Project No. 20-44(37)

WORKSHOPS ON PERFORMANCE MEASURES IN SNOW AND ICE CONTROL OPERATIONS

FINAL REPORT

Prepared for
National Cooperative Highway Research Program (NCHRP)
Transportation Research Board

of

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ABSTRACT

This report documents and presents the results of implementation project NCHRP 20-44(37), through which four workshops were conducted with State DOTs to help customize the measures identified in NCHRP 889 *Performance Measures in Snow and Ice Control Operations* by focusing on the current capabilities for data collection, available maintenance, traffic management, technologies, and resource limitations. This Final Report summarizes the approach and outcomes of project activities in both Phase I and Phase II. This includes a summary of snow and ice performance measures, overarching reactions by State DOT workshop participants to the measures, and implementation accomplishments and findings for each measure, as well as overarching observations of State DOT participants, current capabilities and metrics used by each participating State DOT, the focus areas and agreed upon actions by participating State DOTs over the winter season, and the implementation findings and outcomes for each participating State DOT. A summary of lessons learned from the four workshops is also presented that can be used to inform the approach for conducting any future workshops.

SUMMARY

This section summarizes the key outcomes and findings from this *NCHRP Project 20-44(37) Workshops on Performance Measures in Snow and Ice Control Operations* effort. Overall, a total of 14 states representing AASHTO Regions 1, 3, and 4 participated in this effort, representing a significant portion of the country that routinely experience snow and ice conditions (Figure 1). The 14 participating states represented a mixture of practices for performance measures in snow and ice control operations. Some participating agencies had very robust capabilities refined over many years, with decades of available data and experience, while other agencies are just beginning to explore available data and possible performance measures in this area.

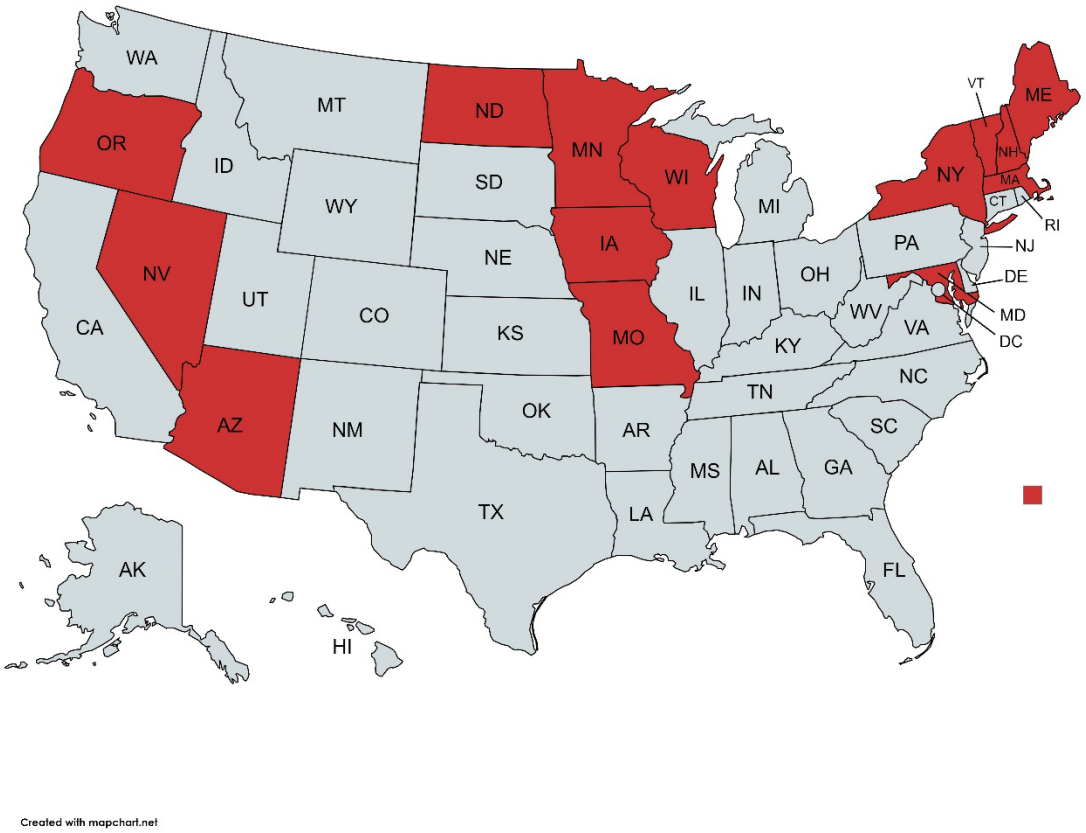


Figure 1. States involved in Implementation Activities. (Source: Mapchart)

A key success factor in performance measurement for many agencies is the ability to tell a compelling story. Most participating states noted that the biggest challenge was the ability to identify, organize, collect, and build data systems and a framework for performance measurement. As an example, Oregon has access to many data sources and telematics information, but this data is siloed in ways that make it very challenging to create a story about performance. Additionally, there was a consistent understanding across participating states that performance must be communicated in different ways to different people: internal information

that is valuable to decision makers may differ for managers in terms of when the timeliness and type of information needed, and the story from performance measures to inform the public will also be different.

This NCHRP Implementation effort was unique in compelling states wishing to participate in the effort to take initiative to do the hard work of collecting and reporting performance measures that work for their agency and align with agency goals. Specifically, with gentle peer pressure and in working collectively with other states, participating agencies were collectively able to advance and develop their own performance measurement capabilities, even if not looking at all snow and ice control operations performance measures.

Through the workshops conducted in this effort and reactions from participating agencies, the areas that resonated most centered on several key topics:

- **Recovery.** All participating agencies considered recovery to be a critical factor but acknowledged a challenge to identify a common factor. New Hampshire's 70-70 (a target of 70 percent of roads that recovered to 70% of speeds within 2 hours) was a meaningful, clear, and realistic performance measure that gained traction among the phase 1 locations.
- **Actual and Anticipated Material Use.** A variety of agency measures focused on material usage. Massachusetts used winter severity to predict expected salt use and understand how the agency was doing. Similarly, Minnesota, North Dakota, and others have moved toward advancing the use of liquid materials instead of salt. A simple liquid-to-salt ratio to measure usage was very effective for both Minnesota and North Dakota. By looking at liquid-to-salt ratio, North Dakota was able to support more investment in agency brine-making equipment and storage facilities.
- **Understanding Event Impacts and Storm Index.** Several agencies conducted work to better understand event impacts and use a storm index. Missouri developed an application that includes a severity index which relates monetized impacts of a weather event on safety, mobility, and recovery costs. Iowa developed a new measure to provide the right information to people about the anticipated impacts of storms, to better anticipate storm severity to drive maintenance and operations responses.
- **Dashboards.** Many states are using dashboards to better visualize information from performance measures. Iowa's visualizations for winter severity were used as a case to purchase more salt. Missouri DOT created a dashboard to help visualize winter storm impact by county. Arizona, North Dakota, and Wisconsin also advanced work on snow and ice performance measurement dashboards.

