art of anti-icing.

Another recently published source of valuable information is the FHWA Road Weather Management Program's *Best Practices for Road Weather Management Version 2.0* (Goodwin 2003). This resource contains case studies from every region of the country, a listing of road weather publications, an overview of environmental sensor technologies, and on-line resources.

The use of the Internet has become so commonplace and habitual that it is difficult for most maintenance personnel (frontline or management) to describe let alone remember their level of Internet use 10 years ago. It is currently used for access and delivery for nearly all RWIS information and data except in cases of satellite information delivery (e.g., Weather Services Inc. and Meteorologix. The Internet has ended the geographic separation and accessibility of individuals wishing to discuss common topics. An example of its success is the snow–ice list server maintained by the University of Iowa Institute of Hydraulic Research Hydroscience and Engineering Department and supported by AASHTO's SICOP. This server connects management- and administrative-level planners and decision makers for winter highway operations throughout the world by means of e-mail. The significance of this resource is imaginable in terms of realizing its potential to completely replace this document in a timely and question-specific manner. All a maintenance manager has to do is pose a question to the group such as, “what is the most cost-effective winter operation technology you use and why?,” sit back, and wait for the response from every road weather climate and size of operation extant.

It is important to note that the information is not peer reviewed other than through each reader’s comments, corrections, or replies to statements made in response to the questions posed; that is, responses must always be put to a relevance and correctness test before basing actions on them. Even with this caveat, the inquiry and exchange of experience and information among this group has enhanced and advanced winter operations at various local levels in an immeasurably successful manner. Two examples of additional use of the Internet in making valuable winter operations information widely available are the FHWA winter maintenance virtual clearinghouse and SICOP websites. The Internet has also connected the agencies with their customers in a highly cost-efficient and valuable way as will be described later under traveler information (see chapter seven).

OPERATIONS

The discussion of operations is divided into five subtopics: Primary Field Operating Conditions, Equipment, Materials, Traditional Activities, and RWIS. Traditional activities include classic methods such as snow removal with truck-mounted plows, maintaining the driving surface during storms, storm clean-up, and controlling blowing snow with snow fences.

Primary Field Operation Conditions

Winter maintenance personnel encounter a variety of adverse pavement conditions that need to be addressed in accomplishing their activities. One survey question asked the agencies to rank the winter pavement conditions that most effect their operations, segregated by urban, suburban, and rural geography. Frontline maintenance personnel are frequently already attuned to issues that are seemingly uncovered in scientific analysis of data collected from a more diverse and geographically dispersed study. It is possible that the description of primary field operation conditions falls within this category. A somewhat surprising picture of the distribution emerges from the survey results. At a frontline level, blowing and drifting snow may seem like a big problem; however, because it is quite location specific, it might not be considered a major problem affecting the winter maintenance community as a whole.

Rural drifting snow was ranked the number one problem by 73% of the responding agencies. When the primary and secondary problem responses are combined, suburban and rural blowing snow is the most prevalent problem faced by 100% of the agencies. Clearly, blowing snow presents an arena for improvement in deployment focus and assistance. Tabler’s *Controlling Blowing and Drifting Snow with Snow Fences and Road Design* (2003) is a valuable and timely update of his earlier 1994 *Design Guidelines for the Control of Blowing and Drifting Snow*.

The development of suburban snowpack is a primary concern of 71% of the responding agencies. Combining the primary and secondary problems indicates that rural, suburban, and urban snowpack; suburban black ice; and urban and suburban frost are the most significant problems. The results of this question are presented in graphic format in Figure 4.

When municipalities’ answers are separated, they rank development of snowpack and black ice as their primary concerns.

Equipment

Equipment includes the communication methods used within the winter maintenance vehicles, the type of trucks and

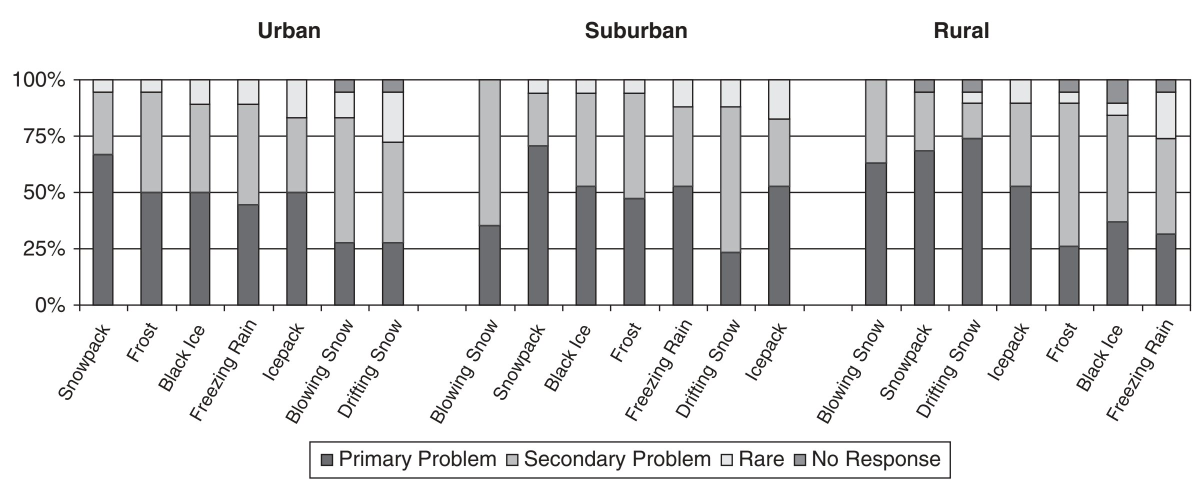


FIGURE 4 Problematic winter pavement surface conditions categorized by the regional characteristics.

their components, and the material holding and application equipment.

Communications

Communications with maintenance trucks is predominately through the use of two-way UHF/VHF and trunk system radios. Seven of the respondents (41%) have deployed 800 MHz systems. Alberta, Manitoba, Nebraska, Saskatchewan, and Washington State cited cellular phones as a method of communication, with Vancouver relying solely on cellular technology.

Surprisingly, 45% of the agencies reported significant problems with their communication systems. The most common problem is inadequate coverage owing to dead spots caused by terrain or a lack of repeaters. Limited channel capacity as well as the limited functionality of 800 MHz systems in mountainous terrain were also cited as technological problems. The drawback associated with cellular communication during emergencies as a result of inadequate capacity was also mentioned. Logistical problems associated with communication to field personnel were also described. These problems include radios being fixed within the vehicle and therefore not useful when crews are outside the truck, and the lack of interoperability with other agency radio systems.

An important trend is seen in the rise of problems associated with increased on-board computerized systems. Interference by radios with other electronic systems was reported by three agencies.

Trucks

The common response from agencies in all road weather climate categories indicated the use of a fleet of both two- and three-axle trucks with a gross vehicle weight range of 25,000 to 50,000 lb for snow and ice control. Horsepower ratings for these vehicles range from 250 to 300 for trucks without a plow wing and from 325 to 400 for those equipped with a wing.

A handful of state DOTs have initiated concept vehicle projects. Under these efforts new technologies and ideas for integrating advanced navigation, surface pavement condition, chemical application, driver environments, and others are being tested in actual over-the-road snowplows. It is anticipated that this area will offer the greatest possibility of advancement in equipment and its operation over the next few years.

Attempts to collect information about changes in the equipment that maintenance departments own and use was limited in its success. Many agencies lack resources to effectively research records regarding past operations and were, therefore, unable to provide data. For the agencies that were able to provide data, there were only minor changes in the number of trucks as categorized by how they are equipped; with only a plow, only a spreader, both a plow and spreader, or all-liquid trucks. Responding agencies with primarily rural maintenance responsibilities on average own and operate approximately 1,000 trucks total.

However, there have been some noteworthy changes in equipment usage. For example, in Maryland, the fleet of motorgraders used has more than tripled; whereas, in contrast, in other states the use of motorgraders to remove roadway ice pack has decreased. There also appears to be a slight increase in use of snowblowers, particularly in rural plains applications.

There has been a dramatic increase in the use of pavement temperature sensors on winter maintenance vehicles. In 1994, very few (less than 1%) winter maintenance vehicles had this equipment; whereas, an average of 30% of the vehicles had pavement temperature sensors at the time of this synthesis. This trend tends to indicate an increasing effort to provide more pavement-specific information to the equipment operator while on task, where it can make the most effective difference in efficiencies. It is important to note that the accuracy and relevance of the temperature data provided by these sensors is highly variable and dependent on mounting, use, and interpretation. Tabler (2003) provides insight to this problem in the results of a recent study.

Plow Blade Types

Plow blade types include one-way-only, V, and reversible, and can be used on either plow trucks or motorgraders. Some motorgraders are equipped with more than one blade for snow removal. Reversible-type blades are used on approximately two-thirds of the plow trucks; whereas approximately one-quarter use one-way-only blades, with the remainder being equipped with V-type blades. Motorgraders in use for winter maintenance are generally equipped with a plow blade mounted at the front of the vehicle in addition to the grader blade. More than 60% use reversible blades for plowing snow and approximately 30% use a V-type blade.

The use of wing plows has also increased in rural areas and is somewhat more widespread in Canada than in the United States. The New Brunswick DOT reported that all of its trucks have been equipped with wing plows for at least 10 years. Maryland use wings with benching capability.

Alberta, Missouri, and Saskatchewan noted using advancements made in their plow designs. Maryland uses rubber blades on some plows, as does Oregon. Oregon also uses ultra-high molecular weight polymer moldboard plows. One improvement based on research is the flush-mounted, carbide insert at the front edge of the blade and a non-zero clearance angle (Nixon 1993).

Spreaders

Application of solids and liquids requires the interaction of three components: (1) box, bed, hopper, and/or liquid tanks; (2) spinner or nozzles; and (3) application rate controls.

The term spreader is used interchangeably in respondent's answers to mean the box or the distribution spinner, or the combination of both. The largest spreader box capacity used by the responding agencies is 15 cubic yards. The overall average size of spreaders described was 8 cubic yards. Spreader box types (hopper, v-box, slide-in, and tailgate) and spinner locations (rear, behind cab, and underbody) are chosen to fit operational experiences and constraints by all the responding agencies and represent the full range of styles. More than 95% of the agencies that calibrate do so on an annual basis. Several report that calibration is also performed when repairs or changes are made to the equipment or material. Indiana indicated that it attempts to accomplish annual calibration, but that it varies from year to year. Edmonton calibrates both monthly and annually. Montana and Oregon responded that they did not calibrate their spreader distribution rates. The balance of the respondents have adapted or adopted commonly known methods to calibrate their spreaders. Some of these include trust in the settings of the electronically automated settings, verification of settings through catch and measure, and various calculations based on equipment speed, chain speed, spinner revolutions, auger revolutions per minute, correlation to ground or vehicle speed, and physical distance versus change in load.

The calculations used in calibration are represented by Nevada, which has been highly successful using the Salt Institute's spreader manual calibration sheet provided in *The Snowfighter's Handbook* (1999) to calibrate older spreaders that make up 20% of their fleet.

Many agencies reported methods to ensure that spreaders maintain calibration and perform at the desired level. Alberta Transportation monitors contractor performance with a spot calibration check of 5% of the units. Others vary among operator-related methods such as a card kept inside the truck and turned in, driver judgment based on route length or one of the following metrics:

- Electronic controls,
- Weekly maintenance management system validation,
- User information versus data,
- Random checks, and
- Third party to the operator.

Nebraska indicated that calibration was hard to truly know, because operators changed the settings after calibration.

In 1994, few agencies reported using truck pre-wetter systems; however, all reported that they now use them to some degree. On average, these systems are used on 40% of the trucks of the responding agencies.

Computerized controls associated with spreading rates for both liquids and solids represent a significant change in equipment available over the 10 years surveyed. Not surprisingly, the use of computerized spreader controls has increased, with 95% of responding agencies reporting increased use. Widespread use started much earlier in Canada then in the United States. Computerized spreader controls are typically used on two-thirds of the winter maintenance vehicles by the organizations surveyed.

Seventeen of the responding agencies described the use of computerized spreader controls. Montana, Nebraska, and Nevada indicated that in-cab data collection technologies allow for better control of materials application. The reduction of application rates, better assurance of appropriate amounts, and daily availability of data are given as benefits of these systems. Manitoba was still monitoring the introduction of spreader controls and data collection. Indiana commented that acceptance has been slow, but is growing. Key problems experienced by the responding agencies included inadequate minimum capacities of the hydraulic system, too may wires and connectors, and corrosion problems with wiring connections.

Materials

The use of chemicals other than sodium chloride (NaCl), all-liquids, and pre-wetting were the most common change in winter operations over the 10 years surveyed. Specifically, the addition of pre-wetting and all-liquid trucks along with the inclusion of easier cab controls and ground speed controllers for spreader operation were key changes to winter operations of the survey group.

Abrasives

Every agency that responded reported the use of abrasives; however, it was clearly indicated that this use is being discouraged because it is not a deicing agent and requires clean-up owing to PM-10 (particulate matter smaller than 10 micrometers) air quality standards. Other problems experienced by states including California, Nevada, Oregon, and Washington involve reducing the amount and potential of the abrasives entering rivers, negatively affecting the riverbeds. Some agencies including California, Edmonton, Nevada, Oregon, and Washington State, reported that they sweep, recover, or recycle abrasive materials, particularly in sensitive areas.

Chemicals

The majority of the responding agencies use NaCl in either solid or liquid brine form as an anti-icing, deicing, or pre-wetting chemical. The cities of Moncton and Vancouver, as well as Connecticut and Nova Scotia, use salt as their sole chemical. The northwestern states of Oregon and Montana do not use road salt at all.

For the balance of agencies calcium chloride (CaCl) is the predominant chemical. Six of the 14 agencies specifically cited use of a corrosion-inhibiting additive. A higher proportion of users of magnesium chloride (10 of the 11) specifically mentioned products with corrosion inhibitors. Alberta, Illinois, and the city of Moncton responded that they apply corrosion inhibitors to their fleet. Only WSDOT replied that they use the complex chloride containing sodium, potassium, and magnesium chlorides. The chemical use by reporting agency can be seen in Table 4.

One of the changes that occurred during this 10-year period (1994 to 2004) was the formation of groups such as the Pacific Northwest Snowfighters Association (PNSA). This organization of state, province, and municipality highway agencies developed specifications leading to a qualified product list of snow and ice control chemicals. The specifications are found on the PNSA website.

TABLE 4
ANTI-ICING, DEICING, AND PRE-WETTING CHEMICALS USED BY SURVEYED HIGHWAY AGENCIES

Agency	NaCl			CaCl		Complex Cl	CMA	Kac	MgCl	
	NaCl	NaCl Brine	NaCl Inhibited	CaCl	CaCl Inhibited				MgCl	MgCl Inhibited
Alberta Transportation	✓	✓		✓	✓				✓	
California DOT	✓	✓					✓			
Connecticut DOT		✓								
City of Edmonton	✓				✓					
Illinois DOT	✓	✓		✓						
Indiana DOT	✓	✓			✓					✓
Idaho TD	✓			✓	✓				✓	✓
ManitobaTransportation & Govt. Services	✓			✓						
Maryland State Highway Admin.	✓	✓		✓				✓	✓	✓
Minnesota DOT	✓	✓		✓			✓	✓	✓	✓
Missouri DOT	✓	✓		✓						
City of Moncton	✓	✓								
Montana DOT										✓
Ministere des Transports du Quebec				✓						
New Brunswick DOT	✓			✓						
Nebraska DOT	✓			✓				✓	✓	✓
Nova Scotia DOT	✓	✓								
Nevada DOT	✓	✓								✓
Oregon DOT							✓			✓
Saskatchewan Highways and Transportation	✓	✓		✓	✓				✓	✓
City of Vancouver	✓									
Washington State DOT			✓		✓	✓	✓			✓

Notes: NaCl = sodium chloride; CaCl = calcium chloride; CMA = calcium magnesium acetate; Kac = potassium acetate; MgCl = magnesium chloride.

All-Liquid

The average all-liquid truck capacity is 1,700 gal. Missouri uses both the largest maximum size of 6,000 gal and largest average size of 5,000 gal. Idaho and Nevada also use larger than average size all-liquid trucks, reflecting their successes in incorporating all-liquid methods in their snow and ice control activities. The efficiency of large all-liquid trucks is championed by Missouri, which reported that one 5,000-gal tanker replaces two or three dump trucks with small tanks. Minnesota provided application rates, the highest at 1,200 gal per lane mile, with an average rate of 300 gal per lane mile.

The manner in which all-liquids are applied has changed over the surveyed 10 years for 70% of the agencies. Nevada did not use all-liquid methodology before 1994 and Alberta deployed this technology in 2001. Improved technology has been a major change in this treatment strategy, greatly increasing the accuracy of application. All-liquid methods have been driven by needs to reduce salt use, environmental concerns, and economic constraints. They have also been driven by the desire for increased LOS. The inclusion and success of on-board pre-wetting of abrasives or chemicals has also prompted increased reliance on liquids. Enhancing this and representing a significant change is the need for increased experience and training.

