Project No. 06-18

# GUIDE FOR SNOW AND ICE CONTROL OPERATIONS

FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies of Sciences, Engineering, and Medicine



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The Texas A&M University System
College Station, Texas

April 2022

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## DISCLAIMER

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## ACKNOWLEDGMENTS

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## ABSTRACT

Under NCHRP 06-18, the research team updated the *1999 AASHTO Snow and Ice Control Guide*. The team expanded the information in the current chapters along with adding in new chapters. Nine chapters in the new snow and ice control guide cover operations, strategies, performance measures, levels of service, personnel, equipment, materials, technologies, road weather information systems, and safety. The appendices provide a variety of resources to support a state, local, or tribal agency with developing a snow and ice control plan, ordering materials, assembling specifications for new equipment, and creating messaging for media releases. The guide is designed to be used as a continuous resource to help an agency mature is winter operations. To achieve the project objectives, the team performed an extensive literature review, engaged with snow and ice professionals, and incorporated feedback from the project's panel to obtain recent and relevant advancements with winter operations. This NCHRP technical report describes the research process and outcomes used to develop the Guide.

# EXECUTIVE SUMMARY

This report documents the development of an improved and expanded version of the winter maintenance guide. The American Association of State Highway and Transportation Officials (AASHTO) *Guide for Snow and Ice Control* was published in 1999. Over the next two decades, as state and local transportation agencies, with the assistance of researchers and experts, improved and expanded winter operation practices, parts of the 1999 guide became outdated.

In 2008, the *Update of the AASHTO Guide for Snow and Ice Control* (Weather Solutions Group, 2008) was released. The updates provided in the guide focused on equipment, materials, and weather information. The chapter on equipment updated and addressed the improvements to snow removal equipment and the latest technologies. The chapter on materials provided new details regarding the chemicals and mixtures being used at the time to prevent the bonding of ice to the pavement, now commonly known as anti-icing. The chapter also contained new information regarding melting and removing snow and ice. The chapter on weather information discussed advancements in weather forecasting and the value of road weather information systems (RWIS).

In 2019, the National Cooperative Highway Research Program (NCHRP) initiated Project 06-18, Guide for Snow and Ice Control Operations. The description of NCHRP 06-18 on the project website notes that:

> substantial changes in the state of practice of snow and ice control have occurred since the publication of [the 1999 AASHTO Guide for Snow and Ice Control] as a result of advancements in plowing equipment, materials handling and storage, communications, technology, strategies, and other aspects of snow and ice control and management. Also, during this period, substantial research on the different aspects of snow and ice control operations has been performed. Because of these changes as well as the environmental implications, budgetary and work force constraints, and the relevant research findings, there is a need to produce a guide that recognizes these issues and provides updated information and guidance on all aspects of snow and ice control operations. Such a guide will help highway agencies and other organizations address relevant issues and perform snow and ice control operations more effectively. (NCHRP, 2019)

Substantial advancements in the knowledge and best practices related to highway, road, and bridge winter maintenance and operations have occurred since the 1999 and 2008 guides. These advancements are included in the deliverables for NCHRP 06-18: Guide for Snow and Ice Control. Below is a sample of the enhancements:

- A snow and ice control policy that includes level of service (LOS), environmental considerations, and avalanches.
- Performance measurement criteria, implementation, and reporting.
- Recruitment, development, and advancement of personnel both with permanent staff, temporary staff, and contractors.
- Summary of the different varieties of equipment, plows, spreaders, brooms, and liquid applicators that are used for snow and ice removal and melting.
- Practices for the acquisition, handling, storage, and application of commonly used and not so commonly used materials for winter maintenance.

- Technology options that could make an agency's winter operations more efficient and transparent to elected officials and the public.
- Explanation of the different types of RWIS, monitoring of the systems, and data options.
- Safety training of personnel, handling of materials, equipment visibility, and good housekeeping.

In addition, the new guide includes appendices that provide additional information and resources, including:

- A glossary of terms.
- Sample snow and ice control plans.
- Sample public information releases and messages.
- Sample contracts for services.
- Sample specifications for equipment.
- Sample specifications for materials.
- Other available resources.

Based on the abundance of publications, research projects, and best practices regarding snow and ice control, it is recommended that key organizations like AASHTO (Snow and Ice Pooled Fund Cooperative Program [SICOP]), Clear Roads, the American Public Works Association, the Professional Snowfighters Association, and the Transportation Research Board (TRB) discuss the possibility of a winter operations information clearinghouse website. Similar to the National Work Zone Safety Information Clearinghouse website (https://www.workzonesafety.org/), such a website could serve as a repository for all publicly available guides, applied research, and best practices. It could be a location where winter maintenance events, conferences, equipment shows, and workshops are placed on a central calendar. A power search tool on the website could help users that need specific preliminary or advanced information on a specific topic. A clearinghouse website would further advance the industry, providing the opportunity for organizations to increase their web presence and more effectively distribute their resources. Practitioners and the NCHRP 06-18 researchers understand that the information to advance and enhance winter operations is evolving quickly. A winter operations information clearinghouse could help with updating the industry on advancements and coalesce their planning and operational efforts.