For states only beginning to explore snow and ice performance measures, it was important to recognize that performance measurement cannot be achieved within a single year or a single data point. Instead, performance measurement is a sustained framework that provides value over several years. In other words, initial data is likely to contain errors that may not be identified from the onset, and it may take several years to understand what data is valuable. As an example, Nevada identified unusual errors in data being reported that needed to be corrected. Additionally, it is hard to identify trends within a single season; rather, it takes several seasons to better understand what the data is saying in order to tell compelling stories for different audiences.

A key takeaway from this effort was that performance measures are being widely used to tell a story and better manage winter operations and maintenance. Initial expectations of performance

measurement among participants centered on the question: “how are we doing?” However, as participants started working on implementation after the initial workshops by developing or refining performance measures, their focus shifted to a question of: “how do we tell our story and manage operations and maintenance better by using data?” This subtle shift removed a potentially punitive aspect (and recognizes the many differences between Districts or maintenance areas regarding staff, lane-miles, and other factors) to make performance measurement more about communicating better with a better story for increased understanding. This finding became more prominent over the course of this effort as participants saw the value of performance measures in making better decisions about purchasing materials and resulting in a better response to the public, commissioners, managers, and decision makers.

CHAPTER 1. Introduction

1.1 Background

The National Cooperative Highway Research Program (NCHRP) Implementation Support Program provides opportunities to conduct collaborative activities to help State Departments of Transportation (DOTs) implement and benefit from NCHRP studies.

Performance measures for snow and ice control are used by State DOTs to help assess performance towards accomplishing agency goals regarding winter storm responses. Complicating the creation and use of these measures is the fact that winter storms (and vehicle travel) do not stop at state borders. Rather, when regional storms occur, they impact regional travel. Therefore, all states can benefit from collaboration with nearby states to develop and use consistent and related snow and ice performance measures.

The NCHRP 20-44(37) project builds on the 2019 *NCHRP Research Report 889 Performance Measures in Snow and Ice Control Operations*, which identified measures of performance for snow and ice control. While there is not a single set of measures that fits all types of agencies, the research determined a process that allows an agency to develop measures that are customized to the objectives of their snow and ice control program and operationalize the measures consistent with their current program and data capabilities.

NCHRP Research Report 889 provided the following guidelines:

- No individual performance measure is a perfect representation of the complexity of snow and ice response.
- Not all performance measures that are important to an agency can be fully controllable by the agency's response activity.
- Starting the process of performance measurement is the first and often the most important step.
- Know what data is available and viable for performance management use.
- For snow and ice control, some level of subjectivity in performance measurement cannot be avoided.
- Lastly, performance measures identified by an agency need to be simple and easily understood not only by their stakeholders but also their own staff.

1.2 Objective

The main objective of this implementation project, NCHRP 20-44(37), was to work with State DOTs to help customize the measures identified in NCHRP 889 by focusing on the current capabilities for data collection, available maintenance, traffic management, technologies, and resource limitations.

1.3 Anticipated Research Outcomes

By working with a collaboration of states, this implementation project allowed each State DOT to consider not only their state's use of new performance measures, but also how they might align their performance measures with neighboring states. This could also help ensure consistency in definitions across an entire region.

State DOTs participating in this effort were able to advance consistent definitions, processes, and reports to quantify performance measures for mobility, safety and environmental aspects of their snow and ice control operations. They were able to share their findings and explore how performance measures can be improved over time for their respective State DOTs.

Finally, the research team envisions that the final products of this study to not only benefit the states participating in the workshops but will also benefit State and local DOTs that might use the resources developed in this project to conduct similar assessments in their states/regions in future years.

1.4 Document Structure

The objective of this Final Report is to summarize the approach and outcomes of project activities in both Phase I and Phase II. The remaining sections of this Final Report include:

- Chapter 2 summarizes the project approach and activities.
- Chapter 3 summarizes the seven snow and ice performance measures, overarching reactions by State DOT participants to the measures, and implementation accomplishments and findings for each measure.
- Chapter 4 presents overarching observations of State DOTs, current capabilities and metrics used by each State DOT as of the initial workshop, the focus areas and agreed upon actions by State DOTs over the winter season, and the implementation findings and outcomes for each State DOT.
- Chapter 5 summarizes discussion items from all four in-person workshops.
- Chapter 6 presents a summary of lessons learned from the four workshops that can be used to inform the approach for conducting any future workshops.
- The Appendix includes workshop materials used in Phase I and Phase II workshops. These materials are:
    - Draft Invitation Letter to proposed State DOT workshop attendees that was sent after receiving approval from NCHRP.
    - Phase II initial workshop Agenda, which is a draft proposed agenda for future workshops.
    - State DOT Participant Read-Ahead Materials and Actions
    - Post-Workshop Evaluation

CHAPTER 2. Research Approach

Phase I included the development and facilitation of two in-person workshops for State DOTs within AASHTO Region 1 and included Tasks 1-5, as described below. The first workshop leveraged the results of the previously developed NCHRP Research Report 889 and helped state DOTs develop more robust snow and ice control performance measures before the 2022-2023 winter season. The second workshop, conducted after the 2022-2023 winter season, examined the results of the implemented measures within the full winter season.

Phase II included the facilitation of two additional in-person workshops for eight State DOTs from other AASHTO regions. These workshops used the same approach and timeline as the two workshops conducted in Phase I (i.e., before and after the 2023-2024 winter season). These workshops built on the experience, findings, and feedback from the Phase I initial and follow-up workshops and used the materials developed for those workshops to provide an overview on the performance measures and required data. Using the previous materials, the research group also illustrated how lacking data and resources can be identified and acquired to accomplish the desired performance measure reporting.

2.1 Task 1: Develop and Conduct Workshop #1

Task 1 activities involved the development and facilitation of Workshop #1, referred to hereafter as Phase I initial workshop, as well as planning and logistics activities and development of workshop content and materials.

The Phase I initial workshop was conducted with two snow and ice control managers from six state DOTs in AASHTO Region 1. AASHTO Region 1 includes states in the northeast from Maine to Maryland. The research team recommended a list of State DOTs to participate in the first workshop to NCHRP based on:

- **State Proximity.** Winter storms and vehicle travel do not stop at state borders. When regional storms occur, they impact regional travel. State proximity is likely to result in similar winter weather patterns, storm severity, and winter maintenance practices. Therefore, states can benefit from collaboration with nearby states to develop and use consistent and related snow and ice performance measures. By working in collaboration, each neighboring DOT will be able to consider not only their state's use of new measures but also how they might align their measures with bordering states.
- **Winter Weather Condition Type.** There are a variety of differences between the weather conditions in each State invited during this Workshop, including States experiencing "lake effect" snow, and States experiencing ice storms or more frequent but lower precipitation events.
- **Dedicated Resources for Winter Maintenance and Operations.** The number of- and severity of winter events historically experienced within a state combined with the amount of dedicated and available funding for winter maintenance operations will impact an agency's planning, response, and recovery efforts. Therefore, selection criteria also include the level of resources and program capability maturity within each potential state agency.

Based on the feedback provided by NCHRP, the research team finalized the list of State DOTs and invited participants for the workshop shown in Table 1 below.