The Montana DOT serves as a unique example of an agency that has made changes in their application of all liquids. The state has transitioned to a just-in-time response to storm conditions. They wait for a 100% assurance that a storm event will actually occur before all-liquid application, rather than basing their decision on a forecast. This approach is a result of efforts to reduce waste, avoid extra costs, eliminate unnecessary vehicle exposure to corrosion, and improve public relations.

Preliminary research on slippery conditions caused by all-liquid applications has occurred during recent years with nondefinitive findings; however, it was suggested to monitor incoming humidity levels, especially during the fall season (Leggett 1999). All-liquid applications can yield good results; however, it is not as forgiving as traditional application of solids. The recommendation of the early research suggests that combining such humidity monitoring with prudent application rate and frequency should reduce the likelihood of this problem occurring. Oregon began a research project in 2003, focusing on the reduced skid resistance caused by anti-icing applications. A survey question attempted to ascertain the general level of awareness of this issue and need for further research. More than 31% of the agencies responded that they did not feel that adequate information was available to avoid unintended consequences of all-liquid applications.

TRADITIONAL TECHNOLOGIES

There are several winter maintenance operations that can be considered traditional activities including the use of various equipment, materials, and technologies such as snowplows, sanders, snowblowers, motorgraders, front-end loaders, salt, grit, and two-way radios. What were emerging technologies 10 to 20 years ago (e.g., snow fences and RWIS) are now reported as traditional uses by a majority of agencies.

Snow Fences

Seventeen of 20 agencies reported using snow fences. Approximately equal numbers of agencies reported using temporary, fixed, and living snow fences (e.g., tree or shrub hedges). Some highway organizations use snow fences extensively, with living snow fences becoming increasingly popular. Examples include Oregon, which reports 30 mi (48.3 km) of roadway centerline protected by fixed snow fencing; New Brunswick, which reports 6.2 mi (10 km) of roadway centerline protected by living snow fencing; and Alberta Transportation, which reports a total of 237 mi (381 km) of cumulative snow fencing with all types combined. Only 41% of the responding agencies that use snow fences reported having an annual maintenance and repair plan and budget for snow fencing.

Other Blowing Snow Control Methods

The WSDOT has installed and tested vortex generators, originally designed to keep Antarctic runways free of drifting snow, on segments of Washington highways in efforts to alleviate drifting snow in the winter and drifting sand year round. Caltrans has installed jet roofs on ridgelines above selected highways to alter the wind flow and reduce the development of avalanche hazard.

ROAD WEATHER INFORMATION SYSTEMS

Use of RWIS has become a mainstream technological methodology in the winter operations toolbox. In 1994, the use of RWIS was fairly widespread geographically; however, it has become an even more essential component to winter operations and is increasingly used by traffic operations. RWIS is multi-faceted, owing to its electronic nature, communication methods, integration requirements, and roadside geographical deployment. This is evident in the various divisions within DOTs responsible for operation and maintenance of their systems. Often the responsibility is divided between operation or use groups and support or system maintenance. Support is most often accomplished at the headquarters or regional communications, electronics, or ITS levels. Central support is also a common source for server responsibility. Operation of the system is predominately at the district maintenance level. Vendor support and federal government (Canada) support are also cited in two instances (Indiana and Moncton) as the parties responsible for maintenance and operation of the system.

Deployment

Most agencies own and operate the majority of their automated weather stations. However, Washington State relies on a far greater overall number of stations at 430 than any other agency for which data were collected. Of these, 75% are owned by entities other than the WSDOT. Idaho similarly makes use of a significant number of weather stations that it does not own. These two agencies have proven the usefulness and benefits of exchanging weather data with other parties.

Eighty-two percent of those agencies that use automated weather stations incorporate pavement sensors with at least some of the stations. Some agencies use more than one pavement sensor at a single automated weather station. Nine of the responding agencies currently use National Transportation Communications for ITS Protocol (NTCIP) for ESS. There are many remote deployment issues that the agencies face including power, communication costs, and impacts to maintenance costs owing to travel distances for centrally based electronics personnel.

Although increased use and expansion of RWIS are described as significant changes in the way winter operations are conducted, 50% of the responding agencies have no deployment strategy or criteria for locating RWIS sites. Idaho, Indiana, Minnesota, Oregon, and Nova Scotia responded positively in this regard. In addition, Alberta, New Brunswick, and Washington State indicated that this was an effort currently under development or in the preliminary stages. Nebraska presently deploys only to trouble spots, rather than to provide a more comprehensive picture of weather data. In 2003, two federally funded projects were begun with regard to siting standards and pavement sensor calibration.

Information Access

Seventeen of 22 reporting agencies provided first-hand access to roadside weather information and pavement surface conditions for the individual winter operations decision makers. The individual winter operations decision maker does not have access to roadside weather and pavement information from RWIS–ESS in two of the municipalities, three provinces, and one state. This appears to be the exception, because of the 16, more than three-quarters use some combination of agency systems and vendor support to provide this access by means of the Internet or on an internal agency-owned network. In Oregon, the ITS unit is working to standardize access to road weather information to appropriate personnel. There are several particular cases where the information is available only on the agency intranet or at a single workstation. Indiana was in the process of deploying an RWIS at the time of the survey. Edmonton and New Brunswick reported the use of vehicle-mounted infrared pavement temperature sensors as their primary access to road weather information.

Road Weather Forecasts

All of the responding agencies provide access to weather forecasts for the individual winter operations decision maker. The most common access is simply the Internet. The cases where agencies responded otherwise were Canadian municipalities, which follow fairly rigid organization of winter operation efforts; that is, policy, plow routes, etc. However, information access and adaptability at the operator level is good. The respondents use a mix of general forecasts (e.g., National Weather Service, Weather Channel, and Meteorologix), federally provided tailored forecasts (e.g., Environment Canada), and consultant highway meteorology firms (e.g., Meridian, Northwest Weathernet, and Surface Systems Inc.) No question specifically asked about the use of pavement temperature forecasts.

Advancements

The agencies were asked how their use of weather information and deployment of roadside weather stations has changed over the period from 1994 to 2004. Fifteen agencies indicated that deployments have increased. For example, Nevada went from no stations in 1994 to 47 in 2003 and Washington State from a dozen to more than 65. Montana deployed all of its sites during the first half of the 10-year period.

Increased resolution and reliance on highway meteorology consultant weather forecasts provided by a surface transportation weather information service was cited by three agencies.

During the late summer of 2003, Transport Canada announced a federal initiative toward development of a national RWIS. Federal subsidy through ITS funding within their Strategic Highway Infrastructure Program is designed to support deployment of RWIS–ESS and the nationwide integration of all sites, including the existing 150, to provide consistent information to all jurisdictions.

Only two of the agencies (Quebec and Saskatchewan) did not have some remote weather sensors in place in 1994 and just began deployment of RWIS systems during the following 10 years. For three others, no significant change other than wider use has occurred over that period. Some of the changes cited by the agencies included:

- More informed decision making,
- Use of the data with training,
- Availability of data at more levels,
- Greater numbers of roadside installations, and
- Movement toward statewide networks.

One of the most significant changes has taken place in Montana where, currently, winter maintenance activities such as anti-icing do not occur until actual conditions change, rather than being based on a weather forecast. Increased use and reliance on pavement temperatures obtained from truck-mounted sensors not available 10 years ago is a change described by several agencies.

A 2-year study of the Wyoming RWIS, published in 1998, indicated that the system would facilitate and improve maintenance operations and enhance the safety and convenience of highway travel if certain critical improvements were made (Tabler 1998). Without these improvements, benefits were expected to be marginal and continued operation might not be cost-effective. Key areas identified for improvement that have cross-agency relevance included the following:

- Integrating separate systems;
- Improving data displays and simplifying use;
- Including supplementary weather information such as NEXRAD (*Nex*t Generation *Rad*ar, which can measure both precipitation and wind), satellite images, and weather maps;
- Making RWIS data and weather information directly accessible in every maintenance station;
- Improving site selection procedures;
- Providing additional training of maintenance staff;
- Providing high-quality weather forecasting services;
- Determining adequate sensor selection for recognition of blowing snow conditions; and
- Dedicating personnel to manage and maintain the system.

CHAPTER FOUR

ENVIRONMENTAL RESPONSIBILITY

Some traditional winter operation strategies are no longer practical owing to environmental constraints. Sixteen of the responding agencies reported investigating environmental impacts related to winter operation activities. Most agencies are making efforts to minimize those impacts through more restrictive use of the impacting strategies, clean-up practices after an individual storm or the winter season concludes, and better containment of materials.

A practice that contributes to adverse environmental impacts is the use of deicing abrasives, including sand. Under the action of traffic much of the sand applied to the roadway is ground into very fine particles and then, as it dries, it becomes airborne. This can result in PM-10 air quality nonattainments for many areas. In addition, these particles can generate silting issues associated with nearby bodies of water. Some agencies have responded to these issues by limiting the use of sand and by recovering it, and, like Edmonton, occasionally recycling it. Oregon makes a concerted effort to recover abrasives in stream-sensitive areas at the end of each winter season. Nevada sweeps where they experience nonattainment problems.

One of the winter operation activities that can affect the environment is the use of road salt and other chemicals. As shown in Table 4, many states apply chemicals to the roadway to prevent bonding between ice or snow and the pavement surface. These chemicals can have significant impacts by polluting storm water runoff and infiltrating other bodies of water. In November 2001, Environment Canada concluded that "road salts that contain inorganic chloride salts with or without ferrocyanide salts are 'toxic' as defined in Section 64 of the Canadian Environmental Protection Act, 1999" and mandated salt management practices ("Assessment Report—Road Salts" 2003). This has driven substantial efforts in developing such management practices.

The runoff pollution problem occurs at both the roadway, where chemicals are applied, and in association with storage of materials, primarily road salt stockpiles. In general, adoption of salt management practices and increased attention to associated environmental impacts of chemical treatments are increasingly important. Many agencies have made modifications to their road salt storage practices by covering stockpiles and capturing runoff. Stockpiles are being protected through a variety of methods including construction of structures designed specifically to house and protect road salt and the use of spray-on stockpile applications that waterproof the stockpile itself.

An example is the PNSA's earlier-mentioned anti-icing chemical specifications that emphasize safety, environmental preservation, infrastructure protection, cost-effectiveness, and performance. In Montana, response to winter storms does not begin until maintenance managers are certain that snow or ice will occur. This approach was implemented in response to public pressure to use road chemicals conservatively out of concern for the environment and for their vehicles. In Oregon, where the public has also emphasized the concern for these impacts, ODOT has implemented best management practices that address all aspects of routine road maintenance, including winter operation activities.

CHAPTER FIVE

SPECIAL CONSIDERATIONS

BLIZZARDS AND DISASTERS

Each decade winter storms of catastrophic proportion occur in North America. Fifty percent of the responding agencies (10 of 20) do not have a strategy to address winter storms beyond their capacities. Agencies that have disaster plans include Alberta Transportation, Connecticut DOT, City of Edmonton, Maryland DOT, Missouri DOT, Ministère des Transports du Québec, New Brunswick DOT, Nebraska DOT, Nevada DOT, and Saskatchewan DOT. Alberta, Nevada, and Saskatchewan all report improvements owing to experience, events, and advancements in technology to such plans over the surveyed 10 years.

SNOW AVALANCHE

Seven of the states and provinces operate routes subject to snow avalanche hazards. Idaho, Montana, and Oregon use temporary, passive methods including stability monitoring, avalanche forecasting, warning, and closure. Alberta, California, Nevada, and Washington all use active methods in the form of forecasting, explosive testing, and stabilization. This is not a complete list of provinces and states with highway avalanche problems. Several that did not respond to the survey are also known to experience and manage avalanche hazards.

Very little change has occurred in the manner and methods (forecasting, closure, use of explosives) of highway avalanche control in recent years; however, costs for control efforts have been steadily rising. Faced with stockpile shortages and other problems related to the once commonly used recoilless rifles, different surplus military weapons have been introduced such as the M-101 105mm howitzer and WSDOT's tank at Steven's Pass. Explosive availability and increased regulation have also affected avalanche control program costs. Caltrans cited the improvement of avalanche control equipment, such as installation of GazEx systems. GazEx is a permanently mounted system of an exploder tube that is filled with a mixture of propane and oxygen and fired by remote control. GazEx was the only option for on-site systems; however, notable recent advancements include the remote "Avalanche Blaster Cache" and mortar technology being evaluated by the Wyoming DOT, along with the AvalHex recently introduced from France. There are several current highway avalanche research projects supported by FHWA and TRB including

- Optimization of the Avalauncher avalanche control projectile,
- Evaluation of remote control equipment for avalanche clean-up,
- Infra-sonic monitoring of avalanche activity, and
- Wind drift disrupters.

DESIGN AND CONSTRUCTION

Edmonton, Manitoba, Minnesota, Montana, New Brunswick, Nebraska, and Oregon responded that they suggested changes to highway design in attempts to reduce winter maintenance costs. Nevada documented maintenance considerations to be included in the design of the I-580 freeway extension between Reno and Carson City. The design recommendations included:

- Incorporation of divided alignments,
- Non-use of undivided alignments with vertical separation,
- Wide shoulders and ditches,
- Sound wall use only with sufficient snow storage area (6 m minimum) and no shadowing of the roadway,
- Design of standard detail for installation of snow poles in proposed barriers,
- Wide medians (15 m minimum) with minimal use of barriers,
- Fills to be 0.74 to 1 m above existing grade (i.e., above the surrounding snow surface throughout a "design winter"), and
- Use of snow fence.

CHAPTER SIX

INSTITUTIONAL AND WORKFORCE ISSUES

Survey responses indicated several varied institutional and workforce issues. As might be expected, these issues are often characterized by the need to balance conflicting interests and demands on the part of the public and executive levels. Ironically, success in meeting maintenance goals set through close observation of these interests and demands frequently serves to further increase the expectations.

One problem area is public expectation and policies toward bare roads. A number of states have implemented bare roads policies. Once in place, the expectation by the public is that highways will be cleared immediately and that driving conditions will be commensurate with clear pavement conditions. Public awareness campaigns that emphasize caution during winter driving, while explaining the efforts of maintenance forces to clear roads, could be very effective in addressing this problem.

Training, particularly with regard to the handling of liquids used for pre-wetting and anti-icing, is also a problem experienced by many agencies with winter maintenance responsibilities. Not surprisingly, the primary winter maintenance operations identified by highway agencies are plowing, sanding/salting, and application of anti-icing materials. Also identified were other snow removal operations such as snowblowing and rotary plowing.

Several agencies commented on the importance of having trained winter maintenance personnel and the difficulties associated with delivering this training effectively and efficiently. Advances in technology compound this problem, as personnel need more and more technically specialized training to make use of advanced equipment and materials. AASHTO has developed a computer-based training program for RWIS and anti-icing. The project's primary goal has been to create an interactive, computer-based training program that is comprehensive at three levels: equipment operators, supervisors, and middle managers. The program was unveiled during 2003 and is very promising, covering information needed by all users, such as basic meteorology and chemistry. Users will be able to customize the program to include such variables as climatic information for their region, treatments for specific local road conditions, and regional and local weather forecasting and monitoring. Operators, supervisors, and managers can then perform simulations for a range of maintenance activity alternatives and view the resulting consequences of their selections.

Organizations use a variety of maintenance skill levels for snow removal from entry level to master level, with the master level more prevalent on rotary plows, snowblowing, and operation of V plows. Similarly, all skill levels conduct sanding and salting activities, whereas anti-icing and deicing are done by journey- and master-level workers 88% of the time. Other master-level activities identified include avalanche control, pay loader, snow route supervisor, and ice removal.

A handful of the agencies reported that they experience difficulties accomplishing winter maintenance as a result of inadequate workforce skills or high turnover rates. These difficulties are particularly pronounced during early winter storms when the workforce is not fully staffed for winter operations. On average, just over 15% of the workforce available for winter operations is considered entry level, just over 53% is considered journey level, and the remainder (32%) is considered master level. In general, turnover rates for the journey and master level are low, ranging from 5% to 10%. Entry-level turnover rates average approximately 10%, with very few agencies reporting entry-level turnover rates above 45%, and one agency reporting 90% for this category. The limited budgets available for both adequate numbers of personnel and their training also present problems for maintenance managers. This problem quickly multiplies the effects of the issues already discussed.

Added emphasis on environmental protection also affects maintenance operations, particularly with regard to the use of chemicals and abrasives. This added emphasis elevates the importance of training skill and the optimization of the application rates of treatment materials.