Finally, agencies should begin to study and incorporate winter operation assessments into their planning processes. The guide developed as part of this research effort has been written to help agencies mature their winter maintenance practices, making them safer, more cost effective, time efficient, and transparent to the public.

# CHAPTER 1. BACKGROUND

## INTRODUCTION

Winter maintenance has been an area of concern for highway agencies in the United States for over a century. According to L. David Minsk (1970), one of the first recorded conferences on snow removal was held in Philadelphia in 1914. The discussions centered around improving snow removal with horses and carts. The passage of the 1916 Federal-Aid Road Act created a need to advance snow removal because roads were beginning to be networked together. Up until the early 1940s, research efforts across the country were focused on improving plows attached to motorized vehicles to advance mechanical snowplowing (Minsk, 1970). Before World War II, few U.S. cities used salt for winter operations. Local governments plowed roads and then spread sand and cinders to improve traction. Automobiles donned snow chains, and the public generally accepted that roads would not always be passable in icy conditions (Plumer, 2015). The February 2014 issue of *National Geographic* reported that "because of its local resource, Detroit was the first city in the world to apply salt to its roads in 1940" (Howard, 2014). In February 1941, sodium chloride was first used as an ice preventive by the State of New Hampshire (Minsk, 1970). Following the Second World War and the expansion of the national highway system, the use of road salt dramatically increased. At that time, cities and their suburbs adopted "bare-pavement" policies under which motorists could expect snow- and ice-free pavements shortly after storms, which resulted in a doubling of salt use every 5 years in the 1950s and 1960s, from 1 million tons in 1955 to nearly 10 million tons less than 15 years later (Goodman & Reuter, 1991).

## PROJECT OBJECTIVES

The objective of NCHRP 06-18 was to develop a guide that will serve as the primary source for guidance on all aspects of snow and ice control operations. The guide is intended for adoption and publication by AASHTO and will supersede the 1999 AASHTO *Guide for Snow and Ice Control*, as well as other guidance on snow and ice control operations. To accomplish this, the following three major efforts were undertaken by the researchers:

- Reviewed the AASHTO *Guide for Snow and Ice Control*, related literature and research findings, and other information relevant to snow and ice control operations (e.g., equipment, materials, technology, and strategies) to identify a scope for the proposed guide. This information was obtained from published and unpublished sources and contacts with practitioners.
- Developed a research report documenting the work performed in the project.
- Developed the *Guide for Snow and Ice Control Operations* as a stand-alone resource that addresses all aspects of snow and ice control operations and serves as the primary source of guidance to the winter maintenance community.

The results of these efforts have been packaged into a stand-alone implementation guide separate from this document. This report specifically addresses the results of the second bullet above.

## CONTENTS OF THIS REPORT

This technical report documents the methodology and results of the various research activities performed as part of NCHRP 06-18. Chapter 2 documents the results of the literature review via library and web searches, unpublished sources, and contact with practitioners. The findings from this effort were used to compare the content of the 1999 AASHTO *Guide for Snow and Ice Control* and the 2008 *Update of the AASHTO Guide for Snow and Ice Control*. This comparison revealed the gaps that needed to be filled with updated information. This side-by-side analysis helped the researchers formulate the table of contents and begin the work of writing each chapter.

Next, Chapter 3 presents the topics and subtopics added to each chapter. These new additions enhance the guidebook by adding advancements made in winter maintenance since the previous two versions were published.

Finally, Chapter 4 presents a summary of the key findings from the guide and provides recommendations for additional research. A separate guide describing the content of each topic in detail, along with implementation strategies, has also been produced as part of this research effort.

# CHAPTER 2. LITERATURE REVIEW

Much of credible winter maintenance literature is not housed in one location. This required the researchers to investigate several sources based on their professional expertise and engage the Texas A&M Transportation Institute (TTI) librarian to conduct a search. The researchers searched resource clearinghouses of NCHRP, the Federal Highway Administration (FHWA) (including SICOP), and state projects related to various aspects of snow and ice control operations.

Following is a list of example sources that the researchers explored:

- AASHTO *Guide for Snow and Ice Control* (1999).
- *Update of the AASHTO Guide for Snow and Ice Control* (2008).
- NCHRP Reports 526 and 577 related to snow and ice control.
- Snow and ice control guidelines developed by states and other transportation agencies.
- TRB meeting compendium and research records.
- FHWA reports and technical publications.
- University transportation research institutes/centers, specifically the Western Transportation Institute, TTI, and the University of Minnesota Local Road Research Program.
- Transportation agencies' research reports.
- Pooled fund organizations, specifically Clear Roads and AASHTO SICOP.
- Research article publications in journals such as the American Society of Civil Engineering (ASCE) *Journal of Cold Regions Engineering*, ASCE *Journal of Transportation Engineering, Cold Regions Science and Technology, Journal of Atmospheric and Oceanic Technology,* and *Procedia Engineering*.