Table 1. Participants in the Phase I Initial Workshop

Participant Name	State/Organization
Brian Burne	Maine DOT
Jim Saban	Maine DOT
Sandi Sauter	Maryland DOT State Highway Administration
Joshua Stonesifer	Maryland DOT State Highway Administration
Mark Goldstein	Massachusetts DOT
John Gendall	Massachusetts DOT
Caleb Dobbins	New Hampshire DOT
David Gray	New Hampshire DOT
Susan Klasen	New Hampshire DOT
Kristina Crowley	New York DOT
Kenneth Relation	New York DOT
Todd Law	Vermont DOT
Robert Faley	Vermont DOT

The Phase I initial workshop was held in Burlington, Vermont on August 2-3, 2022. This 1.5-day workshop was intended to support AASHTO Region 1 State DOTs in implementing and benefitting from the 2019 *NCHRP Research Report 889 Performance Measures in Snow and Ice Control Operations*. Specifically, it included working with participating agencies to analyze and advance their performance measurement activities for snow and ice control.

The Phase I initial workshop was an in-person event to maximize the benefits of collaboration between peer states leveraging the existing relationships between State DOTs, learning from the unique perspectives and capabilities within each state, and identifying opportunities for consistency of performance measures.

One month prior to the workshop, the research team provided read-ahead materials and suggested activities to invitees. The information provided included:

- Invitation letters and draft agenda
- A brief introduction to the performance measures for snow and ice control and the purpose of the Phase I initial workshop.
- Background information on snow and ice performance measurement tools and processes
- Suggestion to participants to review existing performance measures currently used at their state DOT and bring a list of these to the workshop for discussion.
- A description of expected outcomes from the Phase I initial workshop.

The research team leveraged content from the NCHRP Research Report 889 to develop workshop materials and a detailed agenda for the Phase I initial workshop. The draft materials and agenda were submitted to NCHRP and refined based on received feedback. The goals for the Phase I initial workshop were:

- Recapping the findings and lessons learned from NCHRP 889.
- Providing an overview of the key performance measures and required data and resources used within Report 889.

- Guiding participating DOTs in identifying existing data and resources that are available to help acquire information needed to report on the performance measures; and
- Developing a state-specific plan for the winter of 2022 to make progress on snow and ice performance measurement.

The research team gathered feedback from workshop attendees via an evaluation form at the end of the Phase I initial workshop to help understand the value gained from the workshop, perceptions on the approach, and improve future workshops.

2.2 Task 2: Develop and Conduct Workshop #2

Activities within Task 2 involved the development and facilitation of Workshop #2 (Phase I follow-up workshop). This included participants from the same State DOTs as the Phase I initial workshop. Task 2 activities to prepare for the Phase I follow-up workshop included periodic check-ins, workshop planning and logistics, and preparation of content and materials for facilitation of the Phase I follow-up workshop.

The research team held brief, periodic, and informal check-ins with State DOT participants between the Phase I initial and follow-up workshops to discuss the changes planned or implemented within the 2022-2023 winter season, as well as any challenges encountered, or solutions developed. These were held on:

- October 14, 2022.
- November 16, 2022.
- February 2, 2023.
- April 4, 2023.

The research team developed content and materials for the Phase I follow-up workshop with the goal of reviewing each State DOT's results of the performance measures reporting process and identifying successes and obstacles encountered. The research team also developed an agenda that was reviewed and approved by the NCHRP.

The Phase I follow-up workshop was held in Concord, New Hampshire on May 2, 2023, with the same six State DOTs in AASHTO Region 1 that were present in the Phase I initial workshop. This workshop was intended to continue support to AASHTO Region 1 State DOTs in implementing and benefiting from NCHRP Research Report 889. Specifically, it allowed agencies to share their progress implementing their actions identified in the Phase I initial workshop, describing any changes made and resulting benefits as well as any challenges or roadblocks that were encountered. It was an in-person event to maximize the benefits of collaboration between peer states leveraging the existing relationships between State DOTs.

The goals for the Phase I follow-up workshop were:

- Attendees sharing progress on action plans created in the Phase I initial workshop.
- To capture insights from attendees on challenges and opportunities for performance management.
- To capture input from attendees on the NCHRP report to be developed prior to Phase 2 of this project.
- To understand any advice that attendees have for the preparation and conducting of future workshops in this project.

Participants from the same AASHTO Region 1 State DOTs that joined the Phase I initial workshop were invited, and attendees are shown in Table 2 below. Also, University of Albany researchers joined remotely to share research they are conducting to automatically classify status of the roads using image processing of highway camera images.

Table 2. Participants in the Phase I Follow-Up Workshop

Participant Name	State/Organization
Cliff Curtis	Maine DOT
Sandi Sauter	Maryland DOT State Highway Administration
Joshua Stonesifer	Maryland DOT State Highway Administration
Mark Goldstein	Massachusetts DOT
Alan Hanscom	New Hampshire DOT
David Gray	New Hampshire DOT
Susan Klasen	New Hampshire DOT
Joe Thompson	New York DOT
Kenneth Relation	New York DOT
Todd Law	Vermont DOT
Nick Bassil	University of Albany
Carly Sutter	University of Albany
Kara Sulia	University of Albany

2.3 Task 3: Develop Summary of Workshops

The research team generated a summary of the Phase I initial and follow-up workshops in Task 3. Notes from both workshops helped the research team generate a summary of findings, highlighting key discussions from workshops including challenges, successes, lessons learned, and benefits encountered when modifying data collection and performance measures at each State DOT. This summary included the changes required and approach taken by each State DOT during this process. A summary of the feedback from both workshops was also included.

Content from the Summary of Workshops is presented in Section 3 below but has been restructured to separately describe the experience of each State DOT participating in the Phase I initial and follow-up workshops. The summary helped to inform the planning of subsequent workshops and the development of the Phase II Work Plan in Task 4, which is presented in Section 4.

2.4 Task 4: Develop Work Plan for Phase II

Leveraging the experiences from the Phase I initial and follow-up workshops, the research team developed a work plan for Phase II activities. The work plan was based on the initial Amplified Work Plan but was updated and improved based on lessons learned and feedback from the State DOT participants from the Phase I initial and follow-up workshops. The Phase II Work Plan was submitted to NCHRP in May 2023 for review and approval.

2.5 Task 5: Develop Interim Report

The final task of Phase I entailed preparation of an interim report that highlighted:

- Materials developed for the workshops in Tasks 1 and 2 and the approach taken for these workshops.
- A summary of the Phase I initial and follow-up workshops based on content developed for Task 3.
- The proposed work plan for Phase II developed for Task 4.

2.6 Task 6: Develop, Conduct, and Summarize Findings of Two Additional Workshops

The activities in Task 6 centered on the development and facilitation of two additional 1-day workshops, known as the Phase II initial workshop and the Phase II follow-up workshop. Activities included planning and logistics and updating workshop content and materials took place to prepare for workshops, as described below.