Highway agencies were asked to rate several potential improvement and current research areas aimed at aiding snowplow operations. Snowplow operator training and testing was identified as an essential important improvement area by 85% of the agencies, whereas 80% noted forward lighting as an essential improvement area. Nighttime conspicuity (lighting) and daytime conspicuity (snowplow colors, lighting, etc.) were considered essential by 55% and 41% of agencies, respectively.

Other improvement areas were considered good ideas by the agencies, but were not, on average, judged essential. These include the following:

- Better snowplow cabin display and control arrangements;
- Improvements to the driver's vision contrast sensitivity;
- Better in-cab systems to provide location, near-real-time operation data, communications with a base station, and proximity radar;
- Lane departure integrated into the warning system; and
- Magnetic edge line and tactual seat response.

CHAPTER SEVEN

EMERGING TECHNOLOGIES

There are several areas where emerging technologies hold promise for winter highway operations. These include a holistic integration of weather forecasts, pavement conditions, and rules of practice in the form of a maintenance decision support system (MDSS). Other examples are the increasing deployment of fixed anti-icing spray systems, fog warning systems, variable speed limits, and winter maintenance route optimization.

STORM MANAGEMENT

FHWA Maintenance Decision Support System

A significant event during the period covered by this synthesis is the development of a prototype MDSS commissioned by the FHWA Office of Transportation Operations. The prototype was conceived in cooperation with stakeholder state DOTs and operationally tested during the winter of 2002/2003 on selected routes maintained by Iowa. The project goals were to develop a prototype that:

- Capitalizes on existing road and weather data sources;
- Augments data sources where they are weak or where improved accuracy could significantly improve the decision-making task;
- Accomplishes data fusion to make an open, integrated, and understandable presentation of current environmental and road conditions;
- Processes data to generate diagnostic and prognostic maps of road conditions along road corridors, with emphasis on the 1- to 48-h horizon (historical information from the previous 48 h will also be available);
- Provides a display capability on the state of the roadway;
- Supplies a decision support tool, which provides recommendations on road maintenance courses of action; and
- Provides all of the above on a single platform, with simple and intuitive operating requirements, and does so in a readily comprehensible display of results and recommended courses of action, together with anticipated consequences of action or inaction ("Project Description" 2001).

Most agencies surveyed at least know that the FHWA MDSS exists. More than 40% report having had key involvement or participating at a stakeholder level. One-half of the responding agencies familiar with the MDSS believe it will develop into a useful tool.

Key examples identified by the MDSS field testing that are primed for improvement include better near-real-time precipitation information, the value of route thermal mapping in attempting greater accuracy at determining where and when to apply chemicals, and the importance of blowing snow prediction and treatment.

Fixed Anti-Icing Spray Systems

Fixed installations to apply anti-icing liquid are relatively new, primarily occurring over the 10 years covered by this synthesis. Several of the responding agencies have installed such systems on roadway sections and structures. Edmonton, Illinois, Maryland, Minnesota, and Washington State all have bridges with fixed spray systems, representing approximately 12 bridges or structures. Nebraska uses the technology on the approach to some bridges as well as a downgrade to a stoplight. Nevada is in the planning stages of incorporating spray systems in new freeway construction.

Lengths of roadway covered by the various installations vary from 150 ft to 3,500 ft, over two, three, and four lanes, on two-, five-, and eight-lane roads. A majority of the installations use potassium acetate. Magnesium and calcium chloride are also used, but to a lesser extent.

There are many ways in which the agencies have experienced integrating these systems into their operations. For Caltrans, it has reduced the need for storm patrol on an isolated section of road. Less effort by trucks before and early in a storm are benefits cited by Illinois and Maryland, two states that both still spread salt on the structures if storms are in progress or intensifying. Both Maryland and Minnesota have integrated some of their spray systems with an on-site RWIS–ESS. For Maryland, this automation addresses frost control, minor storms, and snow squalls. Minnesota, Nebraska, and Washington State have systems that are manually controlled. The city of Edmonton installed its system only recently, during the 2003 summer, and did not at the time of this synthesis have performance experience to share. Nevada cautioned that conflicts are often encountered between bridge designers and operations in installing the systems on structures.

Route Optimization

The increasing attention to efficient chemical use and resource expenditures drives analysis and planning to a far finer detail than previously. The attachment of actual road surface conditions such as solution chemical concentration and pavement temperature taken by sensors on the truck to the position of the truck along the highway network calculated by an on-board AVL receiver becomes significant. This information can then be processed in terms of the expected route length and conditions, precipitation rates, and the amount of materials still loaded to optimize plowing and spreading activities. This same information has high value as historical records to optimize, plan, and manage activities on an annual basis. When faced with increasing demands from funding sources to validate expenditures, this type of advanced information could be increasingly useful.

TRAVELER INFORMATION

More than 95% of the agencies involved in this study replied that they report winter road conditions regularly to the public. The advent of 511, a nationally designated three-digit phone number for access to traffic and road condition information, has provided a standard method for supplying traveler information. Most of the responding highway agencies use a combination of the Internet, the media, and telephone services such as a hotline or a 511 system to disseminate the information. Figure 5 shows an example of the types of information being provided by Connecticut on the Internet. Oregon's TripCheck has won two awards for its concept and design. Users are able to configure their own set of cameras and road reports to meet their travel routes or patterns.

A number of agencies use a variety of strategies including the Internet as a means to increase public awareness of winter operation goals and constraints. An excellent example is Caltrans' Snow & Ice Control Operations brochure, available as an Adobe Acrobat file on the Caltrans website. Another example is the Idaho Transportation Department's website, which provides both current driving conditions by means of the Road Report and a variety of other winter maintenance information to assist the public. Illinois provides RWIS–ESS information on the Internet to allow the public to view at least a portion of the information electronically. Mn/DOT makes remarkable use of their performance measure "Dashboards" in communicating with the public. Figure 6 shows an example of this type

Connecticut DOT Weather Roundup Report

	Rnd: 4 Time: 1600				Rnd: 5 Time: 1800				Rnd: 6 Time: 2000			
	3/13/2003				3/13/2003				3/13/2003			
Town	Temp	Pre	New	Tot	Temp	Pre	New	Tot	Temp	Pre	New	Tot
FARMINGTON	32	S	0.50	0.50	32	S-	1.00	1.50				
MERIDEN	30	S-	0.25	0.50	30	SW+	0.25	0.75	31	NP	0.00	0.75
UNION	30	S	1.50	2.75	28	S	1.00	3.75	29	SW	0.00	3.75
VERNON	33	S	0.00	0.00	32	S-	0.25	0.25	30	NP	0.00	0.25
WETHERSFIELD	34	S	0.25	0.25	30	S	0.25	0.50	32	NP	0.00	0.50
COLCHESTER	32	S	0.00	0.00	33	S	0.75	0.75	31	NP	0.00	0.75
GROTON	34	S-	0.00	0.00	31	S-	0.00	0.00	31	NP	0.75	0.75
HADDAM	34	S-	0.00	0.00	33	S-	0.00	0.00	32	NP	0.50	0.50
MANSFIELD	32	S	0.00	0.00	32	SIP	0.75	0.75	29	NP	0.25	1.00
NORWICH	30	S-	0.00	0.00	29	S	0.50	0.50	29	NP	0.25	0.75
OLD SAYBROOK	34	S-	0.00	0.00	31	S-	0.00	0.00	31	NP	0.50	0.50
PUTNAM	32	S-	0.25	0.25	31	S	0.50	0.75	30	NP	0.25	1.00
DARIEN	36	S-	0.00	0.00	36	S-	0.00	0.00	36	NP	0.00	0.00
MILFORD	36	S-	0.00	0.00	33	S-	0.25	0.25	33	NP	0.00	0.25
NEW CANAAN	36	S-	0.00	0.00	35	S-	0.75	0.75	35	NP	0.00	0.75
NEW HAVEN	34	S-	0.25	0.25	33	S-	0.25	0.50	33	NP	0.00	0.50
AVON	31	S	0.50	1.50	31	S-	0.00	1.50	30	NP	0.00	1.50
BEACON FALLS	33	S-	0.00	0.00	32	S-	0.25	0.25	33	NP	0.00	0.25
DANBURY	33	S-	0.00	0.00	32	SW	0.25	0.25	31	NP	0.00	0.25
EAST GRANBY	30	S	1.00	2.00	30	S-	0.25	2.25	34	NP	0.50	2.75
LITCHFIELD	32	S	1.00	2.00	32	S-	0.25	2.25	28	SW-	0.25	2.50
NEW MILFORD	34	S-	0.25	0.25	34	S-	0.00	0.25	32	NP	0.00	0.25
NORTH CANAAN	32	S	1.50	3.50	28	S-	1.00	4.50	26	SW-	0.50	5.00
THOMASTON	33	S-	0.50	0.75	31	S-	0.25	1.00	31	NP	0.25	1.25
WATERBURY	32	S+	0.50	0.50	32	S-	0.50	1.00	33	NP	0.00	1.00
WINCHESTER	32	S	1.00	2.00	31	S-	0.25	2.25	31	SW-	0.25	2.50

FIGURE 5 Connecticut road conditions as viewed on Connecticut DOT website. Precipitation codes include: IP (sleet), L (drizzle), NP (no precipitation), R (rain), RIP (rain/sleet), S (snow), SIP (snow/sleet), SW (flurries), Z (freezing rain), and ZIP (freezing rain/sleet).

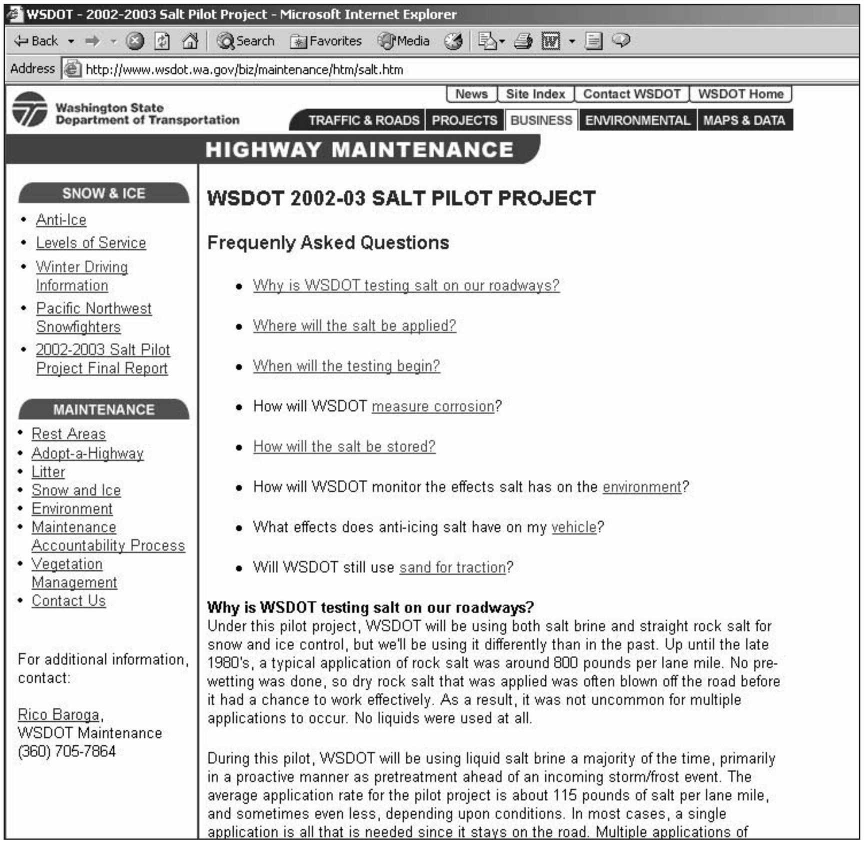


FIGURE 6 Winter maintenance practices for public information as displayed on the WSDOT website.

of public education being done by the WSDOT through their website.

Many of the agencies reported close coordination between different sections within the agency to manage winter maintenance, traffic operations, and information handling. The greatest level of cooperation appears to be between maintenance and those managing information for public dissemination. Maryland makes use of a communications center or emergency operations center to pass weather-related roadway information to the public, either by means of ITS elements or the media.

New Brunswick reported using private call centers to respond to road condition requests. Thirteen of the 22 agencies that make use of a reporting system collaborate and share data with adjacent provinces or states.

Weather Warning Systems

Severe or problematic weather warning is another topic of interest. Nine of 21 agencies reporting indicated that they use severe weather warning systems for fog, visibility, flooded roads, or other conditions. Most of these report using dynamic message signs and/or highway advisory radio systems to warn motorists. Some agencies reported on the use of permanent features such as signs or delineators in areas with chronically poor visibility. Nevada has installed a high wind warning system on a state route in Washoe Valley. Many respondents reported on the use of visibility sensors in association with other RWIS–ESS sensors to detect conditions for which they will then disseminate a warning. Visibility and fog are key issues as cited in a 1999 FHWA Tech Brief that included examples of crashes (*Highway Fog Warning System* 1999).

CHAPTER EIGHT

CONCLUSIONS

Since 1994, advances have been made to the strategies, deployments, and statistics related to conducting winter operations activities on the highways and municipal streets of North America.

Survey responses indicated that several of the emerging advanced technologies and techniques have experienced storm event and agency testing, integration, and adoption. Although a few traditional practices have been discarded, many traditional practices such as plowing and spreading have seen augmentation, modification, adaptation, and improvement through the continual improvement process that is the nature of daily front-line winter maintenance activities.

Agencies and funding sources are now interested in absolute cost and material efficiencies, although the resources for gathering such are rare and the technology limited in deployment. Nonintrusive data gathering is an area with great promise and one of the topics that should receive a high level of future consideration.

Road weather knowledge combined with training has become a crucial part of snow removal and anti-icing decisions. There is greater availability and more widespread use of road weather information than ever before. Previously, road weather information was not always readily available to maintenance staff or was limited to a very small regional deployment such as a metro area or toll road.

North American winter highway operators have better equipment, materials, methods, and are providing higher levels of service to the traveling public than before 1994. Correspondingly, they contend with increasing expectations, tighter budgetary and environmental constraints, and greater demands on information ingestion, collection, and generation.

Several key conclusions emerged from this synthesis. These conclusions are organized here according to similarity, with the first being organizational and the remainder grouped under state of the practice and emerging technologies.

- The organization of snow and ice control or other winter maintenance activities by the various agencies follows logical outlines based on the local needs and governmental structure and includes a current common thread of doing more with less under increasing constraints.
- New chemicals, all-liquid applications, and pre-wetting were the most significant changes to winter operations over the past 10 years, with improved equipment, Road Weather Information Systems (RWIS), and weather forecasts following closely behind.
- Use of computerized controls associated with spreading rates for both liquids and solids represents a significant change in equipment that has occurred over the past 10 years. Ninety-five percent of the responding agencies reported increased use.
- An important trend is seen in the rise of problems associated with the increased use of on-board (truck) computerized systems, such as interference by radios with other electronic systems, complex and fragile wiring, and inadequate hydraulic capacities.
- Although increased use and expansion of RWIS are described as significant changes in the way winter operations are conducted, approximately half of the 17 responding agencies with RWIS have no deployment strategy or criteria for site location.
- Half of the agencies surveyed believe the Maintenance Decision Support System concept will develop into a useful tool.
- Operational and institutional rural drifting snow was ranked as the number one problem by 73% of the agencies. When the primary and secondary problem responses are combined, suburban and rural blowing snow is the most prevalent problem faced by 100% of the agencies.
- Road weather knowledge with training has become a crucial part of the snow removal and anti-icing decisions.
- Use of RWIS has become a mainstream technological methodology in the winter maintenance toolbox. The use of RWIS was fairly widespread geographically 10 years ago; however, it has become an even more essential component to winter operations and is increasingly used by traffic operations for its value in the highway management area of intelligent transportation systems.
- More than 95% of the agencies involved in this study stated that they report winter road conditions regularly to the public through a combination of the Internet, the media, and telephone services such as a hotline or a 511 system.
- A significant problem area is public expectation and bare road policies. A number of states have implemented such policies. Once bare roads policies are in place, the expectation by the public is that highways will be cleared immediately and that driving conditions will be commensurate with clear pavement conditions. Public awareness campaigns that emphasize caution during winter

driving, while explaining the efforts of maintenance forces to clear roads, could be very effective in addressing this problem.

- Training, particularly that concerning pre-wetting and anti-icing, is important. Advances in technology compound the problem, because personnel need more and more technically specialized training to make use of equipment and materials. There are difficulties associated with delivering this training effectively and efficiently to a workforce that may not begin shifts until the snow is ready to fall.
- Added emphasis on environmental protection affects maintenance operations, particularly with regard to the use of chemicals and abrasives. This added emphasis elevates the importance of optimizing the application rates of treatment materials, management strategies, and training.