TTI's full-time librarian conducted the preliminary literature search using both manual and computerized methods. Computerized searches were conducted in the Transport Research International Documentation (TRID) and Transport-Ovid databases. TRID includes the capability to search several databases, including the Highway Research Information Service database for domestic literature, the Highway Research in Progress database for ongoing research studies, and the International Road Research Database for relevant foreign literature. The librarian provided the identified references to the researchers, who then reviewed and compiled applicable content into a literature summary.

Manual searches and formal and informal contacts were also very important during this work. Electronic literature databases commonly lag several months behind current efforts due to their record entry requirements. The researchers had discussions with governmental agency representatives, professional colleagues, and practitioners to uncover relevant studies that are ongoing or recently completed and not yet found in electronic databases.

Finally, the researchers utilized their extensive national and international contacts to identify relevant research. Over 130 pieces of literature were referenced in the guide along with over 100 photographs and diagrams.

The researchers catalogued the research into the following eight areas:

1. Administration, policies, plans, and strategies.
2. Performance measurements and levels of service.

3. Personnel, including contract personnel.
4. Equipment, including trucks, loaders, plows, spreaders, brooms, and liquid applicators.
5. Materials, including purchasing, handling, storage, and application.
6. Technologies, including global positioning systems (GPSs), alternative fuels, unmanned aircraft, and vehicle tracking.
7. Road weather information systems.
8. Safety, including personnel safety, operational safety, facility safety, and public safety.

The researchers modified the chapters based on practitioners' input, including the NCHRP panel, and the expanded and enhanced information discovered and collated during the literature review. The NCHRP 06-18 panel members were invaluable in their willingness to diligently review, comment, and add to the guide.

# CHAPTER 3. THE GUIDE

## OVERVIEW

The new *Guide for Snow and Ice Control Operations* was developed as the primary way to organize and present current information on snow and ice control. The guide is based on common snow and ice control strategies and principles describing advances in technologies and procedures that can improve outcomes while reducing costs. The guide is not intended to specify any single standard, procedure, regulation, or strategy; rather, it is intended to provide guidance on a wide range of topics and potential strategies that agencies can adopt. The guide discusses state-of-the-art equipment, technologies, and processes. In addition, portions of the guide assess potential future impacts on snow and ice control advances just now being developed. Agencies can implement practices that are most relevant to their needs and consistent with their policies and guidelines. The guide is intended to be used by state, local, and tribal governments that provide snow and ice removal services to their respective communities. The guide can be used to:

- Develop the framework for a comprehensive snow and ice control policy.
- Create a framework for a performance measurement and level-of-service matrix.
- Understand the intricacies of recruiting, developing, and advancing an agency's personnel.
- Aid in the understanding and procuring of equipment used in winter maintenance.
- Provide simple explanations for the complex part of understanding winter maintenance materials.
- Show how technology can be used to improve winter maintenance activities.
- Enhance the safety practices of an agency's winter maintenance program.
- Learn common terms and definitions used by the winter maintenance community.

## GUIDE SUMMARY

The guide is organized into nine chapters:

- Chapter 1: Introduction.
- Chapter 2: Snow and Ice Control Operations and Strategies.
- Chapter 3: Performance Measurement and Levels of Service.
- Chapter 4: Personnel.
- Chapter 5: Snow and Ice Control Equipment.
- Chapter 6: Materials Handling, Storage, and Application.
- Chapter 7: Technologies.
- Chapter 8: Road Weather Information.
- Chapter 9: Safety.

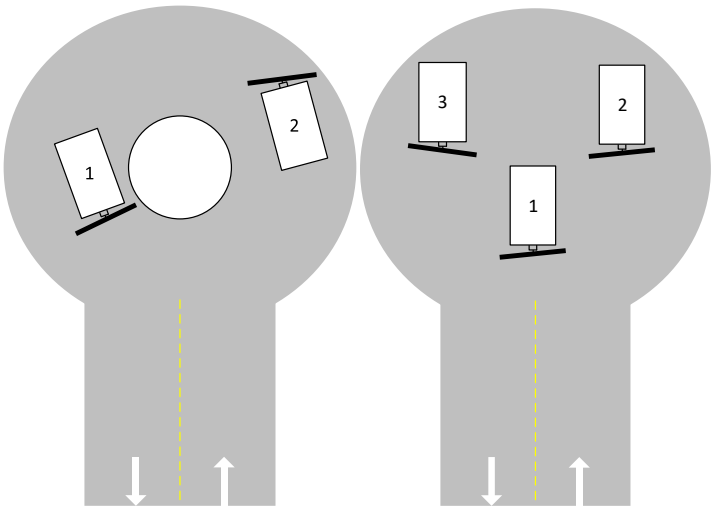
### Chapter 1 Introduction

Chapter 1 introduces the guide's purpose to those charged with the administrative and operational duties of winter maintenance.