The initial scope for Task 6 was to conduct three additional workshops for the other AASHTO regions, each of which would follow the approach of the Phase I initial workshop. However, based on the success of the Phase I workshops, feedback from State DOT participants in the Phase I initial and follow-up workshops, and the research team's recommendation, NCHRP approved a change to Task 6 on August 1, 2023. The modified scope for Task 6 was to conduct two additional workshops for a single group of State DOT participants before and after the 2023-2024 winter season, following the approach of the Phase I initial and follow-up workshops.

The Phase II initial and follow-up workshops were open to participants from any State DOT that had not participated in the Phase I initial and follow-up workshops. Based on available funding, the research team recommended inviting two representatives from 6 State DOTs to participate in each of these workshops. The research team conducted a 1-hour webinar on both September 6, 2023 and September 7, 2023 to broadly share findings from the Phase I initial and follow-up workshops, and also to solicit State DOTs interested in participating in the Phase II initial and follow-up workshops. Specifically, webinar participants were asked to commit to participating in both workshops, as well as interim check-in meetings, and also to take internal agency activities to benefit from what was discussed and learned in the initial Workshop. Based on the feedback received from webinar participants and approval by NCHRP, the research team finalized the list of State DOTs and invited participants for the Phase II initial workshop. Participants in the Phase II initial and follow-up workshops are shown in Table 3 below.

Table 3. Participants in the Phase II Initial and Follow-Up Workshops

Participant Name	State/Organization
Shafique Islam	Arizona DOT
Kevin Duby	Arizona DOT
Tina Greenfield	Iowa DOT
Craig Bargfrede	Iowa DOT
Jed Falgren	Minnesota DOT
Todd Stevens	Minnesota DOT
Mitch Webster*	Minnesota DOT
Paul Denkler	Missouri DOT
LaShonn Ford	Nevada DOT
Brad Darr	North Dakota DOT
Branson Beise+	North Dakota DOT
Miles Nelson*	North Dakota DOT
Patty Caswell	Oregon DOT
Jess Aloiso (online)*	Oregon DOT
Mike Adams	Wisconsin DOT
Cody Churchill	Wisconsin DOT
Emil Juni	Wisconsin DOT

* Participated only in the Phase II follow-up workshop
+ Participated only in the Phase II initial workshop

The research team conducted two workshops during Task 6 as part of Phase II activities in Bloomington, Minnesota: November 15-16, 2023 and May 2, 2024. Efforts included finalizing logistics with the host location, including the meeting venue and reservation of rooms, updating materials developed for the Phase I initial workshop for the Phase II initial workshop, and conducting, facilitating, and capturing notes during the workshops.

One month before the workshop, the research team provided read-ahead materials and suggested activities to NCHRP. The information provided included:

- Invitation letters and draft agenda
- A brief introduction to the performance measures for snow and ice control and the purpose of the workshop.
- Background information on snow and ice performance measurement tools and processes
- Suggestion to participants to review existing performance measures currently used at their State DOT and bring a list of these to the workshop for discussion.
- A description of expected outcomes from the workshop.

The research team conducted an introductory webinar (60 minutes in duration) prior to each workshop with the participating States. The purpose of the webinar was to orient the attendees about the workshop, share information, and encourage participants to review their current practices prior to the workshop.

The research team conducted each workshop leveraging and updating the materials developed for the Phase I initial and follow-up workshops. Per feedback from the Phase I initial and follow-up workshops, networking, collaboration, and exchanges from the in-person workshops were valuable. As a result, the Phase II initial and follow-up workshops followed a similar structure and approach as

the Phase I initial and follow-up workshops, allowing ample time for interaction and discussion. Additionally, after the Phase II initial workshop, participants from the Phase II initial workshop participated in a series of virtual webinar check-in sessions, discussing progress being made and receiving input from the consultant team to help advance their progress. These were conducted on January 25, 2024; February 28, 2024; March 27, 2024; and April 26, 2024.

The research team documented action items and take notes during each workshop. These notes summarized the discussions and were synthesized into a summary of findings from the workshops. Notes from the workshops helped the research team generate a summary of findings, highlighting key discussions from workshops including any experiences, challenges, successes, lessons learned, and benefits encountered when modifying data collection and performance measures at each State DOT in the past. Additionally, this included recommendations and actions discussed by each participant regarding changes required and approach taken to improve performance measurement. A summary of the feedback from both workshops was also included within this document. The summary of workshops informed the development of this Task 7 final report.

2.7 Task 7: Develop Final Project Deliverables

The research team gathered all files and information from the previous tasks, including the materials and presentations from all workshops, to generate three final deliverables.

The first deliverable was this final report documenting the activities of the entire project and incorporating all information gathered from the workshop summaries in Task 3 (Phase I) and Task 6. This also included an evaluation of the workshops based on participant feedback. This report summarized the process used to develop and present workshop materials, provided an overview of the thought process and key lessons used to develop workshops and highlight lessons learned. From the information gathered in the workshops regarding challenges State DOTs faced, the research team included future opportunities and research needs within the final report. This report was submitted to NCHRP for review and comment and updated based on the feedback received.

The second deliverable included all electronic files with the presentation materials and information used for the workshops. These will serve as separate deliverables in a format that is appropriate for use in future workshops or other related forums.

The final deliverable for this project was a brief article developed by the research team for potential publication in the TR News. This article highlighted the purpose of the workshops, their findings, and recommendations for enhancing implementation activities.

CHAPTER 3. Findings and Applications of Snow and Ice Performance Measures Implementation

This section summarizes the seven performance measures from the 2019 *NCHRP Research Report 889 Performance Measures in Snow and Ice Control Operations* that were presented at the initial and follow-up workshops in both Phase I and Phase II, some overarching reactions by State DOT participants to the measures, and accomplishments and findings for each measure. The implementation accomplishments and findings for each measure are provided.

As presented in NCHRP Report 889, there are seven snow and ice-control outcome-based objectives which are listed here and described in more detail below alongside some State DOT reactions:

- Level of Service (LOS) during the event
- Travel reliability during the event
- Recovery from the event
- Safety
- Level of customer satisfaction
- Efficiency
- Environmental stewardship

3.1 PM 1 – Level of Service (LOS) During Event and PM 2 – Recovery

Agencies often considered LOS and recovery performance measures in tandem. There is a significant amount of interest in determining the LOS during an event, as most states already collect friction data that could be used to monitor LOS. As described in the NCHRP Research Report 889, this performance measure would include the percentage of time identified road segments meet agency-defined LOS thresholds during winter storms. This measure has several caveats that allow agencies to focus on a specific road segment and specific thresholds to refine the process before the performance measure is applied statewide. There are many ways LOS can be defined:

- Quantitative assessment of conditions (e.g., field personnel reporting current conditions).
- Accumulation-related threshold (e.g., RWIS locations).
- Friction-related threshold (e.g., friction sensors on RWIS stations, mobile sensors).
- Travel speed-related threshold (e.g., probe data to measure speed changes).