The following are suggested areas of future study:

- Blowing and drifting snow management.
- Impact of outsourcing winter maintenance activities.
- Impact of pavement design such as open grade on black ice formation.
- Operator and decision-maker training.
- Anti-icing chemical issues including vehicle and infrastructure corrosion, slipperiness, and environmental compatibility.
- Nonintrusive data gathering for performance management and research application.

In conclusion, winter highway operations are dynamic and eventful. Winter highway operations now integrate snow and ice control strategies and activities, traveler information, traffic operations, weather effects, environmental impacts, and customer satisfaction. The maintenance worker has at his or her disposal a wide variety and higher quality of tools, techniques, strategies, and material combinations to provide higher levels of service to the traveling public than were available before 1994. At the same time, they contend with increasing expectations, tighter budgetary and environmental constraints, and greater demands on information ingestion, collection, and generation. One of the challenges of this synthesis was to investigate ways to simplify the selection process of what combination(s) to use. Ultimately, the concept of a toolbox or palette with multiple options to choose from continues to be the optimal solution. The drawers of such a toolbox are organized hierarchically; the most used should be placed near the top followed by those that are necessary to operation support.

Winter highway operations, and specifically snow and ice control, have long used this concept of a methods and technology toolbox in accomplishing their tasks. This analogy can be expanded based on the results of the responses to this synthesis. As with any well-used toolbox, it comes with significant instructions. Included with the winter operations toolbox are guides touting constant attention to safety and environmental sensitivity. There are also guidelines from the public relations campaign designed to raise the public's awareness and appreciation of the efforts and role snow and ice control plays in their everyday life that are similar to previous campaigns about work zone driving responsibility. Accompanying this toolbox is a map case containing plans and strategies, which includes plans for the survey of customer expectations, ways to communicate constraints, and strategies to meet desired levels of service with minimal environmental detriments.

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APPENDIX A
Questionnaire

This survey questionnaire focused on capturing changes that have occurred since 1994.

Name of Respondent:

Agency:

1. Please estimate the percentage of roadways under your jurisdiction broken out by these Winter Maintenance Climate Zones:
   a. Urban mountainous
   b. Urban plains/plateau
   c. Urban coastal/lake effect
   d. Urban rarely winter weather
   e. Suburban mountainous
   f. Suburban plains/plateau
   g. Suburban coastal/lake effect
   h. Suburban rarely winter weather
   i. Rural mountainous
   j. Plains/plateau
   k. Rural coastal/lake effect
   l. Rural rarely winter weather
2. What are the primary pavement conditions that occur on your roadways and influence your winter operations strategy? (Rank as 1 = primary, 3 = secondary, 5 = rarely or not at all.)
   a. Snowpack urban
   b. Snowpack suburban
   c. Snowpack rural
   d. Icepack urban
   e. Icepack suburban
   f. Icepack rural
   g. Blowing snow urban
   h. Blowing snow suburban
   i. Blowing snow rural
   j. Drifting snow urban
   k. Drifting snow suburban
   l. Drifting snow rural
   m. Freezing rain urban

n. Freezing rain suburban

o. Freezing rain rural

p. Frost urban

q. Frost suburban

r. Frost rural

s. Black ice urban

t. Black ice suburban

u Black ice rural

v. Other:

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

4. Please describe or attach an example of how you budget, track, and summarize snow and ice control or winter operations costs.

   a. Is this information tied to specific segment locations? Yes ____ No ____

   b. Is a geographic information system (GIS) used for this information and your maintenance management practices?
      Yes ____ No ____

5. What were your winter 2002/03 snow and ice control maintenance costs in $ per lane mile?

   a. What were your highest and lowest annual costs in the past 10 years in $ per lane mile?
      Maximum ________ Minimum ________

6. How do you provide winter maintenance?

   a. Own forces

   b. Improvement district

   c. Contract—private sector

   d. Contract—other government

7. Have you documented any benefits from winter maintenance? Yes ____ No ____ If yes, please attach.

8. Do you use performance measures for winter maintenance evaluation? Yes ____ No ____ If yes, please attach.

9. Please describe the winter operation responsibilities and exchange between different disciplines such as winter maintenance, traffic operations, intelligent transportation systems, and traveler/traffic information within your agency.

10. How many pieces of each equipment type does your agency own or lease?

    a. Plow only: ten years ago

    b. Plow only: now

    c. Spreader only: ten years ago

    d. Spreader only: now

    e. Plow and spreader: ten years ago

    f. Plow and spreader: now

    g. All-liquid trucks: ten years ago

    h. All-liquid trucks: now

i. Motorgraders: ten years ago

j. Motorgraders: now

k. Snowblowers: ten years ago

l. Snowblowers: now

m. Other: ten years ago

n. Other: now

11. What type and size of truck used is currently specified for snow/ice control?

a. No. of axles

b. GVW (gross vehicle weight)

c. Horsepower

12. a. What percentage of your snow and ice control equipment is outfitted with the following?

i. Truck pre-wetter systems: % ten years ago

ii. Truck pre-wetter systems: % now

iii. Wing plows: % ten years ago

iv. Wing plows: % now

v. Pavement temperature sensors: % ten years ago

vi. Pavement temperature sensors: % now

vii. Computerized spreader controls: % ten years ago

viii. Computerized spreader controls: % now

ix. Ergonomic display and equipment controls: % ten years ago

x. Ergonomic display and equipment controls: % now

xi. Automated vehicle location (AVL): % ten years ago

xii. Automated vehicle location (AVL): % now

xiii. Global Positioning System (GPS): % ten years ago

xiv. Global Positioning System (GPS): % now

xv. In-cab data collection and communication: % ten years ago

xvi. In-cab data collection and communication: % now

xvii. Other: % ten years ago

xviii. Other: % now

b. Please indicate the percentage distribution of plow blade types for your equipment.

i. One way: % of trucks

ii. One way: % of motorgraders

iii. V: % of trucks

iv. V: % of motorgraders

v. Reversible: % of trucks

vi. Reversible: % of motorgraders

13. Are there any new plow or cutting edge components you have successfully introduced during the past 10 years?
Yes ____ No ____

14. Do you have any specialized in-cab plow/wing control systems? Yes ____ No ____

15. What are your spreader capacities? Maximum _______ Average _______

16. What type of spreader(s) is/are used (e.g., tailgate, zero velocity)?

17. Are they calibrated? Yes ____ No ____
    a. If yes, how?
    b. How often are they calibrated?
    c. How do you know they maintain their calibration and perform at the specified level?

18. Do you have any computerized spreader control or data collection systems in place? Yes ____ No ____
    a. Have you had any significant experiences, successes, or difficulties with the controls? Yes ____ No ____

19. What is/are your all-liquid truck capacity(ies)?
    a. Maximum
    b. Average

20. What communication with trucks do you use?

21. Do you experience any significant problems with these communication methods? Yes ____ No ____

22. What deicers/chemicals are used by your agency? Please indicate trade name and describe any added corrosion inhibitors.

23. Do you apply corrosion inhibitors to your fleet? Yes ____ No ____

24. Have you changed the manner in which you apply all liquids over the past 10 years? Yes ____ No ____
    If yes, what prompted the action?

25. Do you feel adequate information is available to you to avoid unintended consequences of all-liquid applications?
    Yes ____ No ____
    a. If not, what additional information or data are required?

26. Do you use abrasives? Yes ____ No ____
    a. If not, why?

27. Have you investigated environmental concerns resulting from or not resulting from winter maintenance activities?
    Yes ____ No ____

28. Does the individual winter operations decision maker with in your agency have first-hand information and access to roadside weather information pavement surface conditions (RWIS)? Yes ____ No ____
    a. If yes, how is this access accomplished?
    b. If yes, who developed or provides this access?
    c. Is this access adequate and meet all your needs? Yes ____ No ____

29. Please indicate the number of automated weather stations your organization accesses and uses.
    a. Your agency's
    b. National Weather Service or airport
    c. Other:

30. If your agency owns roadside weather stations (RWIS–ESS), how many pavement sensors are deployed?
    a. Are any active sensors? Yes ____ No ____
    b. If yes, how many?
    c. Are any non-contact sensors? Yes ____ No ____
    d. If yes, how many?
    e. Does your agency use NTCIP–ESS? Yes ____ No ____
31. What organizational level and discipline is responsible for RWIS?
32. Does your agency use a deployment criteria or strategy for RWIS sites? Yes ____ No ____
    a. If yes, please attach a copy.
33. Does your organization provide access to weather forecasts to winter operations decision makers? Yes ____ No ____
    a. If yes, what is the source?
    b. How is it delivered?
    c. What are the interval or frequency and period of the forecast?
34. Has your agency analyzed the RWIS data, developed performance measures or cost–benefit data? Yes ____ No ____
35. Is thermal mapping used or could it be used as part of your RWIS or for operations?
36. What is your familiarity with the FHWA Maintenance Decision Support System (MDSS) initiative? Key involvement
    a. Stakeholder participant
    b. I have heard of it
    c. What is it?
    d. If familiar, what is the most valuable component?
37. Do you report winter road conditions? Yes ____ No ____
    a. If yes, who manages it and how is it communicated to the public?
38. Do you utilize plow routes? Yes ____ No ____
    a. If yes, how do you determine them?
    b. Are they dynamically alterable once the storm begins? Yes ____ No ____
    c. What governs the change?
39. Who realistically decides the applications rate for chemical deicers or abrasive/deicer mixtures in a given storm?
    a. What reference is used to determine or change the rates?
40. Please describe your storm clean-up plans?
41. In your winter maintenance toolbox, which tools are well used?
42. What tools have broken or been thrown away in the past 10 years?
43. Which of the following are important improvements you feel can be made? Improvement of driver's vision contrast sensitivity

a. Magnetic edge line tape and tactual seat display

b. Forward lighting

c. Conspicuity daytime snowplow colors

d. Nighttime conspicuity

e. Better snowplow cabin display and control arrangements

f. Proximity radar, lane departure integrated in warning system

g. Location, real-time operation data and communication system with base station

h. Snowplow operator training and testing

i. Other:

44. Is skill distribution or annual turnover a problem to performing winter operations?

    a. Entry: % of winter workforce

    b. Entry: % of annual winter workforce turnover

    c. Journey: % of winter workforce

    d. Journey: % of annual winter workforce turnover

    e. Master: % of winter workforce

    f. Master: % of annual winter workforce turnover

45. Does your strategy plan include dealing with winter storms categorized as a disaster; i.e., beyond capability of your agency?

    a. Has this changed in the past 10 years?

46. Do you utilize snow fences? Yes ____ No ____

    a. Type

        i. Temporary

        ii. Fixed

        iii. Living

    b. What is the protected roadway centerline length for each of the types?

        i. Temporary

        ii. Fixed

        iii. Living

    c. What is the cumulative length of each type of snow fence?

        i. Temporary

        ii. Fixed

        iii. Living

    d. Do you have an annual maintenance/repair plan and budget for snow fence? Yes ____ No ____

47. Do you have any fixed deicing spray installations? Yes ____ No ____

    a. If yes, please describe the length, lane coverage, whether it is for a bridge, curve, etc.

    b. What type of chemical do you use with the system?

48. Are any of your routes subject to snow avalanche hazard? Yes ____ No ____

    a. If yes, please describe your method of hazard reduction.

49. Does your agency utilize or operate any visibility, fog, flooded road, or other severe weather warning systems?
Yes ____ No ____

50. Does your agency actively address reduced visibility or fog? Yes ____ No ____

51. Has your agency initiated or suggested any changes in highway design to reduce winter maintenance costs?
Yes ____ No ____

52. Please comment on your greatest and least problems as well as areas you feel the greatest improvements can be made relative to winter highway operations during the next 5 years.

APPENDIX B

Agencies Responding To Survey

STATES

California Department of Transportation
Connecticut Department of Transportation
Idaho Transportation Department
Illinois Department of Transportation
Indiana Department of Transportation
Maryland State Highway Administration
Minnesota Department of Transportation
Missouri Department of Transportation
Montana Department of Transportation
Nebraska Department of Transportation
Nevada Department of Transportation
Oregon Department of Transportation
Washington State Department of Transportation

PROVINCES

Alberta Transportation
Manitoba Transportation and Government Services
Ministère des Transports du Québec
New Brunswick Department of Transportation
Nova Scotia Department of Transportation
Saskatchewan Highways and Transportation

MUNICIPALITIES

City of Edmonton, Alberta
City of Moncton, New Brunswick
City of Vancouver, British Columbia

APPENDIX C

Questionnaire Response Matrix

Question\Agency	California DOT	Connecticut DOT	Idaho Transportation Department	Illinois DOT	Indiana DOT	Maryland State Highway Administration	Minnesota DOT
1. What would you describe as the three key changes that have occurred affecting your winter maintenance operation over the past 10 years?	Upgrading snow removal equipment & avalanche control system, information network & fog warning system	Brine trucks, RWIS, radar access at section manager's office	Liquid anti-icing chemicals and strategy. Real-time weather data (RWIS). Improvement of trucks/equipment	Use of 23% salt brine, loss of hwy. maintainers, increase in lane miles	1. Creation of Winter Operations Team to review and disseminate info., which leads to recommendations regarding snow & ice removal, materials, equipment, and activities. 2. Use of liquids. 3. Improving quality of equipment and use of technology; e.g., ground speed control	1. Level of service increased to current "bare roads policy." 2. Society has an increased focus on protecting the environment and expects SHA to manage winter storms accordingly. 3. Use of many new snow & ice control materials & technologies allows meeting challenges of 1 & 2	1. Anti-icing/pre-wetting/ RWIS 2. Customer surveys 3. Environmental issues w/salt and sand
2. Do you have a strategy and/or policy manual governing snow and ice control maintenance?	Y	Y	Y	Y	Y	N	Y
3. Please describe or attach an example of how you budget, track, and summarize snow and ice control or winter operations costs.		Costs captured by class codes by district (4)	Formula for past costs and amount of lane miles by district for budget. Track & produce reports using Maintenance Management System (MMS)		Salt budgeted on 10 year average Usage tracked on 2 week reports from districts Cost tracked by subdistrict	Budget funded through SHA operating budget as is routine maintenance budget. Predicting use for winter is extremely difficult, threatening routine budget. Prediction is based on mild-to-average winter assuming overages from severe conditions will be reimbursed. Documentation of events is extensive	
Is this information tied to specific segment locations?			Y	Y	Y	N	Y
4. What were your winter 2002/03 snow and ice control maintenance costs in $ per lane mile?	$27,763,155.00	Not tracked this way	Not available yet	$899.00	Not computed	$3,873.64	$668.12. Includes labor, equipment, and materials
b. What were your highest and lowest annual cost in the past 10 years in $ per lane mile? Maximum	$43,140,721.00		$1,764.00	$1,067.00	N/C	$3,873.64	
c. Minimum	$23,433,111.00		$671.00	$439.00	N/C	$804.87	
6. Have you documented any benefits from winter maintenance?	N	N	Y	N	N	N	N
7. Do you use performance measures for winter maintenance evaluation?		N	N		N	N	Y