## Chapter 2 Snow and Ice Control Operations and Strategies

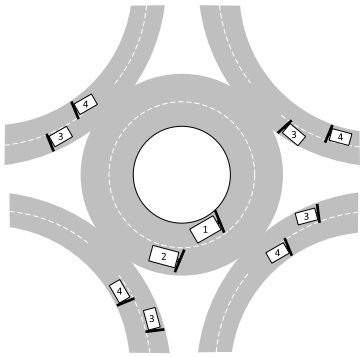
Chapter 2 was expanded from four subtopics in the 1999 *Guide for Snow and Ice Control* to eight subtopics on snow and ice control operations and strategies. Chapter 2 is now presented as a road map for winter maintenance leadership and management to create a succinct snow and ice control plan that includes prewinter planning all the way through end-of-season activities. It directs the user of the guide through creating a comprehensive snow and ice control plan along with recommendations for elected leaders to adopt policies that are consistent with the plan.

Successful snow removal is dependent on a list of factors, including but not limited to wind speed, temperature, snowfall amounts, urban versus rural setting, storage, street parking, and roadway geometry. Chapter 2 addresses the topic of complex geometries and non-standard features by including figures like the ones shown in Figure 1 and Figure 2.




*Note: The numbers represent passes, not necessarily the number of trucks.*

**Figure 1. Snow Removal from Cul-de-Sacs with Center Island (Left) and without Center Island (Right).**



*Note: The numbers represent passes, not necessarily the number of trucks.*

**Figure 2. Snow Removal from a Two-Lane Roundabout.**

Examples like these provide the users of the guide with ideas on how to address areas of their agency's road network that may need extra attention, extra training, or extra time to clear.

Chapter 2 is augmented by Appendix A and Appendix B. Appendix A provides a glossary of terms that can be used in writing plans, at public meetings, and when communicating with the media. The glossary of terms will help the user understand terms used throughout the guide, enhance credibility, and standardize terminology consistently within the winter maintenance profession. Appendix B is populated with sample snow and ice control policies that provide templates for state, county, and city agencies. With the topics covered in Chapter 2 and with Appendices A and B, agencies will have what they need to start or expand upon existing programs. The full table of contents of Chapter 2 is shown in Figure 3.



**Figure 3. Chapter 2 Table of Contents.**

## Chapter 3 Performance Measurement and Levels of Service

Chapter 3 is a new chapter to the AASHTO *Guide for Snow and Ice Control* and provides details on performance measurement and levels of service. As described in Chapter 1: Background of this report, over 100 years ago, the public had different expectations of winter operations, being content with staying at home, driving slow on cinders, and donning chains on

their tires. As snowplowing techniques evolved, equipment became more powerful, sodium chloride and other materials became more effectively applied, and the economy grew, the public's expectation for passable roads steadily increased. Chapter 3 can help an agency think through what roads will be cleared and in what order and for what reasons. Chapter 3 describes different levels of road clearing criteria and safe speed conditions for agencies to consider. Having a clear definition of different conditions can help when communicating to elected leaders, media, and the public. The public can be taught over time to understand the different performance measures being communicated by the agency and what that means for travel. It can also help an agency declare emergency orders with credibility.

Chapter 3 provides tables like the ones shown in Table 1 for the Minnesota Department of Transportation (MnDOT) and Table 2 for the New York State Department of Transportation (NYSDOT) as examples for agencies to consider when trying to decide their targets.

**Table 1. Bare Lane Regain Time Classifications Used by MnDOT (Minnesota Depratment of Transportation, 2010).**

| Classification | Annual Average Daily Traffic | Target Regain Time |
|---|---|---|
| Super commuter | Over 30,000 | 0–3 hours |
| Urban commuter | 10,000–30,000 | 2–5 hours |
| Rural commuter | 2,000–10,000 | 4–9 hours |
| Primary | 800–2,000 | 6–12 hours |
| Secondary | Under 800 | 9–36 hours |

Note: MnDOT defines *bare lane* for all classifications as having all driving lanes 95 percent free of snow and ice between the outer edges of the wheel paths, and having less than 1 inch of accumulation on the centerline of the roadway.

**Table 2. Bare Lane Regain Time Classifications Used by NYSDOT (New York State Department of Transportation, 2012).**

| Level of Service | Highway Class | Recommended Maximum Allowable Accumulation during a Storm | Elapsed Time after Event End That Full Width of Pavement Width Should Be Cleared (Hours) |
|---|---|---|---|
| Regular LOS | A1 | 2.0 | 1.5 |
| | A2, B, C | 2.5 | 2.0 |
| Modified LOS | A1 | 2.5 | 2.0 |
| | A2, B, C | 3.5 | 3.0 |

Note: Regular LOS should be provided on all classes of highways between 4 a.m. and 10 p.m. Monday through Friday, and at all times on highways having average daily traffic (ADT) of 50,000 vehicles per day or more. Modified LOS should be provided on all classes of highways between 10 p.m. and 4 a.m. Monday through Friday, and all day Saturday and Sunday, except for highways with an ADT of 50,000 vehicles per day. A1 highways are expressways with low average running speeds, A2 highways are expressways with high average running speeds, B highways are major State highways, and C highways are minor State highways.