Participating State DOTs noted that this measure was understandable and appreciated the flexibility in defining it to meet their operational objectives for specific roadways. Phase I initial workshop discussions indicated that State DOTs are interested in using new data sources (especially speed or grip data) for understanding LOS during and after an event. Phase II initial workshop participants discussed the various speed probe data sources their agencies use, the use of volume-weighted speeds, and exploring reporting capabilities from Vaisala, maintenance decision support systems (MDSS), or GeoTab, as well as collecting cycle time or friction and speed relationships for this measure.

Recovery focuses on the percentage of identified segments meeting the agency-identified time to return to ‘acceptable criteria’ after an event. This performance measure is important as it helps agencies assess their winter storm management and their response performance, which can help support response decisions and post-event analysis and identification of improvements for following events. NCHRP Research Report 889 describes data that can be used to get this value, which includes

the amount of time that passes from the end of a winter storm event until acceptable surface conditions exist again (e.g., bare pavement). Another way to determine this is by looking at the variation in speed. Traffic speed will be reduced during a winter storm given the condition of the roadways. Looking at the resumption of normal traffic speeds would help determine when recovery is complete, and roadways are back to normal.

Similar to the LOS measure, recovery was noted by the Phase I initial workshop participants as squarely in line with ongoing initiatives and all States had considered variations of this measure in their maintenance programs. Several Phase II initial workshop participants liked this measure better than LOS, but not the subjective self-reporting aspect; participants were therefore interested in automating the measure using MDSS or Vaisala reporting, for example.

A measure of particular interest was developed by New Hampshire and tested in two locations on I-89 using RWIS data and TomTom probe traffic data. The measure examined the ability to maintain roadways in fashion that the public travel speeds do not drop below 70% of the posted speed limit with a target of reaching that goal 70% of the time; in the selected locations on I-89 the posted speed limit was 65 mph, and 70% of that is 45.5 mph. Figure 2 shows this measure for a January winter event.

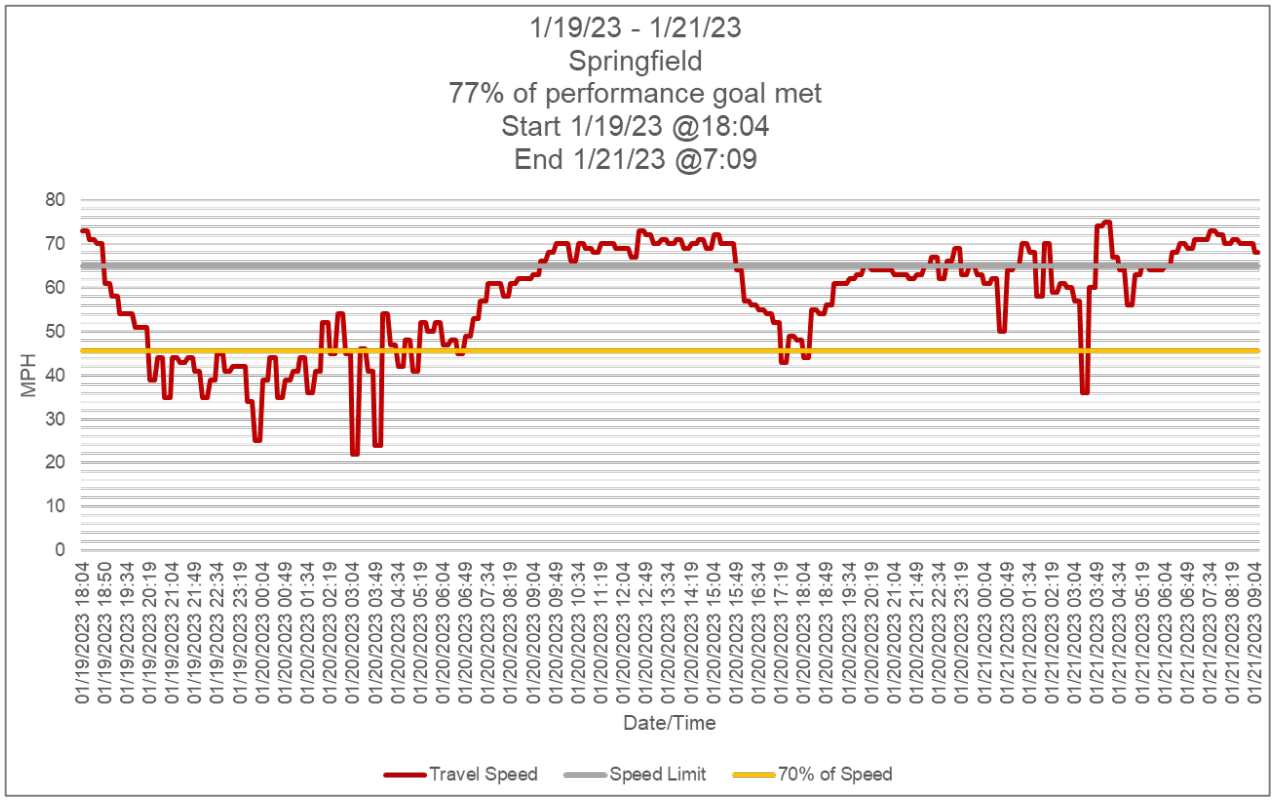


Figure 2. For a January winter weather event, New Hampshire depicted travel speeds against the speed limit and the performance goal of 70% of the speed limit (45.5 mph). (Source: New Hampshire DOT)

North Dakota developed a performance measure using speed data from weigh in motion (WIM) stations, automatic traffic recorders (ATR), and non-intrusive speed detectors as an indicator for recovery time; the measure also includes a friction value given uncertainty that speed data alone would be adequate for determining recovery and has the potential to replace speed recovery in the future. Specifically, speed recovery is measured across 73 locations statewide, including 66 ATR and

7 environmental sensor stations (ESS), and North Dakota plans to further automate the friction portion for better analysis and comparison. Overall, North Dakota believes speed data is generally more comprehensible to the public compared to friction.

Finally, New York successfully explored the use of closed-circuit television (CCTV) cameras for road condition reporting and was working to finalize the algorithm to make it operational. Specifically, camera images taken every 5 minutes from 2400 sites were used with AI algorithms developed to recognize camera images compared to human determined conditions. This "training" of the AI enabled automated processing of camera images and determination of real time road and driving conditions.

3.2 PM 3 – Reliability

Reliability is not point-based like other measures, but rather is segment or route-based representations of reliability of travel times. Reliability is tied to the variation experienced and can include factors like how much extra time it took to get to a location compared to the usual amount of time it takes, or how much extra time must be built into a trip to arrive at a destination on time. NCHRP Research Report 889 notes this can be used to measure the quality of service for travelers for specific trips, using a calculation of ratio of peak-period travel time to free-flow travel time averaged across urban areas, road sections and time periods weighted by vehicle miles traveled (VMT). This can also be calculated using the travel time index (TTI) during storms versus the pre-specified additional TTI for trips and storm severity levels. Data to measure reliability can come from travel times from the toll booth and probe data.

Participating State DOTs had limited experience with calculating reliability measures. While several of State DOTs in the Phase I initial workshop expressed interest, especially with access to data from their operations groups, no agencies expressed interest in this measure in the Phase II initial workshop.