8. Please describe the winter operation responsibilities and exchange between different disciplines such as winter maintenance, traffic operations, intelligent transportation systems (ITS), and traveler/traffic information within your agency.	Everyone works together		Maintenance personnel collect road condition info. 4 times/day for input to Road Report	Winter responsibilities: Operations. Traffic operations not involved. Traveler/traffic info. is by central bureau of operations	Improved communications. ITS, message boards. Working on ITS not implemented	Maintenance forces are primary with support from other disciplines. SHA has an EOC as clearinghouse for statewide info. on road/weather conditions and resources deployed. In severe storms Governor's Office is informed. Pertinent info. is compiled by SHA office of communications personnel relayed to radio and TV for public	RWIS 511 mn.org: public info. via web and cell phone ITS: Automatic bridge deicing systems
9. How many pieces of each equipment type does your agency own or lease?							
a. Plow only: 10 years ago		0		N/A	1,200		Unavailable
b. Plow only: now	287	0	42	N/A	1,268		852 plow trucks
c. Spreader only: 10 years ago		0		N/A	900	602	Unavailable
d. Spreader only: now	78	0	0	N/A	946	655—State owned	852 plow trucks
e. Plow and spreader: 10 years ago		632		N/A	N/A	0	Unavailable
f. Plow and spreader: now	573	632	391	N/A	N/A	11	852 plow trucks
g. All-liquid trucks: 10 years ago		0		N/A	0	34	Unavailable
h. All-liquid trucks: now	125	3	21	N/A	51	31	Y
i. Motorgraders: 10 years ago		2		N/A	37	13	Unavailable
j. Motorgraders: now	184	2	53	N/A	24	41	62
k. Snowblowers: 10 years ago		0		N/A	0	4	Unavailable
l. Snowblowers: now	119	0 (airports only)	27	N/A	0	3	Y
m. Other: 10 years ago					0		
n. Other: now					0		
10. What type and size of truck is currently specified for snow ice control?							
a. No. of axles		2	2 & 3	2	Single & tandem	2	1–2
b. Gross vehicle weight	30,000–34,000 & 60,000–64,000	70,000	35,000 & 58,000	32,500 lb	41,000 S/A, 52,000 T/A	39,500	21,840–32,000
c. Horsepower	275 & 425	240	250 & 370	210	275	250–275	265–310
11. What percent of your snow and ice control equipment is outfitted with the following?							
a. Truck pre-wetter systems: percent 10 years ago		0		0	0	0	5
b. Truck pre-wetter systems: percent now	50	6	51	30	75	90	85
c. Wing plows: percent 10 years ago		8		0	0	0	10
d. Wing plows: percent now	15	8	2	4	1	5	80
e. Pavement temperature sensors: percent 10 years ago		0		0	0	0	0
f. Pavement temperature sensors: percent now		15	25	8	Few	5	100
g. Computerized spreader controls: percent 10 years ago		0		0	0	0	0

h. Computerized spreader controls: percent now	80	100	100	95	75	90	30
i. Ergonomic display and equipment controls: percent 10 years ago		0		0	0	0	0
j. Ergonomic display and equipment controls: percent now		0		5	0	60	5
k. AVL: percent 10 years ago		0		0	0	0	0
l. AVL: percent now	?	0		0	0	<1	0
m. GPS: percent 10 years ago		0		0	0	0	0
n. GPS: percent now		0		0	0	<1	<1
o. In-cab data collection and communication: percent 10 years ago		0		0	0	0	0
p. In-cab data collection and communication: percent now	0	0		0	75	10	0
q. Other: percent 10 years ago				0	0	N/A	
r. Other: percent now				0	0	N/A	
12. Please indicate the percentage distribution of plow blade types for your equipment.							
a. One-way: percent of trucks	20	10	59	10	1	4	5
b. One-way: percent of motorgraders	15	0	0	N/A	0		0
c. V: percent of trucks		0	0	5	1	—	<1
d. V: percent of motorgraders	5	0	100	N/A	0	75	0
e. Reversible: percent of trucks	80	90	41	5	98	96	95
f. Reversible: percent of motorgraders	85	0	0	N/A	0		0
13. Are there any new plow or cutting edge components you have successfully introduced during the past 10 years?		N	Y	N	N	Y: Rubber blades on some applications	N
14. Do you have any specialized in-cab plow/wing control systems?	Y	Y	N	Y	N	Y: Some with benching capability	Y
15. What are your spreader capacities? Maximum			5 & 9 cubic yd	N/A	13' = 8.5 cubic yd	8 tons (v-box)	150 lb/lane mile
b. Average		5 yd	Same	N/A	10' = 6.5 cubic yd	* 6 tons	300 lb/lane mile
16. What type of spreader(s) is/are used (e.g., tailgate, zero velocity)	Tailgate, hopper type, conveyor	Hopper & dual dump style	Tailgate, all are v-box type with conveyor chain & spinner type distribution	Tailgate	10' and 13' Slip-In Hopper Spreader	Tailgate & v-box	Tailgate, zero velocity, ground oriented
17. Are they calibrated?	Y	Y	Y	Y	Y	Y	Y
b. If yes, how?	Output per auger RPM, automated/onboard electronics	7:2 mix applied to multi-lane roads	Ground speed	Sec 6-200.6.2 for calibration procedure	Weigh material	Formula—manual & computer software	Measure output or electronic
c. How often are they calibrated?		Start of winter season or when vehicle goes in for service during winter	Annually at a minimum	Annually & after major component changes	Varies—would like annually	Once/season unless new computer installed	Once/season

d. How do you know they maintain their calibration and perform at the specified level?		Calibration card displayed inside truck, worksheet turned in to manager of each section	Usually only if mechanical problem occurs and they are re-checked	Operator judgment	Random checks	Data stored in new systems. Output monitored to see correlation to usage per lane mile	User monitoring/compare to data collection
19. Describe any computerized spreader control or data collection systems in place.	Apitech spread Pac w/Dicky–John ICS 2000 Spreader & Muncie MESP 3001–CAL Model	None	Controllers are Gresen GRS-20-30 & Raven DCS-710	N/A	Muncie Ground Speed Controls on new trucks	Dickey–John Control Point allows SHA to preprogram multiple liquid and granular application rates	Use Swenson w/Dickey–John controller
b. Please include any significant experiences, successes, or difficulties.					Acceptance slow, but growing		Good success
20. What is/are your all-liquid truck capacity(ies)?							
a. Maximum		500 gal	3,500, 2,500, 1,000		5,000 gal	3,200	1,200 gal/lane mile
b. Average			2,500, 2,000, 1,000		1,800 gal	1,700	300 gal/lane mile
21. What communication with trucks do you use?	800 MHz	VHF—low band analog	UHF	47 MHz—UHF/VHF repeaters in Chicago	Low band moving to 800 MHz	Low band mobile 2-way radios at 47 MHz	UHF/VHF & 800 MHz
22. Do you experience any significant problems with these communication methods?		N	N		N	Y	N
b. Describe, if yes.	Mountain terrain can cause dead spots			Limited channel capacity & interference from vehicle system	We have some dead spots in the hilly areas of the state	Not enough channels; existing too crowded. Radios are truck-mounted, not good out of truck. Not inner-operable with other highway agencies	
23. What deicers/chemicals are used by your agency? Please indicate trade name and describe any added corrosion inhibitors.	Sodium chloride, salt brines, calcium magnesium acetate (CMA)	Salt brine	$MgCl_2$ & calcium CL: Meltdown w/shield LSW, Icestop IC 2000, Geomelt C	Rock salt or sodium chloride is primary deicer. Calcium chloride too. Increased use of sodium chloride solution	Salt, calcium chloride w/inhibitor, magnesium chloride w/inhibitor, salt brine. Other products: Ice Ban. Caliber & Geomelt evaluated.	Salt, salt brine, magnesium chloride (liquid), calcium chloride (flake), potassium acetate, caliber	Salt brine,magnesium chloride, Ice Ban M-50, Ice Ban M-80, Caliber M1000, Caliber M2000, Anderson's super Deicer, FreezGard Zero, salt, calcium chloride, potassium acetate, CMA, sand
24. Do you apply corrosion inhibitors to your fleet?	N	N	N	Y	N	N	N
b. What prompted any changes in the manner in which you apply all liquids over the past 10 years?			Experience	Increased use of 23% salt brine to try to prevent accidents on frosted bridges & reduce trust callouts	Improved technology & proven techniques	Past: liquids to salt using overhead spray. Now: on-board pre-wetting systems. It allows adding liquid to salt as needed. Also, have limited number of anti-icing trucks allowing pretreat roads & bridges. Use liquids in our two automated bridge anti-icing systems	Anti-icing—direct application prevent/pretreat was prompted by need to reduce salt for environmental and cost reasons
27. Do you use abrasives?		Y	Y	Y	Y	Y	Y
29. Does the individual winter operations decision maker within your agency have first-hand information and access to roadside weather information pavement surface conditions (RWIS)?	Y	Y	Y	Y	N	Y	Y

b. If yes, how is this access accomplished?		Maintenance mgr. Computer in office & home to access RWIS sites	Internet	Detailed RWIS data on dept. internal computer system. Limited RWIS on department intranet & Internet	INDOT to have RWIS up 2003/2004 winter. Limited stations now	Dist. & frontline maint. shop managers have access to RWIS on ScanWeb work & home. Mgrs. & engineers in maintenance hq. office and EOC to same and info. avail throughout Maryland DOT	Statewide RWIS using Internet interface
c. If yes, who developed or provides this access? (RWIS GUI)		RWIS vendor	Third party developed interface	RWIS data originally collected by vendor SSI who sends to dept computer systems	31 sites purchased from SSI. 16 installing now. All should be on web '03–'04	SSI ScanWeb/WSI Weather Source/SSI forecast products. Maintained by SHA's CHART Integration Team	Agency with contract vendor developed the system. Agency and forecast vendor provide data
d. Is this access adequate and meet all your needs?		Y	Y	Y	Not determined	Y	Y
30. Please indicate the number of automated weather stations your organization accesses and uses.		9	100–150	51	31	62	92
a. Your agency's		9	29	51	27	62	76
b. National Weather Service or airport			25–50		0	N/A	16
c. Other:			50–70		4	N/A	
31. If your agency owns roadside weather stations (RWIS–ESS), how many pavement sensors are deployed?		32	~65	204 (4/site)	31	158	150
b. Are any active sensors?		Y	N	N	N	Y	N
c. If yes, how many?		32				158	
d. Are any non-contact sensors?		N	N	N	N	N	N
e. If yes, how many?							
f. Does your agency use NTCIP–ESS?		N	N	Y	Y	Y	Y
32. What organizational level and discipline is responsible for RWIS?		Manager of radio communications	No formal program yet	Central bureau of operations (maintenance)	Service agreement w/vendor monitored by central office	CHART (ITS) Integration Team maintains servers/software. Office of maintenance personnel maintain field equip.	Statewide headquarters with district elect. maintenance
34. What is the source of weather forecasts to winter operations decision makers?		Accu-Weather, Inc.	NWS and VAMS in selected areas	Dept. computer system. Dept. intranet & Internet systems	Contract–Meridian Environmental Technology, Inc.	WSI Weather Source, SSI Winter Forecasts	NWS/contract/and free provider
c. How is it delivered?		Fax & Internet	Internet	Dedicated computer system & dept. Internet & intranet. Storm warnings also faxed to specific users	Internet & fax storm warning	FTP via Internet and satellite feed	Internet
d. What are the interval or frequency and period of the forecast?		Daily and at 4-h intervals during storms	2/24 h forecasts/day	4/day	Two set forecasts at 4:00 am and 2:00 pm with updates as needed	15 min radars, NWS text and SSI forecasts are 2 to 6 times daily	12 h update at 3 am and 6 am. 48 h updated every 6 h
35. How has your use of weather information and deployment of roadside weather stations changed over the past 10 years?		RWIS allows managers to make more informed decisions	We did not use VAMS then. RWIS data not as available to maintenance staff	No. of stations increased. W/training & RWIS knowledge, decision makers use data as crucial part of their snow & anti-icing treatment	RWIS only available in Indianapolis and Toll Road. In past 2 yr, INDOT has committed to state-wide network. Greater emphasis placed on accurate weather forecasts	Past: relied on NWS local TV and calling contacts in surrounding states. Now: has consolidated efforts into a single source for all weather info. using RWIS	Just implemented 2 yr ago
39. Do you report winter road conditions?		Y	Y	Y	Y	Y	Y

b. If yes, who manages it and how is it communicated to the public?		Storm center manned 24 h during storm. Number is broadcast to public	Maintenance Section & Public Affairs via website & 1-800 recording	District offices call in and report conditions. Database updated & map on web is updated for public	Internally to date. INDOT working on public report	Managed & disseminated via statewide intranet through EORS. Critical info. assembled by EOC for public affairs personnel who use radio & TV news to reach public	Office of Traffic Engineer via 511mn.org
c. Do you collaborate or share data with adjacent districts or states?		N	N	N		Y	Y
40. Do you utilize plow routes?	N	Y	N	Y	Y	Y	Y
b. If yes, how do you determine them?		Districts designate routes through maintenance garages		Lengths determined by highway classification & ADT	Created to cover all Interstates, U.S., and state routes in a unit	Maintenance shop level based on lane miles. Some routes cross shop or dist. boundaries	Determined by staffing and performance targets
c. Are they dynamically alterable once the storm begins?		N		Y	Y	Y	Y
d. What governs the change?				Reduction in LOS can be made on lowest priority routes first	Routes designed for worst case covering unit. Storm cover, manpower, intensity could cause change	Intensity of storm conditions, availability of hired contract trucks & SHA equipment operability	District supervisors
41. Who realistically decides the applications rate for chemical deicers or abrasive/deicer mixtures in a given storm?	Field supervisor	General supervisor or area manager	Operator	Plow operator	Driver or unit foreman	LOS & intensity of storm are 2 factors driving application rates. Shop manager gives general direction. Frontline SHA operators & route supervisors have flexibility in use based on conditions in field	Operator, infra-red pavement temperature sensors, RWIS input
b. What reference is used to determine or change the rates?		Department snow and Ice policy		Judgment			
42. Please describe your storm clean-up plans?	Use grader, snowblower, & plow truck to push back snow bank & make final cut with snowblower to keep melting snow from running across road. Apply abrasives to keep materials away from stormwater drains	Push back, snow removal bridge decks, key ramps & intersections, commuter lots	Pushing back off shoulders, cutting down snow berm at edge of road. Lastly, signs, gores, in front of concrete barriers & driveways	After driving lanes cleared, shoulders (Interstates), then rest areas, truck pull-offs, frontage roads, etc.	Clean-up begins after storm is over or if extra equipment is available	Varies dependent on type & intensity of storm. Push back shoulders; address site distance problems; scrape back to curb and assure inlets, drains, and curb openings are cleared; free intersections, clear accel. & decal. lanes & high sides of ramps & bridges of slush/snow; clear park & ride lots & rest areas; push any spilled salt back into barn & clean equipment	Mainline first, priority A,B,C cleanup; see snow and ice guidance from No. 2
43. In your winter maintenance toolbox, which tools are well used?	Snowplows and sanders, Snowblowers, graders, front-end loaders			Rock salt, 23% salt brine, calcium chloride, RWIS weather forecasts, winter prep.	Weather service, our radio system, training, anti-icing	RWIS, liquid applicator tanks, but is difficult. Saddle tank capability for pre-wetting salt on trucks. Salt brine & magnesium chloride	Plows, materials, anti-icing
44. What tools have broken or been thrown away in the past 10 years?	75mm recoilless rifle; don't use liquid deicers directly on snow pack		Can't think of any thrown away	None	Use of sand	Abrasives except for mountains in western state. Overhead spray systems. Zero Velocity Spreader, Epoke spreader & Ice Ban, CMAK, lessening liquid magnesium	Tyler zero velocity sander
49. Do you utilize snow fences?	Y	N	Y	Y	Y	Y	Y
b. Type							

i. Temporary			Y	Y	Y		Y
ii. Fixed	Y		Y				Y
iii. Living			Y	Y		Y	Y
e. Do you have an annual maintenance/repair plan and budget for snow fence?	As needed	N	N	Y	N	N	Y
50. Do you have any fixed deicing spray installations	Y	N	N	Y	N	Y	Y
b. If yes, please describe the length, lane coverage, whether it is for a bridge, curve, etc.	Curve, length unknown			Two bridges have spray injection system. Length = 474'		1. Bridge, 150' long, EB 2 lanes, WB 3 lanes 2. Bridge, 600' long, EB 2 lanes, WB 3 lanes	All bridge six locations (Interstate and truck highways)
c. What type of chemical do you use with the system?	Liquid magnesium chloride			Magnesium chloride w/corn derivative		Potassium acetate	Potassium acetate and magnesium chloride
d. How is the operation of the system integrated into your snow and ice control program?	Reduces need for storm patrol for isolated section of road			Salt still spread on structure if storm in progress. No requirement for salt brine if systems working		RWIS/ScanWeb automated primarily for frost control, minor storms, snow squalls & early part of large storms. Salt trucks deployed as storm intensifies	District controlled. Some integrated w/RWIS
51. Are any of your routes subject to snow avalanche hazard?	Y	N	Y	N	N	N	N
b. If yes, please describe your method of hazard reduction.	Blasters to stabilize zones		Monitoring snow stability measurements. Training personnel				
52. Does your agency utilize or operate any visibility, fog, flooded road, or other severe weather warning systems?	Y	Y	N	N	Y	N	Y
b. If yes, please describe.	Aim beam of light at receptor at 2 m. This and loop detector measures freeway speed. Info. passed to transp. mngt. center	VMS overhead signs operated by 24-h manned operations center					RWIS stations have visibility sensors
53. Does your agency actively address reduced visibility or fog?	Y	N	N	N	N	Y	N
b. If yes, please describe.	If either sight distance drops to low or stopped traffic is detected, caution messages are placed on changeable message signs					Overhead message signs to alert motorists	

55. Please comment on your greatest and least problems as well as areas you feel the greatest improvements can be made relative to winter highway operations during the next 5 years.	Greatest problem is early season storms coming prior to arrival of trained seasonal employees. Least problem is getting the equipment needed to maintain at a high standard	Using more salt brine makes spring clean-up easier because fewer abrasives are being used	Problems: issues surrounding chemical deicers. Training personnel in all new technologies & equipment	Problem here is providing desired LOS w/reduction in head count & increased lane miles	Problem: Sufficient numbers of trained personnel. Asset: dedicated hard-working personnel in place. Use of technology to compensate for doing more with less is critical	Greatest challenge: adjusting to increasing LOS and simultaneous cutbacks in workforce. Compounded by diminishing pool of hired equip. to supplement SHA forces. Also, balancing protection of environment while maintaining safe roads during and after storms. Combating challenges with increased training of managers & frontline forces, & increased use or new materials and technologies	