Appendix B and Appendix C provide sample snow and ice control plans and public information messages, respectively, which can help an agency navigate performance metrics, levels of service, and media communications.

The table of contents for Chapter 3 is provided in Figure 4.

**Figure 4. Chapter 3 Table of Contents.**

## Chapter 4 Personnel

Chapter 4 focuses on personnel and has been expanded from the AASHTO *Guide for Snow and Ice Control* to include recruitment, development, and advancement of highway agency personnel in the area of winter maintenance. As mentioned previously, equipment is increasingly powerful, furnished with automation, and outfitted with different snow removal and snow melting devices. Winter maintenance personnel now need to know how to blend brine, calibrate spreaders, and plow snow on roads with varying geometries. In addition, each device needs to be maintained and stored properly when not in use. It is important that personnel be trained and continually retrained in the use and care of winter maintenance equipment. Chapter 4 provides explanations and examples to address recruitment, development, and advancement, as shown in Figure 5, Figure 6, and Table 3.


**Figure 5. Recruitment Poster Example from the Maine Department of Transportation (Fay, 2021).**


**Figure 6. Snowplow Operator Training from MnDOT.**

**Table 3. Ohio Department of Transportation's Career Track for the Highway Technician Program (Fay, 2021).**

| Job Title | Requirements to Move to Next Step |
|---|---|
| HT 1 | Successful completion of all level 1 training courses and certifications; valid CDL |
| HT 2 | Successful completion of all level 1 and 2 training courses and certifications; 12 months of cross training in construction inspection |
| HT 3 | Successful completion of all level 1, 2, and 3 training courses and certifications; 24 months of construction and/or testing experience |
| HT 4 | Successful completion of all level 1, 2, 3, and 4 training courses and certifications; 24 months construction and/or testing experience |
| HT 5 | Maximum step |

Chapter 4 is augmented by Appendix G. Appendix G provides equipment calibration aids and training resources. Figure 7 shows the table of contents for Chapter 4.



**Figure 7. Chapter 4 Table of Contents.**

## Chapter 5 Snow and Ice Control Equipment

Chapter 5 describes the different types of equipment available to remove and melt snow and ice. Chapter 5 guides agencies through a listing of equipment and devices that can help them achieve their winter maintenance goals. Each agency must consider different types of snow events, geographic challenges, and population densities. Figure 8 through Figure 13 provide photographs that highlight the variety of equipment discussed in Chapter 5.

*Source: TranBC (https://www.tranbc.ca/2020/03/10/spotted-3-types-of-snow-plows-found-on-bc-highways/)*

**Figure 8. Tandem-Axle Truck with a Wing Plow, Underbody Plow, Front Plow, and Hopper.**

*Source: TranBC (https://www.tranbc.ca/2020/03/10/spotted-3-types-of-snow-plows-found-on-bc-highways/)*

**Figure 9. Rotary Snow Blower Clearing Avalanche in British Columbia.**

*Source: Oregon Department of Transportation (https://www.oregon.gov/odot/Regions/Documents/Region5/WinterRoadwayGuide.pdf)*

**Figure 10. Double Wing Plows Deployed.**

*Source: Pennsylvania Department of Transportation*

**Figure 11. Anti-icing Unit.**


*Source: Hannah Blankenship, Alaska Department of Transportation (DOT) and Public Facilities*

**Figure 12. Ice Breaker on Alaska DOT Truck.**

*Source: Novi, MI, Department of Public Works*

**Figure 13. Modified Chute with Prewetting Plumbed to Interior of Chute.**

In addition to descriptions of various types of equipment, Chapter 5 includes a section on equipment maintenance. Agencies must understand the proper way to clean equipment thoroughly, the corrosive properties of some materials used for winter maintenance, and the proper storage of equipment so that it will last. The end of Chapter 5 and Appendix E provide resources to help an agency begin developing bid packages for new equipment and for life-cycle cost calculations. Additionally, Chapter 5 and Appendix G provide guidance and resources to assist in the critical task of spreader controller calibration.

The table of contents for Chapter 5 is provided in Figure 14.

**Figure 14. Chapter 5 Table of Contents.**

## Chapter 6 Materials Handling, Storage, and Application

Chapter 6 was assembled to assist highway agencies with evaluating material acquisition, storage, and application processes. Additionally, Chapter 6 helps agencies identify opportunities to reduce costs, increase levels of service, and be sensitive to the natural environment in their use of material.