Maryland successfully created a Regional Integrated Transportation Information System (RITIS) dashboard for District Maintenance Supervisors that allowed users to establish alerts that were triggered based on RITIS speed data values (e.g., when speeds drop below 50% of free flow speed and return above 50% of free flow). This required buy-in from maintenance staff, especially around the use of new performance data.

3.3 PM 4a and 4b – Fatalities and Injuries

As described in NCHRP Research Report 889, the five-year rolling average of number of fatalities and injuries during a winter season measure uses detailed crash records and weather event data to evaluate seasonal differences. This value can help identify where additional maintenance and incident management planning resources should be directed geographically and temporally. It is also valuable to connect fatalities and weather to explain why there are such significant resources and time funneled into winter weather treatment.

The Phase I initial workshop participants recognized the value of measuring fatalities and injuries but noted a significant lack of control over these measures, as they are influenced by a variety of factors including driver capabilities and awareness. In the Phase II initial workshop, Missouri and North Dakota agreed to explore crash changes against winter severity.

Missouri developed a Titan application that includes a severity index that relates monetized impacts of a weather event on safety, mobility, and recovery costs. The app is normalized statewide by county using biggest events and associated costs. A dashboard, depicted in Figure 3, shows average costs and the geographic impact of individual events compared to baseline. Safety impacts in the app severity index are monetized by using crash costs. The change in number of crashes during an event were examined using the number of crashes on a clear weather day within one week of the event as a baseline. Costs in the app also include pre-treatment and other costs to the public incurred during the event even though an event start time is from the end of precipitation.

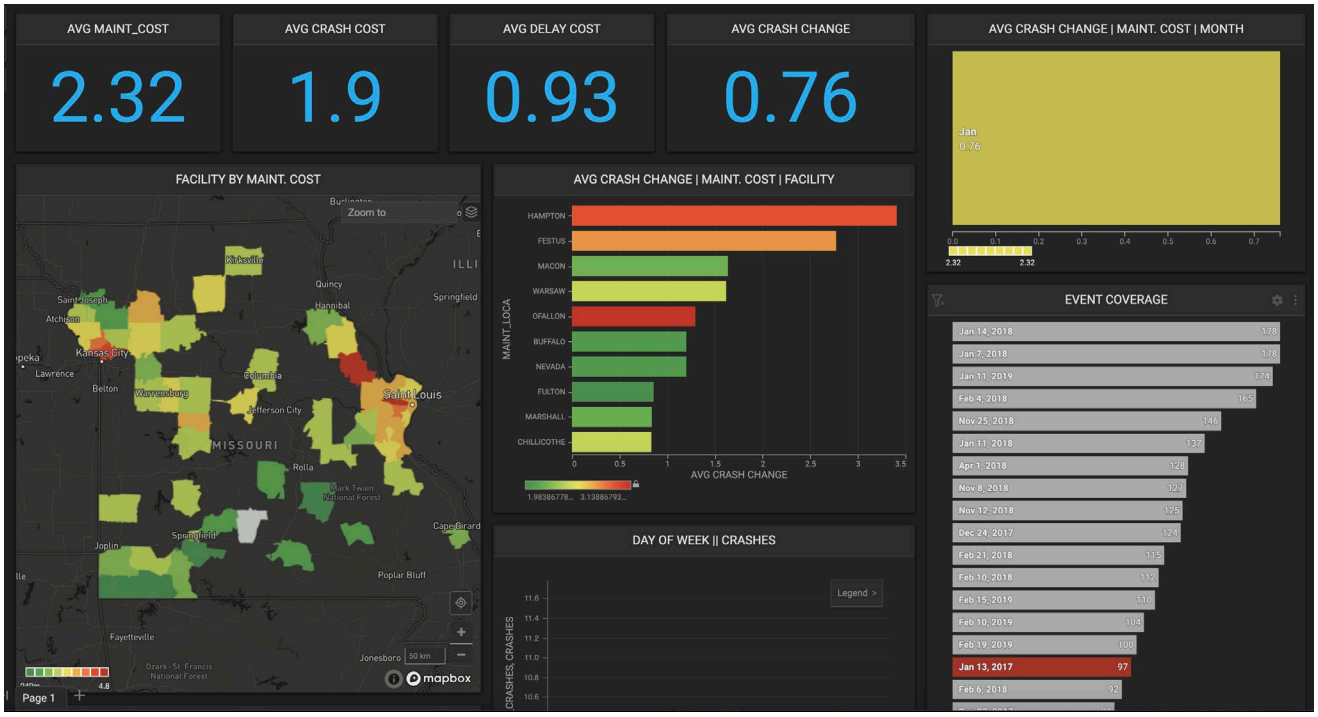


Figure 3. The Missouri Titan app includes a dashboard that shows impacts of a single weather event by county, including the average crash change for the event. (Source: Missouri DOT)

3.4 PM 5 – Customer Satisfaction

Customer satisfaction data can be collected through seasonal surveys or surveys after major weather events. NCHRP Report 889 notes how data collected provides support to event response decisions and post-event analysis by allowing agencies to see how the public perceive their performance changes. When gathering data on customer satisfaction, it is important to consider the severity of an event as generally, satisfaction decreases when severity of an event increases.

There was not significant interest in gauging customer satisfaction in either the Phase I initial workshop or the Phase II initial workshop. State DOTs in the Phase I initial workshop were open to asking snow and ice control related questions if their agency was conducting a survey. Speaking with a Public Information Officer (PIO) would help these agencies take a proactive approach to their winter maintenance program.

The Minnesota Department of Transportation (MnDOT) has historically conducted a biennial omnibus customer satisfaction survey that includes maintenance and operations activities. Specifically, the Statewide Public Opinion Survey asks respondents: “How well do you think

MnDOT is performing in clearing roads of snow and ice?" Responses are on a 1-10 scale, representing extremely poor to extremely good. Figure 4 shows that public opinion of MnDOT's performance has been steady between a 7 and 8 from 2012 to 2024.

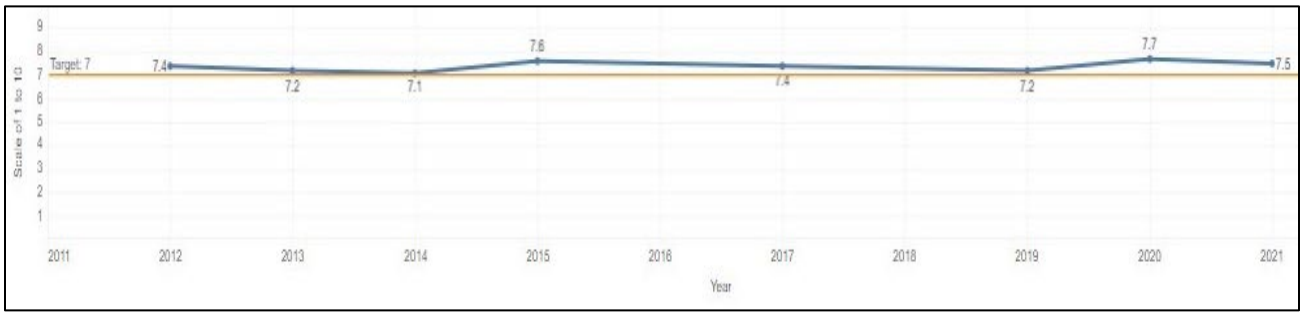


Figure 4. Public opinion of Minnesota's performance in clearing snow and ice from 2012-2021 has been steady. (Source: Minnesota DOT)

3.5 PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship

Agency efficiency is the standardized cost of snow and ice control that is spent to meet an established performance criteria for a given winter severity, as detailed in NCHRP Report 889. Capturing this data helps assess the efficiency of agency spending, by looking at the usage of winter maintenance resources. Factors driving cost include geographic size, functional class or roadway, density of roadway, location of roadway (rural versus urban area), hot spots, timing, number, and intensity of events.