Question\Agency	Missouri DOT	Montana DOT	Nebraska DOT	Nevada DOT	Oregon DOT	Washington DOT
1. What would you describe as the three key changes that have occurred affecting your winter maintenance operation over the past 10 years?	1. Anti-icing 2. Ground speed controllers 3. Salt brine	1. Use of liquid deicers 2. Improvements in equipment 3. Use of RWIS/weather data	Better equipment; use of liquids; higher demands for "dry" pavement	Anti-icing w/salt brine & magnesium chloride. Improved equip., including pre-wetting & temperature sensors on plow blades. Implementation and installation of RWIS sites & improved weather forecasting	1. Maintenance funding constraints & limited personnel resources 2. Environmental constraints on use of sanding & anti-icing materials 3. Pavement damage resulting from studded tire usage in Oregon	1. Anti-icing 2. RWIS 3. Performance measures
2. Do you have a strategy and/or policy manual governing snow and ice control maintenance?	Y		N	Y	Y	Y
3. Please describe or attach an example of how you budget, track, and summarize snow and ice control or winter operations costs.	Use Activities and Functions for budgeting & tracking expenditures. Activity = snow & ice operations Functions = removal of snow & ice from roadway, anti-icing & frost control & storm clean-up		Maintenance budget & work program based on historical data. Specific maint. activity codes to which supervisors report their crew time, equipment, & materials, as well as incidental expenses	Line item budgeting. Winter ops. for labor & materials through operations. Funds based on zero base line budgeting mechanism allocated by Nevada legislature on biannual basis. Funds distributed to department districts by NVDOT financial management office. Severe winters have direct impact on funds available for other maint. tasks. All tasks tracked by use of maint. management system		History of expenditures with flexibility to alter with winter weather storms
Is this information tied to specific segment locations?	N	Y	Y	Y	Y	Y
4. What were your winter 2002/03 snow and ice control maintenance costs in $ per lane mile?	Not yet computed	$522.00	$832.14	$326.43	Unable to obtain exact figures	$1,478.00
b. What was your highest and lowest annual cost in the past 10 years in $ per lane mile? Maximum	$464.00	$594.00	$1,036.44	$585.14	$1,091.00	$1,571.00
c. Minimum	$263.00	$338.00	$441.69	$326.43	$672.00	$1,136.00
6. Have you documented any benefits from winter maintenance?	N		N	N	N	N/A
7. Do you use performance measures for winter maintenance evaluation?	N	N	N	N	N	Y

8. Please describe the winter operation responsibilities and exchange between different disciplines such as winter maintenance, traffic operations, ITS, and traveler/traffic information within your agency.	Traffic operations is responsible for the RWIS & ITS programs		Dist. maintenance personnel. Highway advisory signs, road closures, etc. Road conditions are joint between dist. maintenance personnel & Highway Patrol. Accessible via web or 511 line	TOCs & ITS are in infancy in Nevada. First installations are in south w/little or no winter. In snow areas some variable message boards are in place for road conditions & chain controls. Radio comm. is utilized between field personnel for updating conditions to centralized traveler info. centers	TripCheck accessed at www.tripcheck.com had detailed winter travel info: real-time road & weather	Maintenance personnel keep roadway safe for public. Traffic ops. works with ITS for public information. Maintenance offices give hourly updates to traffic information folks
9. How many pieces of each equipment type does your agency own or lease?						
a. Plow only: 10 years ago		0	35	0	N/A	Same
b. Plow only: now		0	29	0	775	N/A
c. Spreader only: 10 years ago		0		0	N/A	Same
d. Spreader only: now		0		0	435 + 21 chassis mount	N/A
e. Plow and spreader: 10 years ago		650	575	250	N/A	Same
f. Plow and spreader: now	1,700	650	600	277	N/A	214
g. All-liquid trucks: 10 years ago		0	0	0	2	5
h. All-liquid trucks: now	4	50	20	17	35	22
i. Motorgraders: 10 years ago		120	176	53	N/A	Same
j. Motorgraders: now	237	95	137	55	77	48
k. Snowblowers: 10 years ago		40	34	12	N/A	Same
l. Snowblowers: now	7	40	28	19	35	24
m. Other: 10 years ago						0 pre-wet system
n. Other: now						40 pre-wet system
10. What type and size of truck is currently specified for snow ice control?						
a. No. of axles	2 & 3	2	3	Single & tandem	3	Single & double
b. Gross vehicle weight	32,000 & 56,000	56,000	47,000 lb	12,500 & 34,000	50K	38,000
c. Horsepower	210 & 270–300	335	250 Min.	275–400	370	54,000
11. What percent of your snow and ice control equipment is outfitted with the following?						300+
a. Truck pre-wetter systems: percent 10 years ago	60	0		0	0	1
b. Truck pre-wetter systems: percent now	90	25	10	21	2	30
c. Wing plows: percent 10 years ago	1	1	10	5	N/A	0
d. Wing plows: percent now	5	25	10	17	10	10
e. Pavement temperature sensors: percent 10 years ago	1	0	0	0	N/A	0
f. Pavement temperature sensors: percent now	50	25	10	92	0	20
g. Computerized spreader controls: percent 10 years ago	1	0	0	0	N/A	0
h. Computerized spreader controls: percent now	75	25	10	80	0	20
i. Ergonomic display and equipment controls: percent 10 years ago		0	0	0	N/A	0
j. Ergonomic display and equipment controls: percent now		35	10	0	0	2

k. AVL: percent 10 years ago	0	0	0	0	N/A	N/A
l. AVL: percent now	0	0	15	0	0	N/A
m. GPS: percent 10 years ago	0	0	0	0	N/A	N/A
n. GPS: percent now	0	0	0	0	0	N/A
o. In-cab data collection and communication: percent 10 years ago	0	0	0	dc-0/radio 95	N/A	0
p. In-cab data collection and communication: percent now	0	0	15	dc-0/radio-98	0	0
q. Other: percent 10 years ago						0 hand-held data collection and communication
r. Other: percent now						20 hand-held PDA
12. Please indicate the percentage distribution of plow blade types for your equipment.						
a. One-way: percent of trucks	2	10	10	65	42	10
b. One-way: percent of motorgraders		10	0			0
c. V: percent of trucks	1	0	20	0	1	0
d. V: percent of motorgraders	40	90	50			30
e. Reversible: percent of trucks	97	90	90	38	12	90
f. Reversible: percent of motorgraders		0	0	100	100	100
13. Are there any new plow or cutting edge components you have successfully introduced during the past 10 years?	Y	N	N	N	Rubber & UHMW	N
14. Do you have any specialized in-cab plow/wing control systems?	Y	N	Y	Y	4-way float front plow	N
15. What are your spreader capacities? Maximum	12 ton	8 cu yd	12 yd	10 yd	10	10 yd
b. Average	8 ton	8 cu yd	10 yd	6 yd	8	10 yd
16. What type of spreader(s) is used (e.g., tailgate, zero velocity)	Slip-in, tailgate or under tailgate, zero velocity	Slide in bin sander (v-box)	Tailgate	v-type hopper w/few zero velocity	Tailgate	Hopper, tailgate, zero velocity & belt or chain-fed to spinner
17. Are they calibrated?	Y	N	Y	Y	N	Y
b. If yes, how?	Load, weigh, unload, weigh, calculate application rates		Run auger on setting & weigh amount put out in 1 min. Assume trucks will run at 30 mph and cover 1 mi in 2 min. Set to put on 500 lb/mi of straight salt or 750 lb per mi for salt and sand mix	Older spreaders = 20% of fleet use sheet attached. Other units use a computerized system allowing data to be programmed by use of the operating manual		Electronically; manually figuring out chain speed and revolutions, weighing amount of product. At a chain speed setting in correlation with ground speed
c. How often are they calibrated?	Yearly, before winter use		Annually	Once per year		Beginning of season and as needed during winter operations
d. How do you know they maintain their calibration and perform at the specified level?	Operator's look for expected duration compared to their route		Operators given settings. Hard to control, Operators do change settings	Operator monitoring application & re-checking calibration after equip. does hydraulic system repairs		Experience with amount of product used. Normally takes "x" amount for specific area

19. Describe any computerized spreader control or data collection systems in place.	Tyler Zero Velocity—Requires 40 GPM hydraulic system. Considerable number of wires and connectors. GL400 Spreadrite System—Wires and connectors creating problems. Swenson Zero Velocity—Similar problems with wires and connectors	Computer controls on liquid spreader. This has cut our application rates greatly, ensuring appropriate amounts used. New spreader systems to have computer controls and data storage	Tech, Force America & raven ground speed controllers and salters. Give data daily or by load and provide better control of amounts put down	Integrated Spreader Control generates a computerized printout of the exact amounts of material used		Raven systems for liquid & dry spreading
b. Please include any significant experiences, successes, or difficulties.		Infrared thermometers have been well received by operators				Flight chain electronics have not been reliable to date
20. What is/are your all-liquid truck capacity(ies)?						
a. Maximum	6,000 gal	2,000	5,000 gal	3,500 gal	2,600	6,000
b. Average	5,000 gal	1,500	250 gal	3,000 gal	1,000	1,000
21. What communication with trucks do you use?	UHF/VHF narrow band	VHF	VHF, some cellular	800 MHz radios	150 MHz band	800 MHz & Nextel cellular
22. Do you experience any significant problems with these communication methods?	Y	N	N	Y	Y	Y
b. Describe, if yes.	Radio has created problems by radio frequency affecting computers on truck	95% coverage		Areas where dead spots exist where no radio communication Is possible	Obsolete analog system. System nearing end of life cycle. Cost of converting to digital is expensive	800 system is unreliable in hills
23. What deicers/chemicals are used by your agency? Please indicate trade name and describe any added corrosion inhibitors.	Sodium chloride, salt brine, liquid calcium chloride, flake calcium chloride	PNS Category 1 list. (FreezGard Zero w/Shield LS, Ice Stop CI 2000). This year all liquid products (calcium & magnesium chlorides) have to be 75% less corrosive than sodium chloride to mild steel (mag = FreezGard Zero—CI Plus—from North American Salt and calcium = Geomelt C—from America West). No additional inhibitors are added by MDT	MgCl, NaCl, CaCl, Kac, Caliber 1000, Caliber 2000	Sodium chloride straight or mixed w/sand. Salt brine. Magnesium chloride (ice-stop). One district is experimenting with a spray on corrosion inhibitor	CMA—CMA, rust inhibited mag—FreezGard Zero with shield LSW	Inhibited magnesium chloride liquid/FreezGard and Ice Stop, inhibited calcium chloride/Geomelt Liquid, inhibited sodium solid/Clear Lane PNS and Ice Slicer, CMA
24. Do you apply corrosion inhibitors to your fleet?	N	N	N	N	N	N
b. What prompted any changes in the manner in which you apply all liquids over the past 10 years?	Using 5,000 gal. Tanker trucks take place of 2 or 3 dump trucks with smaller tanks	Better equip. allowed us to more accurately place product and in more than one lane. Currently waiting for assurance that a storm event will actually happen before anti-icing instead of strictly a forecast. This will reduce waste/cost, unnecessary vehicle exposure to corrosion, and improve public relations	Better control for amount applied and greater versatility	Did not apply 10 yr ago. Changes due to environmental & economical considerations	Training, experience, & new technology	Experience caused lowering of rates and better when and where use
27. Do you use abrasives?	Y	Y	Y	Y	Y	Y
29. Does the individual winter operations decision maker within your agency have first-hand information and access to roadside weather information pavement surface conditions (RWIS)?	Y	Y	Y	Y	Y	Y

b. If yes, how is this access accomplished?	Access by Internet or direct access	Internet & contracted services for 60 RWIS–ESS	All RWIS data are stored in central server. Accessible to maint. personnel statewide	RWIS info. is available on NVDOT's intranet. Still working on communications to all sites	Tripcheck.com & individual RWIS	Data from RWIS are accessed via WSDOT intranet. Available on six state servers using ScanWeb.Some RWIS data are posted on WSDOT Traffic & Weather website and the rWeather website
c. If yes, who developed or provides this access? (RWIS GUI)	Agency & RWIS provider	Agency, RWIS vendor & third party	Provided by Nebraska DOT, managed in part by vendor SSI	NVDOT data processing & communication sections, comm. consultants, & RWIS vendors	ODOT developed TripCheck. Surface systems include developed interface to the RWIS stations	RWIS vendor, agency, and third party developed interface
d. Is this access adequate and meet all your needs?	N	N	Y	Y	Y	N
30. Please indicate the number of automated weather stations your organization accesses and uses.	37	60	71	49	40	430
a. Your agency's	15	60	43	47	30	75
b. National Weather Service or airport	22	?	28	2	10	31
c. Other:						324
31. If your agency owns roadside weather stations (RWIS–ESS), how many pavement sensors are deployed?	15	60	70	127	20	
b. Are any active sensors?	Y	N	N	N	Y	N
c. If yes, how many?	15				10	
d. Are any non-contact sensors?	N	N	N	N	Y	N
e. If yes, how many?					10	
f. Does your agency use NTCIP–ESS?	N	N	Y	N	Y	Y
32. What organizational level and discipline is responsible for RWIS?	District level	Division level	Central electronics, district electronics, & contract	Districts with information sent to central server	ITS unit at HQ Traffic Management Section	Regional ITS technicians provide RWIS maintenance
34. What is the source of weather forecasts to winter operations' decision makers?	Contract	VAMS (NW Weather Net & SSI)	NWS & some contract	NWS, contracted weather forecasting service, contracted weather satellite service	TripCheck, NWS & SSI	NWS, Northwest Avalanche Center & contract weather services. With U of W have developed new weather info. website providing site-specific forecasts
c. How is it delivered?	Fax, Internet	Internet	Internet, fax, and phone	Internet, direct satellite connection, and fax	Fax, Internet	Fax, Internet, e-mail, contractor's website, internal website, phone, dispatchers, radio
d. What are the interval or frequency and period of the forecast?	Routine—daily for 24 h period Emergency—as conditions change	6 h updates, as major events are pending	2x/day or more if storm pending	Internet & direct satellite are on-demand. Contracted weather service updates 3x/day	Approx. every couple of hours.	2x/day, forecasts to 24 or 36 h
35. How has your use of weather information and deployment of roadside weather stations changed over the past 10 years?	No change	Deployed RWIS in 1993–1997, initially used in conjunction with site-specific forecasts. Recent changes in business practice have made use of these tools limited. MDT employs a "just-in-time" deicing strategy to avoid unnecessary applications	Current RWIS deployment is to trouble spots & not primarily to fill in weather data. Have better integration between weather forecasts & RWIS data	Have gone from nothing to installation of 47 RWIS sites with additional sites in the procurement phase. Executed a contract this year with advanced satellite weather forecasting ability	ITS unit working to standardize delivery of info. through TripCheck, ScanWeb, by SSI & reg. TOCs	System expanded from dozen sites to current level of 65 and growing