There have been many advancements in the use and application of different types of material since the 1999 *Guide for Snow and Ice Control* was published. It can be overwhelming to review the list of available materials, learn how to write bid documents for the acquisition of

these materials, prepare the facility to properly store and load these materials, and take into consideration application rates that are effective and environmentally sensitive. The information in Chapter 6 is split into sections that will enable the user to learn the details of handling, storing, and applying materials. Chapter 6 presents mitigation of loss guides, as seen in Figure 15 and Figure 16.

| Loss of Materials | Effective Guiding Principles |
|---|---|
| **Spillage of salt during handling procedures** | Promote indoor operations.<br>Collect and dispose of onsite contaminants. |
| **Salt dissolved from uncovered stockpiles** | Place stockpile inside storage facilities. Control site drainage. |
| **Spillage of liquid chemicals during production or handling** | Use low permeable surfaces to reduce infiltration and control runoff. |
| **Vehicle Washing** | Collect and reuse or properly manage site drainage to comply with local water quality regulations. |
| **Salt dust from exposed salt piles** | Properly cover stockpiles and control emissions. |

*Source: Transportation Association of Canada (2013)*

**Figure 15. Causes of Material Loss and Mitigation Strategy.**

| Practice | Effective Operations and Maintenance |
|---|---|
| **Salt Handling** | • Load spreaders inside<br>• Minimize spills and sweep pads immediately after a spill<br>• Avoid overloading spreaders<br>• Calibrate spreaders<br>• Return excess salt and sand to storage facility after a storm |
| **Vehicle Washing** | • Remove residual solids to minimize salt concentration in wash water<br>• Wash vehicles indoors or where water can be contained<br>• Properly dispose of wash water or reuse for brine production |
| **Sand and Salt Mixing** | • Mix inside or on low permeable pad<br>• Mix during good weather to prevent loss due to precipitation or wind<br>• Store mixture into storage facility. |
| **Salt Brine Production and Storage** | • Proper design of water supply<br>• If regulations allow, use wash water or stormwater for brine production<br>• Provide secondary containment near storage tanks<br>• Inspect tanks, pumps and pipes to ensure no leaks |

*Source: Transportation Association of Canada (2013)*

**Figure 16. Effective Operations and Maintenance Used to Reduce the Loss of Materials.**

To complement the guidance in Chapter 6, Appendix F was populated with sample specifications for a wide array of commonly used material to melt snow and ice and prevent bonding to the pavement.

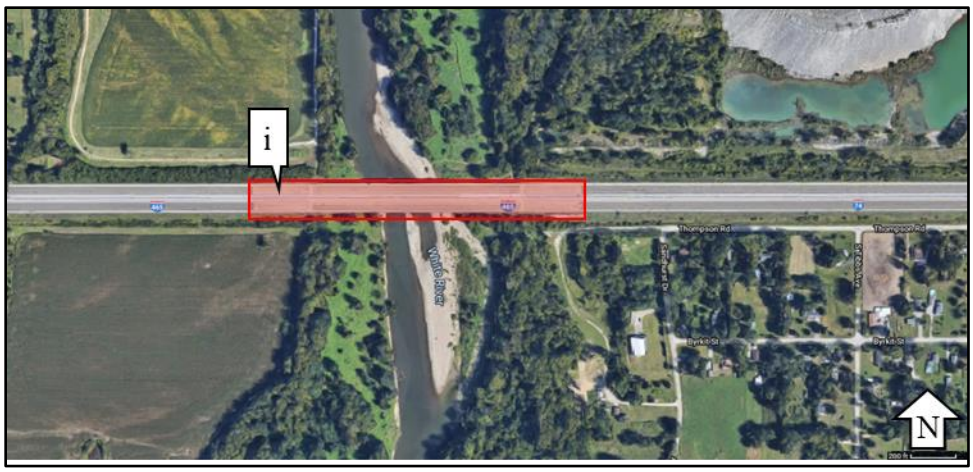
Figure 17 presents the table of contents for Chapter 6.