All States have adequate information to measure agency efficiency. Agency efficiency is measured in terms of inputs (workers, material, etc.) and outputs (lane miles plowed, etc.). Data collection has improved, as there are new tools and maintenance management systems that tie in activity data and crew information into normal operations management. As a next step, States need to find ways to normalize data – comparing the data from a season to the expected values so that there is a story to tell on why a certain number of resources are used. Historical data and severity-based data would also be useful in measuring efficiency.

Similarly, environmental stewardship indicates whether an agency is within an 'acceptable' difference between the expected and actual use of salt and other materials during a winter season, as described in NCHRP Report 889. This measure allows an agency to assess the quantity of materials used in each storm and given season to achieve the agency's LOS while not compromising the environment. Material usage varies depending on the storm and season severity, LOS, proactive approaches taken, if there are computerized dispensing equipment, equipment calibration, and yearly weather patterns.

States are all trying to find the balance on the 'three-legged stool' of the environment, money, and safety when it comes to winter maintenance. Salt is a major expense financially and causes impacts to the environment but helps maintain or restore safe driving conditions and is something that is considered in the winter maintenance program.

A variety of states have demonstrated performance measures related to both agency efficiency and environmental stewardship, given these types of performance measures often go hand in hand. As an example, MnDOT is making efforts to utilize more liquids in order to reduce chlorides introduced

into the environment and to achieve better utilization of salt applied. Specifically, MnDOT developed a performance measure for liquid-to-solid ratio, illustrated in Figure 5, The Department has noted that using brine may save up to 30% of total salt applied than if salt alone were used, resulting in a cost savings that can be calculated. Next steps for MnDOT are to determine the environmental benefits of reducing salt runoff into lakes given lower salt usage when brine is used instead, which has potential national significance to demonstrate reduced environmental impacts.

Unit Of Measure Name	(All)					
Resource Name	(All)					
	Column Labels					
Values	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Sum of Gal Liq (total)	5,779,476	6,548,607	6,594,318	8,097,527	14,144,434	**9,735,807**
Sum of Tons Salt (total)	256,525	212,398	159,303	189,467	260,380	**114,046**
Sum of Tons Abrasive (total)	35,383	22,331	18,133	29,090	36,439	**11,045**
Sum of Gals / Ton	**23**	**31**	**41**	**43**	**54**	**85**

Figure 5. Minnesota calculates a brine-salt ratio for gallons of liquid brine used versus tons of salt (Source: Minnesota DOT)

As a result of this project, North Dakota also calculated a brine-salt ratio for each District based on the gallons of liquid brine used versus tons of salt and then generates a value of potential cost savings if more brine had been used. Specifically, the brine-salt ratio helps North Dakota determine potential cost savings and encourages the use of brine over salt. The use of this performance measure has helped both states to justify costs of procuring brine equipment for winter maintenance operations. North Dakota also measures labor costs for winter maintenance with a focus on efficiency and implements measures such as snow fences and liquid to solid ratio performance measures to reduce salt usage and associated costs.

Additionally, MnDOT has implemented innovative nature-based solutions like paying farmers to not harvest several rows of corn or place haybales adjacent to highways to act as a temporary snow fence. This strategy has potential long-term performance implications, and a measure could be developed to predict benefits of snow fence by the number of miles.

Massachusetts provides another success story for this performance measure. Note that most equipment in the state is hired out and whenever a crew begins an activity, resource usage is recorded. For this effort, Massachusetts successfully determined a correlation between Winter Severity and contractor hours for winter maintenance for a given event, as well as a correlation between contractor hours and salt usage.

CHAPTER 4. State DOT Implementation Activities

Looking at the tools each agency uses to measure their current performance, as well as the data available and processes in place, each State DOT at the initial workshops in Phase I and Phase II defined what objectives and performance measures they were already using to measure the performance of their snow and ice program. This section presents overarching observations of State DOTs, current capabilities and metrics used by each State DOT as of the Phase I initial workshop, the focus areas and agreed upon actions by State DOTs for the 2022-2023 winter season in the Phase I initial workshop or the 2023-2024 winter season in the Phase II initial workshop, and the findings and outcomes each State DOT presented at the Phase I follow-up workshop or the Phase II follow-up workshop, respectively. The workshop each State DOT participated in is noted below, as well as the section that the outcomes are presented.

State DOTs in the Phase I initial workshop

- 4.1 Maine
- 4.2 Maryland
- 4.3 Massachusetts
- 4.4 New Hampshire
- 4.5 New York
- 4.6 Vermont

State DOTs in the Phase II initial workshop

- 4.7 Arizona
- 4.8 Iowa
- 4.9 Minnesota
- 4.10 Missouri
- 4.11 Nevada
- 4.12 North Dakota
- 4.13 Oregon
- 4.14 Wisconsin

4.1 Maine

At the Phase I initial workshop, Maine DOT participants presented their current activities to measure performance. Given State resources, LOS is determined by roadway priority and snowplow cycle times. Corridors with higher traffic such as interstates are prioritized over lower-level corridors when it comes to plowing and have shorter plow lengths and cycle times. Recovery goals are also based on the level of corridor. For interstates, Maine has a goal of returning the Interstates to bare pavement in four daylight hours following a storm. Lower-level corridors may go 24 hours before post-storm recovery is completed. Maine's general approach, for all roadways, is to keep them open as long as possible.

In terms of maintenance management, storm reports are created for each event and material costs are charged to the event accordingly. Unfortunately, this does not help with capturing start or end times of the storm event, as pre-treatment activities and their costs are also included in the event report. Maine noted that they are interested in exploring the use of travel speeds as a surrogate measure for return to normal.

At the Phase I initial workshop, Maine DOT participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Maine is interested in looking at speed data compared to friction. On a weekly basis, Maine receives a spreadsheet from Vaisala that provides information on grip sensors including severity of deteriorated grip, and how quickly there was response to the deteriorated grip. Maine would like to take the friction data, combine it with speed data, and create an automated process to generate reports on season-wide correlation between friction and speed.