39. Do you report winter road conditions?	Y	Y	Y	Y	Y	Y
b. If yes, who manages it and how is it communicated to the public?	District input to Internet web page	Maintenance HQ, reported at field level, entered into database & disseminated via email, fax, Internet & 511 phone service	Joint—NEDOT, Hwy. Patrol & Meridan Environ. Tech. Inc. Managed by Meridan. On web & 511 phone line	Recorded messages accessible by phone. Weather radio stations. Working on an Internet access and upgrade of ITS statewide	TripCheck via Internet & toll free phone updated through Highway Travel condition Information System	By means of WSDOT website managed through Traffic Management Systems
c. Do you collaborate or share data with adjacent districts or states?	Y	N	Y	Y	Y	Y
40. Do you utilize plow routes?	Y	Y	Y	N	Y	Y
b. If yes, how do you determine them?	AADT & functional classification of routes	Developed on a local basis & supported by LOS guidelines	All roads covered. Priority to major & emergency routes, then school bus/work routes, then lighter routes		LOS categories	Experienced resources and ADT
c. Are they dynamically alterable once the storm begins?	Y	Y	Y		Y	Y
d. What governs the change?	Equipment, personnel shortages, or severity of storm	Storm activity on local basis	Maintenance supervisor or maintenance superintendent		Road/weather conditions	Storm
41. Who realistically decides the applications rate for chemical deicers or abrasive/deicer mixtures in a given storm?	Snowplow drivers	Manufacturer guidelines or HQ. Subsequent reapplications are decided in field	Maint. supervisor sets rates, but operator has option to change if conditions warrant	District engineers	Centrally by ODOT office of maintenance in consultation with district maintenance personnel	Operator
b. What reference is used to determine or change the rates?	MoDOT's Operator's Guide to Anti-Icing (based on FHWA Manual of Practice for an Effective Anti-Icing Program)	Dependent on surface conditions, temperatures, forecasts, time of day, managed transition qualifiers, wind, traffic, LOS guides		Case studies, effectiveness to bare pavement policy, other research		Predetermined work sheet for each area, history, and experience
42. Please describe your storm clean-up plans?	Push snow off of shoulders, remove snow piles at ramps, on bridges, etc., to avoid ramping affect	Urban: haul off wind-rowed snow or push back snow berms at intersections. Deicing & plowing slush. Rural: plowing shoulders during normal shift. Non-attainment air quality communities may require sweeping of any abrasives applied during cold events. Cutting snow-pack with a motor patrol to smooth rutted roads may occur in rural areas or mountain passes	After roads cleared, snow is pushed back from shoulders & benched if necessary	See attached plow plans	Abrasives recovered in stream-sensitive areas at end of winter season; otherwise, roads are swept and flushed according to "Desired Conditions of Maintenance Features on State Highways"	Traveled lanes then shoulders & pullouts. Clean-up of abrasives in sensitive areas ASAP. Other areas swept as weather allows—low priority
43. In your winter maintenance toolbox, which tools are well used?	Liquid chemicals, wider front snow plows	Plowing, abrasives w/salt, anti-icing & deicing, pre-wetting of abrasives, rotary plows, wing plows, better use of weather forecasts, better communication w/traveling public, web cams	Plows, spreaders, ground control units, liquids, & trucks	Anti-icing and storm forecasting	Anti-icing, information dissemination	RWIS, accurate weather forecasting
44. What tools have broken or been thrown away in the past 10 years?	None	Dry sand, cutting snow pack with motor patrols, abrasives without chemicals, gasoline engines (only diesel)	Zero velocity spreaders, reducing abrasives	Heavy dependency on abrasives for deicing. Anti-icing has reduced the amount of salt and sand that is applied to roadways during a storm incident		
49. Do you utilize snow fences?	N	Y	Y	Y	Y	Y
b. Type						
i. Temporary		Y	Y			Y
ii. Fixed		Y	Y	Y	Y	
iii. Living		Y	Y			Y

e. Do you have an annual maintenance/repair plan and budget for snow fence?			N	N	N	N
50. Do you have any fixed deicing spray installations	N	N	Y	N	N	Y
b. If yes, please describe the length, lane coverage, whether it is for a bridge, curve, etc.			400 ft, 2 lanes each way approaches to bridges 200 ft, 2 lanes, heads on bridge deck 900 ft, 2 lanes each way, spray heads on deck & approaches 500 ft, 3 lanes, downgrade to stop light	Planning stages for a new freeway construction		1. Overhead structure 2-lane hwy; 4 nozzles on centerline of 60-ft structure. 2. I-90 east end of Columbia River Bridge at 50 mph curve and 6% grade. 4 lanes (2 each way) nozzles are on the lane lines and system begins at bridge & continues for 3,500 ft east. Viewed on DOT traffic cam
c. What type of chemical do you use with the system?			Kac, Caliber 1000, and Ice Ban			Potassium acetate from “Envirotech” NC3000
d. How is the operation of the system integrated into your snow and ice control program?			Not really integrated			Manual; weather forecasts for pre-treat & observe for trigger during event
51. Are any of your routes subject to snow avalanche hazard?	N	Y	N	Y	Y	Y
b. If yes, please describe your method of hazard reduction.		Place warning of possibility and remove debris after event		Permanently installed Gas-x cannons on slopes prone to avalanche. Contracted services to place demolitions in potential slide areas	Monitor for snow stability and avalanche forecasts	Avalanche areas identified throughout mountain passes. Variable messages & other signs to warn motorists. Use explosives to bring down problem or hazardous areas. Tank & howitzer. Use NW Avalanche Center for info.
52. Does your agency utilize or operate any visibility, fog, flooded road, or other severe weather warning systems?	N		N	Y	Y	Y
b. If yes, please describe.				VMS controlled by RWIS sites provide display road restrictions due to wind speeds. Other VMS address road conditions and chain control req. Changing chain control signs from manually turned to radio controlled	Flood warning and severe weather warning system w/flashing beacons & HAR	Variable message signs & radio advisory warnings
53. Does your agency actively address reduced visibility or fog?	N	N	N	N	Y	N
b. If yes, please describe.				Have installed one automatic speed reduction system in fog prone area; not operational right now	“Basic Rule” speed law. Drivers can be cited for “too fast for conditions” even if less than posted speed	

55. Please comment on your greatest and least problems as well as areas you feel the greatest improvements can be made relative to winter highway operations during the next 5 years.	Greatest: 1. Increase plowing production to reduce exposure time between plows and public. Plowing wider and/or faster 2. Plowing snow on multi-lane routes, 3 to 4 lanes wide without plowing towards median. 3. Controlling/reducing use and need for chemicals		Loss of experienced personnel through retirement. Maintaining adequate numbers of personnel to do the job. Getting equip. to track the operations. Getting reliable weather forecasts to prepare	Greatest problem is to address customer service requirements in accordance with state's bare road policy and address environmental concerns with use of salts and requirements to reduce air-born particulates in air quality maintenance areas. The NVDOT top management has been supportive and allocated necessary funds to install a RWIS network and provide for the upgrade of equipment to meet new technologies. In the times of deficits in state budgets it will be a challenge to continue to move forward with new and innovative winter maintenance techniques that help improve customer service and provide an efficient and effective winter maintenance program	Anti-icing and environmental are greatest problems	Improvements to visibility. Maintaining higher LOS with fewer resources

Question\Agency	Alberta Transportation	Manitoba Transportation & Govt. Services	New Brunswick DOT	Nova Scotia DOT	Ministere des Transports du Quebec	Saskatchewan Highways & Transportation
1. What would you describe as the three key changes that have occurred affecting your winter maintenance operation over the past 10 years?	All winter operations contracted out to private industry in 1996. Double highway network in 2001; roads once looked after by the municipalities were transferred to the department. Network double, but our snowplow fleet only increased by about 20%. Development of salt management practices in the last few of years in light of environmental concerns with salt	Higher user expectations, development of winter LOS, improvement in equipment	1. Demands for higher level of service/bare pavement. 2. Higher service requirements for out-of-province, long-distance trucking. 3. Increased availability of information.	Computerized salt controls; improved forecasting tools	Training of personnel in road weather info. surface conditions & winter operations; pre-wetting of salt & multi-purpose trucks	Equipment technology—larger more powerful equipment. Advances in snow & ice control; i.e., pre-wetting equipment. Reduced severity in winter storm events—lower than average precipitation
2. Do you have a strategy and/or policy manual governing snow and ice control maintenance?	Y	Y	Y	Y	Y	Y
3. Please describe or attach an example of how you budget, track, and summarize snow and ice control or winter operations costs.	Snowplow hours and material usage is tracked on a segment basis. Winter budgets are developed using a running 5-year average of the items that are tracked. All items are tracked electronically through the department's Maintenance Contract Management System. MCMS is a computer-based software used to track all highway maintenance activities and costs	We budget & track all maintenance activities in our MMS				
Is this information tied to specific segment locations?	Y	N	N		N/A	N
4. What were your winter 2002/03 snow and ice control maintenance costs in $ per lane mile?	Accurate info. only to 1996/97	Not monitored on lane basis	2,900/lane mile (1,800/lane km)	$870.00	5,045 $can/km	$1,100.00
b. What were your highest and lowest annual costs in the past 10 years in $ per lane mile? Maximum	3,475.00		2,900/lane mile (1,800/lane km)		5,045 $can/km	$1200

c. Minimum	2,177.00		2,000/lane mile (1,400/lane km)		3,809 $can/km	800
6. Have you documented any benefits from winter maintenance?	N	N	N	N	N	Y
7. Do you use performance measures for winter maintenance evaluation?	Y	Y	N	Y	Y	N
8. Please describe the winter operation responsibilities and exchange between different disciplines such as winter maintenance, traffic operations, ITS, and traveler/traffic information within your agency.	Currently looking at a number of ITS initiatives such as variable message signs and remote weather information sites to provide a higher level of service to the traveling public. All functional areas that are effected by these initiatives are involved in the review	Provide travel info. to public through interaction with field staff	No separate disciplines for the identified areas			Preservation (maintenance) services. Primarily responsible for snow & ice control. A provincial communication center that monitors changing weather conditions to alert department crews & general public. Road condition updates are undertaken as weather changes and work crews complete snow & ice control activities. Department also tries to minimize maintenance require-ments by taking into consideration various design features to ensure that snow drifting & accumulation is minimized
9. How many pieces of each equipment type does your agency own or lease?	All equipment is owned by private maintenance contractors					
a. Plow only: 10 years ago			46		N/A	0
b. Plow only: now			21		29	0
c. Spreader only: 10 years ago			0		N/A	0
d. Spreader only: now	0		0		0	0
e. Plow and spreader: 10 years ago		102	376		N/A	400
f. Plow and spreader: now	533	152	406		276	320
g. All-liquid trucks: 10 years ago		0	0		0	0
h. All-liquid trucks: now	0	0	0		0	3
i. Motorgraders: 10 years ago		108	82		N/A	120
j. Motorgraders: now	50	108	76		56	80
k. Snowblowers: 10 years ago		21	16		N/A	5
l. Snowblowers: now	1	21	16	2	49	3
m. Other: 10 years ago						
n. Other: now						
10. What type and size of truck is currently specified for snow ice control?						
a. No. of axles	3	3	3 (tandem 6 x 4)		3 (some 2 and 4)	3
b. Gross vehicle weight		64,000	44,001–60,000 lb		27,000 kg	22 tonnes
c. Horsepower	Minimum 275 without wing & minimum 325 with wing	385	310		355 or 395 hp	400 hp
11. What percent of your snow and ice control equipment is outfitted with the following?						
a. Truck pre-wetter systems: percent 10 years ago		0	0		0	0
b. Truck pre-wetter systems: percent now	10	14	1		80	10

c. Wing plows: percent 10 years ago		90	100		90	5
d. Wing plows: percent now	35	52	100		90	80
e. Pavement temperature sensors: percent 10 years ago		0	1	0	0	0
f. Pavement temperature sensors: percent now	10	0	100	2	1	3
g. Computerized spreader controls: percent 10 years ago		0	10		100	0
h. Computerized spreader controls: percent now	100	14	95	100	100	5
i. Ergonomic display and equipment controls: percent 10 years ago		0			0	0
j. Ergonomic display and equipment controls: percent now	0	32			0	0
k. AVL: percent 10 years ago		0	0		0	0
l. AVL: percent now	0	0	0	0	0	0
m. GPS: percent 10 years ago		0	0		0	0
n. GPS: percent now	1	0	0	0	2	2
o. In-cab data collection and communication: percent 10 years ago		0	0		0	0
p. In-cab data collection and communication: percent now	100 (refers to communication with operator)	14	0	100	2	2
q. Other: percent 10 years ago			5—electric over hydraulic joystick plow			
r. Other: percent now			90			
12. Please indicate the percentage distribution of plow blade types for your equipment.						
a. One-way: percent of trucks	35	28	80		60	50
b. One-way: percent of motorgraders	2	5	100		0	0
c. V: percent of trucks	0	7	40		0	0
d. V: percent of motorgraders	5	15	100		0	0
e. Reversible: percent of trucks	65	65	20		40	50
f. Reversible: percent of motorgraders	93	0			0	100
13. Are there any new plow or cutting edge components you have successfully introduced during the past 10 years?	Y	N	Y		N	Y
14. Do you have any specialized in-cab plow/wing control systems?	Y	N	Y	Y	Y	Y
15. What are your spreader capacities? Maximum		10 cubic yd	250 kg/km		9 m^3 (11 yd^3) for 3 axle trucks	300 lb/mi
b. Average		6 cubic yd	10–150 kg/km	10 tonne	6 m^3 (8 yd^3) for 2 axle trucks	100 lb/mi

16. What type of spreader(s) is used (e.g., tailgate, zero velocity)	Compuspreader. Premium spread control device. Types 210, 220 & 230. Spreaders are located under the truck	Tailgate, 2-way spreaders, side tilt spreaders, forward tilt, stainless steel hoppers	Combination box, driver side front discharge spreader with chute & spinner choice some rear on old hoppers some u-box with front and rear options (rear not used)	Tailgate	v-box with spinners located on each side behind cab	Spinners located mid-section; few rear spreaders
17. Are they calibrated?	Y	Y	Y	Y	Y	Y
b. If yes, how?	Mechanics yearly calibrate each truck unit to company specifications	Material is weighed, spreaders are checked in the shop	Procedure in manual to verify application rate		Vumertric method	Spinners calibrated to equipment speed & required application rates
c. How often are they calibrated?	Yearly	Annually	Once/year plus any time unit serviced or operator questions accuracy	Annually	Once/yr	Annual, or as required if something changes, type of salt, etc.
d. How do you know they maintain their calibration and perform at the specified level?	Department has developed Contract Performance Measures in which the maintenance contractors are measured on a yearly basis. Part of the measures is a "Quality Assurance and Quality Control" program the contractor must implement. They are measured on how well they met requirements on yearly basis. One req. is spot calibration on 5% of units. Documentation must be provided	Spreader operator experience	Operator instructors coordinate the calibration & report to supervisors		Comparison with quantity of salt & sand loaded into the truck	Record keeping
19. Describe any computerized spreader control or data collection systems in place.		Compuspread 230 & 440	Dickey–John is major supplier and Compuspread/Basic (<30 units) and Apitech (<15 units)	Mostly Compuspread, a few Dickey–John	Dickey–John ICS 2000 and ACE Chlorobyte	Currently implementing new automated computer controlled system to winter maintenance fleet
b. Please include any significant experiences, successes, or difficulties.		We are presently monitoring the success or failure of this equipment through the use of process improvement teams	Dickey–John has unit compatibility and ease of use for operators			
20. What is/are your all-liquid truck capacity(ies)?						
a. Maximum	300 gal (Can)		N/A	None	Not used	1,000 gal tank
b. Average	150 gal (Can)		N/A	None		1,000 gal tank
21. What communication with trucks do you use?	Mike radios (cell phone and radio combined as one)	Fleet net radio, cell phones	400 MHz UHF integrated radio linked and interconnected through central switch to all provincial radio users (police, ambulance, etc.)	2-way radio	UHF/VHF	UHF/VHP—fleetnet radio system; cell phones
22. Do you experience any significant problems with these communication methods?	Y	Y	N	N	Y	Y
b. Describe, if yes.	Some areas have dead spots. Reduced as new towers installed	We vary the equipment used to suit the area			Some problems with diffusion's pattern in some areas. Also, radio installation can make interference with electronic devices	Areas w/limited or no radio or cell coverage
23. What deicers/chemicals are used by your agency? Please indicate trade name and describe any added corrosion inhibitors.	Calcium chloride, Coal Guard & Tiger Chemicals. Sodium chloride, magnesium chloride, salt brine	Sodium and calcium chloride. Experimenting with pre-wetting with Ice Ban, calibre, and salt brines. No corrosion inhibitors	Sodium chloride road salt, calcium chloride brine for pre-wetting	Rock salt, salt brine	Calcium chloride	NaCl—solid; brine NaCl solution—anti-icing pre-wetting; liquid calcium chloride—lower temp. ranges; calcium flake—northern locations; Calibre 3000—prewet sand & pre-wetting; Ice Ban—same; magnesium chloride—lower temperature ranges

24. Do you apply corrosion inhibitors to your fleet?	Y	N	N	N	N	N
b. What prompted any changes in the manner in which you apply all liquids over the past 10 years?	In process of getting the maintenance contractors to update their fleet to include pre-wetting devices. Not part of the tool box prior to 2001. Environmental concerns & LOS requirements prompted move to pre-wetting					Economics; better salt management practices; better training & understanding in regards to road salt science
27. Do you use abrasives?	Y	Y	Y	Y	Y	Y
29. Does the individual winter operations decision maker within your agency have first-hand information and access to roadside weather information pavement surface conditions (RWIS)?	Y	N	Y	Y	Y	N
b. If yes, how is this access accomplished?	Internet		Limited RWIS, but site-specific hourly weather forecast & 100 vehicle-mounted I/R pavement temperature sensors	Department intranet site	RWIS data via website	One road weather info. pavement surface condition sensor; investigating technology to add more
c. If yes, who developed or provides this access? (RWIS–GUI)	Environment Canada (federal government agency)		RWIS vendor, weather service provider	Agency developed by RWIS vendor	Agency	NWS, Environment Canada, provides weather forecasting & pavement temperature predictions in regard to the RWIS info.
d. Is this access adequate and meet all your needs?	Y		Y	Y	Y	Y
30. Please indicate the number of automated weather stations your organization accesses and uses.	5	0	10	18	18	
a. Your agency's	5		9	18	18	
b. National Weather Service or airport					0	Environment Canada
c. Other			9			Outside agency provides info.
31. If your agency owns roadside weather stations (RWIS–ESS), how many pavement sensors are deployed?	5		2		18	1
b. Are any active sensors?	N		N	Y	Y	Y
c. If yes, how many?				13	10	2
d. Are any non-contact sensors?				N	N	Y
e. If yes, how many?						4
f. Does your agency use NTCIP–ESS?	N		Y	Y	Y	N
32. What organizational level and discipline is responsible for RWIS?	District level maintenance for operation/head office for technical support		Central office	Head office, Highway Operations Section	District level maintenance & central organization	District level maintenance
34. What is the source of weather forecasts to winter operations decision makers?	Agreement with Environment Canada	Environment Canada site through the web, radios	Service agreement with Environment Canada	Environment Canada (Meteorological Services Canada)	National Weather Service	NWS through Environment Canada
c. How is it delivered?	Internet, fax, and phone	Radio, Internet	Email, website, and fax	Intranet, pagers	Fax, radio, Internet	Fax, Internet, & direct contact with meteorologist
d. What are the interval or frequency and period of the forecast?	2 h	N/A	2x/day	3 am & 3 pm	3/day	Real-time info. with updates as events change