**Figure 17. Chapter 6 Table of Contents.**

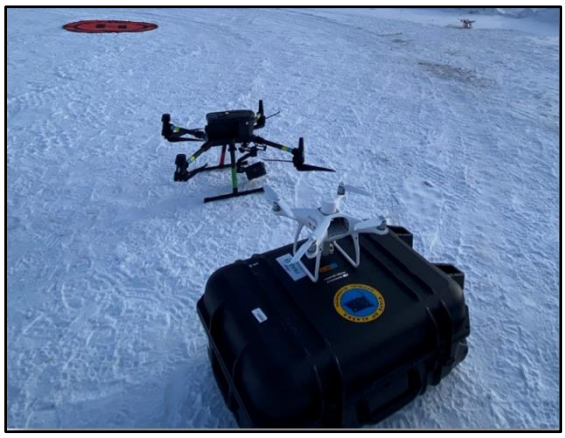
## Chapter 7 Technologies

The literature review, web searches, and discussion of best practices with transportation agencies revealed significant advancements in the implementation of technologies in winter maintenance, which are covered in Chapter 7. One of the primary advancements has been with RWIS, which received its own chapter (Chapter 8) due to its significance and level of detail. Chapter 7 discusses advances in GPSs, equipment monitoring systems, driver assistance systems, maintenance decision support systems (MDSSs), and other technologies. Technologies can assist agencies with knowing real-time locations of snowplow trucks, amounts of material applied and where, pavement temperature, and air temperature. Technologies can also provide data that allow an agency to track and monitor its performance and level-of-service targets. Using technologies can help make material application more precise, saving on material waste. Chapter 7 also covers liquid production, inventory control of materials, and the importance of buy-in from personnel responsible for adapting to the new technologies. Some of the information provided in Chapter 7 include the examples shown in Figure 18 through Figure 20.




*Source: Indiana DOT*
*Note: i = geofenced application zone.*

**Figure 18. Example of I-465 Application Zone on a White River Bridge.**



*Source: Alaska DOT*

**Figure 19. Alaska DOT Avalanche Drone Units.**

*Source: West Des Moines, IA*

**Figure 20. Multifilling Station at West Des Moines, IA, Department of Public Works.**

Chapter 7 ends with a list of other resources to assist the user in compiling as much information as possible to aid in specifying, acquiring, and implementing new technologies for winter maintenance.

The table of contents for Chapter 7 is provided in Figure 21.



**Figure 21. Chapter 7 Table of Contents.**

## Chapter 8 Road Weather Information

Chapter 8 delves into the multitude of options an agency has in selecting an RWIS to add real-time weather conditions and pavement temperatures to winter forecasts and winter weather monitoring. RWIS can provide valuable data to the managers and leadership of an agency's winter maintenance operations.

An agency can pick one or multiple sites to install RWIS, including an environmental sensor station (ESS). An ESS can be equipped with closed-caption television (CCTV) and devices that measure the following:

- Air temperature.
- Wind speed and direction.
- Humidity.
- Precipitation type and intensity.
- Pavement temperature.
- Pavement grip, which is converted to friction.
- Pavement condition (e.g., ice, snow, dry, etc.).

Due to advancements in technology, an agency has many choices on the type of RWIS to adopt. The primary ones covered and detailed in Chapter 8 are:

- Stationary ESS.
- Portable ESS.
- Mobile ESS.
- Mini ESS.

Chapter 8 also includes information on maintaining RWIS equipment and sensors. It is important for an agency to understand the upfront and operational costs of an RWIS. An example of RWIS provided in Chapter 8 is shown in Figure 22.

*Source: New Jersey DOT*

**Figure 22. New Jersey DOT RWIS Trailer.**

Winter storms can be very localized. A portable RWIS, like the one shown in Figure 22, can supplement weather forecasting and real-time weather information by being placed in the vicinity needing additional monitoring. The end of Chapter 8 provides a list of additional resources to further assist an agency with its understanding of RWIS technology.

The table of contents for Chapter 8 is provided in Figure 23.



**Figure 23. Chapter 8 Table of Contents.**

## Chapter 9 Safety

Chapter 9 covers safety and specifies issues and practices related to personal safety, public safety, vehicle and equipment safety, operational safety, and facilities safety. Each safety topic needs to be understood and addressed by winter maintenance managers and practiced by

winter maintenance personnel. The different topics in Chapter 9 could serve as an outline for a winter maintenance manager's safety tailgate talks or prewinter meetings.

The full list of safety and other related topics is shown in the table of contents for Chapter 9, which is displayed in Figure 24.



**Figure 24. Chapter 9 Table of Contents.**

## Appendices

The guide includes seven appendices:

- Appendix A—Glossary of Terms.
- Appendix B—Sample Snow and Ice Control Plans.
- Appendix C—Sample Public Information Releases and Messages.
- Appendix D—Sample Contracts for Services.

- Appendix E—Sample Specifications for Equipment.
- Appendix F—Sample Specifications for Materials.
- Appendix G—Available Resources.

The appendices provide additional details and examples as a means of delivering a toolbox of resources that explain the different topics discussed throughout the guide. There are template plans, specifications, contracts, public information messages, and other resources in the appendices that can make advancing an agency's winter operations smoother and less arduous.

# CHAPTER 4. SUMMARY OF KEY FINDINGS, FUTURE RESEARCH NEEDS, AND POTENTIAL IMPLEMENTATION DIRECTIONS

This chapter presents a summary of the key findings from each chapter of the new NCHRP *Guide for Snow and Ice Control Operations* and recommendations for additional research. The separate guide, which covers each topic in detail and includes implementation strategies, was produced as part of this research effort.

## KEY FINDINGS AND FUTURE RESEARCH NEEDS

Each chapter of the guide is composed of new and expanded information. Table 4 summarizes the key findings of each chapter and future research needed for the winter maintenance industry. The listing starts with Chapter 2 of the guide since Chapter 1 is simply an introduction.