35. How has your use of weather information and deployment of roadside weather stations changed over the past 10 years?	Not significantly; department is just moving toward this technology on a wider scale	Has not	Greatly increased use of 12 h weather forecast info. (1 h resolution) and meteorologist consultation. Use road temperature from mobile sensors to assist salt application rate determination		Deployment of roadside weather stations started in 1997	No knowledge of RWIS then. Evaluating now for national & provincial
39. Do you report winter road conditions?	Y	Y	Y	Y	Y	Y
b. If yes, who manages it and how is it communicated to the public?	Road maintenance crews do daily checks for most roads & report conditions to Alberta Motor Association. AMA is a private association that provides road condition reports to the general public free of charge by either phone or Internet. AMA also receives road condition reports from the Royal Canadian Mounted Police from time to time	Head office road info. clerk manages info. gathered from regional field staff & relates this info. to the public through the Internet & phone	District operations collect info. & transmit to communications centre, who compile and distribute to media, etc., and to contract call centre who respond to 1-800 calls from public	Highway operation section. Via toll free phone message & Internet	Agency, communicated to public via website	Automated phone system updated manually when conditions change; personal info. to individuals, if required; Internet with up-to-date road conditions; during severe events—local radio stations
c. Do you collaborate or share data with adjacent districts or states?	Y	Y with Internet	Y	Y	N	Y
40. Do you utilize plow routes?	Y	Y	Y	Y	Y	Y
b. If yes, how do you determine them?		Winter LOS statements	Timing, division location, salt routes, service levels		Geographical location & climatic conditions & contractors proximity	Based on equipment & labor resources that have been predetermined by road classification, average annual daily traffic, safety concerns
c. Are they dynamically alterable once the storm begins?	N	Y	Y	Y	N	Y
d. What governs the change?		Local area supervisors depending on storm event and their field experience	Sometimes service levels (high levels treated first, then lower levels) Equipment breakdowns Special conditions	Front line supervisors		Road conditions & safety concerns may cause operators to deviate
41. Who realistically decides the application rate for chemical deicers or abrasive/deicer mixtures in a given storm?	Operator decides what applications rate	Guidelines in winter LOS. Local area supervisor uses best judgment. Operators use discretion	Highway supervisor determines general rates; equipment operator adjusts rates locally	Truck operator with some influence from supervisors	Team leader	Equipment operator
b. What reference is used to determine or change the rates?	Operators receive training		Super uses storm response guide, pavement temperature info. and graph, and experience. Operator depends on conditions and past experience		Experience; air temperature is factor for type of deicer with road surface conditions, weather, & RWIS information	Developed charts & actual conditions
42. Please describe your storm clean-up plans?	Shoulders and approaches are cleared, driving lanes are plowed. Snow piles in medians or at approaches are pushed into ditch far enough so that visibility is not a problem. Piles that cannot be pushed into ditch are removed. Generally abrasives are not removed	Described in LOS	During normal operating hours and in daylight we push back snow banks and bench/shelf		Snow removal per attached document	Clear/plow driving lanes first. Apply salt or other deicing chemicals possible. Then work on shoulders & highway approaches. Check that obstructions or other barriers minimize the collection of drifting snow
43. In your winter maintenance toolbox, which tools are well used?		Truck plows, graders, loaders, salt & sand spreaders	1. Information: weather, road temperature; 2. Training: plowing, winter science; 3. Mechanical tools: improved plows (left-hand		Chemical deicers or abrasive/deicer moistures & pre-wetting	

			wing); 4. Communications			
44. What tools have broken or been thrown away in the past 10 years?		None	1. Mechanical: hopper spreader boxes, U-boxes		Pre-wetting difficult to integrate	
49. Do you utilize snow fences?	Y	Y	Y some	Y	Y	
b. Type						
i. Temporary	Y	Y	Y		Y	
ii. Fixed	Y			Y		
iii. Living		Y	Y		Y	
e. Do you have an annual maintenance/repair plan and budget for snow fence?	Y	Y	N	N	N	N
50. Do you have any fixed deicing spray installations	N	N	N	N		N
b. If yes, please describe the length, lane coverage, whether it is for a bridge, curve, etc.						
c. What type of chemical do you use with the system?						
d. How is the operation of the system integrated into your snow and ice control program?						
51. Are any of your routes subject to snow avalanche hazard?	Y	N	N	N	N	N
b. If yes, please describe your method of hazard reduction.	Described in Emergency Response Policy					
52. Does your agency utilize or operate any visibility, fog, flooded road, or other severe weather warning systems?	N	N	N	N	Y	N
b. If yes, please describe.					Sign boards along roads & info. through website	
53. Does your agency actively address reduced visibility or fog?	Y	Y	N	N	N	Y
b. If yes, please describe.		Conditions are reported on Internet & via phone & use of media. Orange delineators are placed on the roadside in chronic poor visibility areas. Shelterbelts are planted & maintained				Only provide permanent warning sign at extreme potential locations

55. Please comment on your greatest and least problems, as well as areas you feel the greatest improvements can be made relative to winter highway operations during the next 5 years.	Greatest problem is public perception. The public expects the roads to be bare and dry at all times. Many do not drive according to road conditions. Need to work on public awareness of winter driving. Training for operators on pre-wetting and anti-icing is also crucial. Training material should be geared to the operator level	Increased public expectations, poor driving for conditions, commuter traffic, global warming has changed weather patterns. Funding shortages for equipment is also issue. Good things: excellent staff w/substantial experience. Looking into pre-wetting sand & salt, anti-icing, RWIS	Greatest challenge—managing traveler & staff expectations & communicating our program goals and objectives internally & externally. Includes rationalizing LOS among various road classes & needs. Needs most attention to improvement. Other challenge is delivery of training to staff with resources. Challenge to modify work procedures & labor agreements to realize the benefits of new or improved tools such as RWIS. Least problems occur with snow & ice clearing on arterial high service roads, due to clear objectives, good geometrics, and good road surface		Road users travel too fast and fail to develop a safe attitude on winter road surface conditions. Expectations are that roads will be in same condition as summer. This makes operations requirements & related costs significant. Meteorological knowledge shall be improved over next 5 years as well as training of operations personnel & access to weather info.	Major emphasis on road salt management issues. In next 5 years department will take steps to better manage this re: application and storage. Improvements in equipment & training will help address some problems. Continuing with research and implement more environmental friendly alternatives to road salt

Question\Agency	City of Edmonton	City of Moncton	City of Vancouver
1. What would you describe as the three key changes that have occurred affecting your winter maintenance operation over the past 10 years?	Streetscape adjacent to roadway, customer expectation for bare all the time, environment	Pre-wetting of salt; RWIS; use of casuals to supplement workforce	New salters; easier cab controls; pre-wetting units
2. Do you have a strategy and/or policy manual governing snow and ice control maintenance?	Y	Y	Y
3. Please describe or attach an example of how you budget, track, and summarize snow and ice control or winter operations costs.		See attached	
Is this information tied to specific segment locations?	Y	N	
4. What were your winter 2002/03 snow and ice control maintenance costs in $ per lane mile?	6,000/lane km		
b. What was your highest and lowest annual cost in the past 10 years in $ per lane mile? Maximum	6,250/lane km		
c. Minimum	4,500/lane km		
6. Have you documented any benefits from winter maintenance?	Y	N	
7. Do you use performance measures for winter maintenance evaluation?	Y	N	
8. Please describe the winter operation responsibilities and exchange between different disciplines such as winter maintenance, traffic operations, ITS, and traveler/traffic information within your agency.	All together		

9. How many pieces of each equipment type does your agency own or lease?			
a. Plow only: 10 years ago	22	15	
b. Plow only: now	22	17	
c. Spreader only: 10 years ago	82	3	
d. Spreader only: now	82	3	6
e. Plow and spreader: 10 years ago	82	5	28
f. Plow and spreader: now	82	6	28
g. All-liquid trucks: 10 years ago	75	0	0
h. All-liquid trucks: now	75	0	0
i. Motorgraders: 10 years ago	20	2	2
j. Motorgraders: now	20	2	2
k. Snowblowers: 10 years ago	12	2	
l. Snowblowers: now	12	4	4
m. Other: ten years ago	15 walk plows		
n. Other: now	15 walk plows		
10. What type and size of truck is currently specified for snow ice control?			
a. No. of axles	3	3	
b. Gross vehicle weight	45,000	60,000	
c. Horsepower	260	395	
11. What percent of your snow and ice control equipment is outfitted with the following?			
a. Truck pre-wetter systems: percent 10 years ago	91	0	
b. Truck pre-wetter systems: percent now	91	100	5
c. Wing plows: percent 10 years ago	0	0	
d. Wing plows: percent now	0	100	
e. Pavement temperature sensors: percent 10 years ago	0	0	
f. Pavement temperature sensors: percent now	50	30	
g. Computerized spreader controls: percent 10 years ago	100	90	
h. Computerized spreader controls: percent now	100	100	
i. Ergonomic display and equipment controls: percent 10 years ago	100		
j. Ergonomic display and equipment controls: percent now	100		
k. AVL: percent 10 years ago	0	0	
l. AVL: percent now	15	0	
m. GPS: percent 10 years ago	0	0	
n. GPS: percent now	15	0	
o. In-cab data collection and communication: percent 10 years ago	100	100	

p. In-cab data collection and communication: percent now	100	100	
q. Other: percent 10 years ago			
r. Other: percent now			
12. Please indicate the percentage distribution of plow blade types for your equipment.			
a. One-way: percent of trucks	0	0	
b. One-way: percent of motorgraders	0	100	
c. V: percent of trucks		80	
d. V: percent of motorgraders	50	100	
e. Reversible: percent of trucks	100	100	
f. Reversible: percent of motorgraders	100	100	
13. Are there any new plow or cutting edge components you have successfully introduced during the past 10 years?	N		N
14. Do you have any specialized in-cab plow/wing control systems?	N	Y	N
15. What are your spreader capacities? Maximum	11 yd	14 metric tonnes	
b. Average	11 yd	14 metric tonnes	6 yd
16. What type of spreader(s) is used (e.g., tailgate, zero velocity)	Custom-built frame mounts that unload in hanging racks	Behind cab mount	
17. Are they calibrated?	N		
b. If yes, how?	Annual on a track	Catch and measure (salt/sand) speed and distance	
c. How often are they calibrated?	Annual plus monthly	Annually	
d. How do you know they maintain their calibration and perform at the specified level?	MMS validated weekly	Electronically/hydraulic controlled/speed & distance (computer controlled)	
19. Describe any computerized spreader control or data collection systems in place.	All the same Compuspread	Dickey–John unit	Dickey–John
b. Please include any significant experiences, successes, or difficulties.			
20. What is/are your all-liquid truck capacity(s)?			
a. Maximum	1,100 litres		
b. Average			
21. What communication with trucks do you use?	2-way 800 MHz system	800 MHz	Cell phone
22. Do you experience any significant problems with these communication methods?	N?	N	N
b. Describe, if yes.			
23. What deicers/chemicals are used by your agency? Please indicate trade name and describe any added corrosion inhibitors.	Road salt (fine only); liquid calcium with inhibitors	Salt brine and pure salt	Salt only
24. Do you apply corrosion inhibitors to your fleet?	?	Y	N

b. What prompted any changes in the manner in which you apply all liquids over the past 10 years?	Use 100% more often than just for stickability	Salt brine application	
27. Do you use abrasives?	Y	Y	
29. Does the individual winter operations decision maker within your agency have first-hand information and access to roadside weather information pavement surface conditions (RWIS)?	N	Y	N
b. If yes, how is this access accomplished?	Patrol every 2 h and use vehicle-counted sensors	Accessed through Environment Canada website	
c. If yes, who developed or provides this access? (RWIS–GUI)		Environment Canada	
d. Is this access adequate and meet all your needs?		Y	
30. Please indicate the number of automated weather stations your organization accesses and uses.		1	
a. Your agency's		1	
b. National Weather Service or airport			
c. Other	None		
31. If your agency owns roadside weather stations (RWIS–ESS), how many pavement sensors are deployed?			
b. Are any active sensors?	N		
c. If yes, how many?			
d. Are any non-contact sensors?			
e. If yes, how many?			
f. Does your agency use NTCIP–ESS?			
32. What organizational level and discipline is responsible for RWIS?		Federal government	
34. What is the source of weather forecasts to winter operations decision makers?	Environment Canada special paid for reports every 6 h		NWS
c. How is it delivered?	Fax		Telephone
d. What are the interval or frequency and period of the forecast?	6 h		As much as we want
35. How has your use of weather information and deployment of roadside weather stations changed over the past 10 years?	Same		
39. Do you report winter road conditions?	N	Y	Y
b. If yes, who manages it and how is it communicated to the public?		Report to local radio stations and council	Through media
c. Do you collaborate or share data with adjacent districts or states?		Y	N
40. Do you utilize plow routes?	Y	Y	N
b. If yes, how do you determine them?	Based on traffic volumes and speed and bus service	Determined by location of emergency services such as.…	
c. Are they dynamically alterable once the storm begins?	N	N	
d. What governs the change?	Road class change … bus service		

41. Who realistically decides the applications rate for chemical deicers or abrasive/deicer mixtures in a given storm?	Maintenance staff based on our weather conditions to meet road safety and balance environmental concerns	Supervisor in charge of snow storm	
b. What reference is used to determine or change the rates?			
42. Please describe your storm clean-up plans?	Plow to bare, stack and remove to snow sites, sweep all paved roads in the spring, and recycle sand	Load and haul in downtown area. Blow back subdivisions and main drags. Some drags have to be hauled if buildings are too close to the street	
43. In your winter maintenance toolbox, which tools are well used?	Too many to list	Weather reports, snow storm reports, salt analysis spreadsheet	
44. What tools have broken or been thrown away in the past 10 years?	None	None	
49. Do you utilize snow fences?	N	Y	
b. Type			
i. Temporary			
ii. Fixed		Y	
iii. Living			
e. Do you have an annual maintenance/repair plan and budget for snow fence?	Y	Y	
50. Do you have any fixed deicing spray installations?	Y	N	N
b. If yes, please describe the length, lane coverage, whether it is for a bridge, curve, etc.	Bridge		
c. What type of chemical do you use with the system?	Calcium chloride same as road material		
d. How is the operation of the system integrated into your snow and ice control program?	Just installed this summer		
51. Are any of your routes subject to snow avalanche hazard?	N	N	N
b. If yes, please describe your method of hazard reduction.			
52. Does your agency utilize or operate any visibility, fog, flooded road, or other severe weather warning systems?	N	Y	N
b. If yes, please describe.		Local radio and TV	
53. Does your agency actively address reduced visibility or fog?	N	N	
b. If yes, please describe.			
55. Please comment on your greatest and least problems as well as areas you feel the greatest improvements can be made relative to winter highway operations during the next 5 years.		By-law strengthening & enforcement; contractors plowing snow onto sidewalks that have been opened; salt classified toxic—reducing salt consumption using methods such as anti-icing & pre-wetting; Public education needs more explanation by way of various media	

Abbreviations: MMS = maintenance management system; RWIS = Road Weather Information System; LOS = levels of service; SHA = state highway agency; N/C = not computed; ITS = intelligent transportation system; S/A = single axle; T/A = tandem axle; EOC = emergency operations center; AVL = automatic vehicle location; GPS = global positioning system; CMA = calcium magnesium acetate; ESS = Environmental Sensor Stations; VAMS = Value Added Meteorology Service; NWS = National Weather Service; SR = state route; EORS = emergency operations reporting system; EB = eastbound; WB = westbound; N/A = not available; UHMW = ultra-high molecular weight (polyethylene); GPM = gallons per minute; ADT = average daily traffic; AADT = average annual daily traffic; TOCs = traffic operations centers; HAR = highway advisory radio; GUI = graphic user interface; I/R = infrared.

Abbreviations used without definitions in TRB publications:

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