**Table 4. Summary of Key Findings and Future Research Needs.**

| Chapter | Key Findings | Future Research Needs |
|---|---|---|
| **2** | • Enhanced information on snow and ice control policies.<br>• Greater attention to communication, coordination, and outreach.<br>• Planning, procurement, benefit-cost, and avalanches. | • Development of procedures and policies to incorporate winter operations into the planning and design of new transportation projects.<br>• Development of more efficient ways to collect data measuring the success or failure of maintaining level-of-service targets. |
| **3** | • Expanded procedures and options to define levels of service.<br>• Collection of data to verify levels of service have been achieved. | • Onboard equipment to collect level-of-service verifications.<br>• Creation of better templates for data visualization (e.g., website dashboards) to relay progress to the public and media. |
| **4** | • Due to the advancement in equipment, attachments, and technologies, ongoing training and educating of personnel is important. This will allow them to advance and to be cross-trained if they need to be assigned to a different piece of equipment.<br>• Increased credibility inside the industry due to personnel being able to obtain specialized certifications in winter maintenance. | • Additional data and results that demonstrate the value and benefit of simulator training.<br>• Expanded web-based training, which has improved since the initial delivery of technical knowledge. |
| **5** | • Immense increase in the size and types of equipment manufactured and used for winter operations.<br>• Vast increase in the attachments used to apply solid, prewetted, and liquid-only materials. | • Continued refinement of equipment attachments in exploring more efficient distribution of snow and ice melting materials and mixing of liquids resulting in minimizing material usage and increased melting effectiveness. |

| | | |
|---|---|---|
| | • Robust features of facilities with covered buildings for materials, large wash bays, and better post-winter storage capabilities. | • Refined methods to collect and measure water and soil samples to monitor impacts of winter maintenance on the environment. |
| **6** | • Improvements to material storage, especially salt, to prevent waste and pollution.<br>• Better application of materials to achieve performance goals without excessive waste.<br>• Longevity of better equipment and better care and washing of equipment.<br>• Use of drones/LIDAR to measure stockpiles. | • Continued advancement with corrosion inhibitors.<br>• Further development of mixing techniques to make mixing, testing, and loading more efficient. |
| **7** | • Advancements with GPS units along with driver assistance systems.<br>• Use of alternative fuels.<br>• Adaptation of MDSSs. | • Impact of connected and autonomous vehicles on winter maintenance.<br>• More reliable sensors attached to vehicles (e.g., pavement temperature sensors). |
| **8** | • Integration of RWIS data into the intelligent transportation system network.<br>• Development and successful application of mobile and portable RWIS. | • Sharing of RWIS data with other agencies to improve storm and condition tracking. |
| **9** | • Improved practices and handling of materials.<br>• Enhanced conspicuity markings and lighting.<br>• Expanded safety training and safety training resources. | • Continued research on lighting (e.g., color combinations, strobe versus steady burn).<br>• Use of GPS to mark hazards as a tool to remind drivers and operators of nearby risks. |
| **Appendices** | • Amount and variety of winter maintenance information available for agencies of all sizes (state, local, and tribal).<br>• Increased efforts to take advantage of all media outlets to convey information to the public. | • With the great advancements in several areas of winter maintenance brought on by the work of many organizations, creation of a winter maintenance information clearinghouse website similar to the work zone safety information clearinghouse (https://www.workzonesafety.org/). |

## POTENTIAL IMPLEMENTATION DIRECTIONS

The intent of the guide is to be a resource for agencies to mature their winter maintenance operations. Agencies are constantly evolving because of policy priorities of elected officials, population or economic growth, or expansion of geographic boundaries. Based on the changing nature of communities, winter operations should change as well.

In addition to providing helpful winter operational recommendations, ideas, and explanations in the guide, researchers also developed and included an implementation maturity map (see Figure 25). The purpose of the implementation maturity map is to help keep the information provided in the guide from overwhelming the user. It is intended to provide a

starting point for agencies, as well as direction toward success in achieving winter operations goals.


**Figure 25. Implementation Maturity Map for Winter Operations.**

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| ADT | Average Daily Traffic |
| ASCE | American Society of Civil Engineers |
| CCTV | Closed-Caption Television |
| DOT | Department of Transportation |
| ESS | Environmental Sensor Station |
| FHWA | Federal Highway Administration |
| GPS | Global Positioning System |
| LOS | Level of Service |
| MDSS | Maintenance Decision Support System |
| MnDOT | Minnesota Department of Transportation |
| NCHRP | National Cooperative Highway Research Program |
| NYSDOT | New York State Department of Transportation |
| RWIS | Road Weather Information Systems |
| SICOP | Snow and Ice Pooled Fund Cooperative Program |
| TRB | Transportation Research Board |
| TRID | Transport Research International Documentation |
| TTI | Texas A&M Transportation Institute |