- **PM 2 – Recovery Current and Potential Use.** Maine has recovery times for levels one through four roadways that are three daylight hours, eight daylight hours, twenty-four daylight hours, and thirty daylight hours, respectively. Maine is unable to determine what percent of time those recovery times are met. Maine's policy includes that reporting on the conditions should occur when a crew comes in, when the conditions change, when the crew leaves, and every two hours but unfortunately, due to staffing limitations, this business practice cannot be supported. Interstate cameras are time stamped and can be used to monitor conditions during the daytime to see if the roads are bare or not, which is more reliable than expecting crew to call in conditions every two hours. Maine would like to use speed as an indicator that roads are back to normal after an event and thinks that Maine 295 would be the best roadway to begin with instead of relying on crew to report conditions.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Maine has a seasonal winter storm index related to usage and costs that help them look at their material usage. Maine has all the data to make a graphic like Massachusetts and New Hampshire to track event severity and salt consumption, however, they have not taken the step to make the correlation line to determine if they are over or under their estimated salt usage given their WSI. It would not be a significant effort for Maine to make this extra step and be on par with Massachusetts and New Hampshire. Maine also tracks the past miles that crews report, the number of times an area was plowed, etc. to look at different time periods. Additionally, Maine tracks the storm count and looks at the average cost per storm.

Some of these were translated into actions for Maine to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the Phase I follow-up workshop are presented in Table 4.

Table 4. Maine DOT Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Actions for 2022-2023	Progress and Findings
Recovery and Level of Service	

• Translate the Excel spreadsheet into a PowerBI dashboard to allow for easier calculations of service and recovery related measures.
• Identify a priority corridor to develop a standard on level of services and recovery measure.
  o Define corridor boundaries.
  o Create a standardized report that pulls together speed, friction, and manual observations into the winter event timeline.
  o Report back on process followed and repeatability on other corridors and roads
	• Maine DOT noted that they are advancing to next steps that include looking at Waze congestion data to see how it correlates with snow and ice (compare the 5 Waze congestion levels with performance with the intent of integrating this with available Maine DOT telematics); additional support underway for storm counts and storm durations.
	• A key finding of the workshops was noting that custom dashboards would be optimal, such that the system would identify BMPs for specific locations and conditions.

Agency Efficiency and Environmental Stewardship	

Correlate AWSSI to salt use in an equation that can be used to project expected salt use and costs	• Reported that a success that was supported by these workshops was that they are currently working on finalizing their 2022–2023-year end winter maintenance reporting. This report will include:
	  o Salt use per mile.
	  o Miles traveled.
	  o Correlation with winter severity (Note: Maine DOT is now using the AWSSI for this correlation).
	• A second success was successfully using AWSSI as part of the year-end report.
	• As part of the year end reporting, Maine DOT will break down the winter activities into storms encountered, responses, costs, etc. They will identify a scorecard for each region/district to:
	  o Enable discussions with neighboring districts; and
	  o Encourage discussions throughout this summer for preparations towards newt winter.
	• Expressed that a priority is placed on reducing salt use whenever possible.

4.2 Maryland

At the Phase I initial workshop, Maryland participants presented their current activities to measure performance. In Maryland, an event begins when there is information on the event's impact and the appropriate staff is activated. If there is activation of the winter maintenance crew, an event can exist without precipitation, or it can start before precipitation begins. For every event, salt usage, contractor and state hours (regular and overtime), brine usage, accumulation type and amounts, and average pavement temperatures are tracked.

A key difference between Maryland and the other participating states is that Maryland treats all roads in the same manner, with no prioritization based on level. Even with no prioritization, Maryland does not close roads. Instead of prioritizing roadway treatment by road level, traffic often dictates plow cycle times.

Maryland defines return to normal when roads are back to bare pavement, or running wet, with the goal of four hours from when precipitation stops. An exception to the four-hour metric is if there has been more than eight inches of precipitation reported, although in these scenarios, the roads are generally cleared within four hours. This measure is also only applied to interstate and priority one (P1) arterials

At the Phase I initial workshop, Maryland participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Maryland is interested in pursuing Mobile Advanced Road Weather Information Sensor (MARWIS) data for friction information. Previously, Maryland measured friction in front of snowplow trains and after snowplow trains to see the immediate impacts that plowing had on friction, which was successful. Currently, they use field observations and technology to collect data on road conditions. Maryland is also interested in looking at the data from specific storms and road segments to tell a better story on the conditions.
- **PM 2 – Recovery Current and Potential Use.** Maryland uses four hours as the timeframe for all interstates and primary arterials. Within four hours post event, there should be bare pavement. Maryland will stick with this measure for four hours but would like to automate processes more. Adding enough sensors strategically across the State to gather information would be beneficial, as they do not have sensors in many high traffic areas.
- **PM 3 – Reliability Current and Potential Use.** Maryland has access to the full data suite that RITIS provides; given this, they could request that the University of Maryland Center for Advanced Transportation Technology (CATT) Laboratory generate reports on reliability on certain corridors given weather events.
- **PM 4a and 4b – Fatalities and Injuries Current and Potential Use.** Participants recognized the value of measuring fatalities and injuries but noted a significant lack of control over these measures, as they are influenced by a variety of factors including driver capabilities and awareness. Maryland is already aware of problem areas.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Maryland also has all the data and is working on creating an internal winter storm index. They believe that once they have an established winter storm index and find an adequate system to keep track of their salt usage compared to the index, they will be able to use this to determine efficiency. Maryland has a way of incorporating ice into their winter storm index. Maryland uses a scaling factor of ten that they apply (i.e., for each inch of ice, ten inches of snow are represented in the winter storm index. An example of this is if there is half an inch of ice, this would be equivalent to five inches of snow. This scaling factor accounts for the significant amount of salt and other materials used to manage ice. Other components of the Maryland winter storm index show that they have reduced salt usage. Looking at the comprehensive salt management plan, they were using 1000 lbs. of salt per lane mile per inch and are now down to 500 lbs. of salt per lane mile per inch. This is compared to the average temperature across the winter to determine the efficiency of their program. This measure will vary greatly depending on pavement temperatures and the type/severity of each winter event.

Some of these were translated into actions for Maryland to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the Phase I follow-up workshop are presented in Table 5. Figure 6 presents additional findings identified by Maryland DOT.

Table 5. Maryland DOT Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Actions for 2022-2023	Progress and Findings
Recovery and Level of Service	
Reach out to RITIS / Coordinated Highways Action Response Team (CHART) staff to see what reports could be generated for weather and travel speeds	• Maryland DOT cited that a major success from the workshops was their increased understanding and use of RITIS data and performance reports. ○ They cited the use of RITIS data to compare average travel speeds to the winter storm and specifically speed at locations where pavement grip deterioration is detected from RWIS stations.
Agency Efficiency and Environmental Stewardship	
Identify a resource/team member who can help maximize the utility of the spreadsheet for analysis.	• Noted that an opportunity exists to use speed data to compare the treatment performances of brine vs. more traditional granular applications (not relying solely on human opinion).
Reliability	
Reach out to RITIS to see if they can correlate reliability metrics with weather timelines	• Successfully created a RITIS dashboard for SHA District Maintenance Supervisors that allows users to establish alerts that are triggered based on RITIS speed data values (e.g., when speeds drop below 50% of free flow speed and return above 50% of free flow). • Finding: Need buy-in from maintenance staff, especially around the use of new performance data.

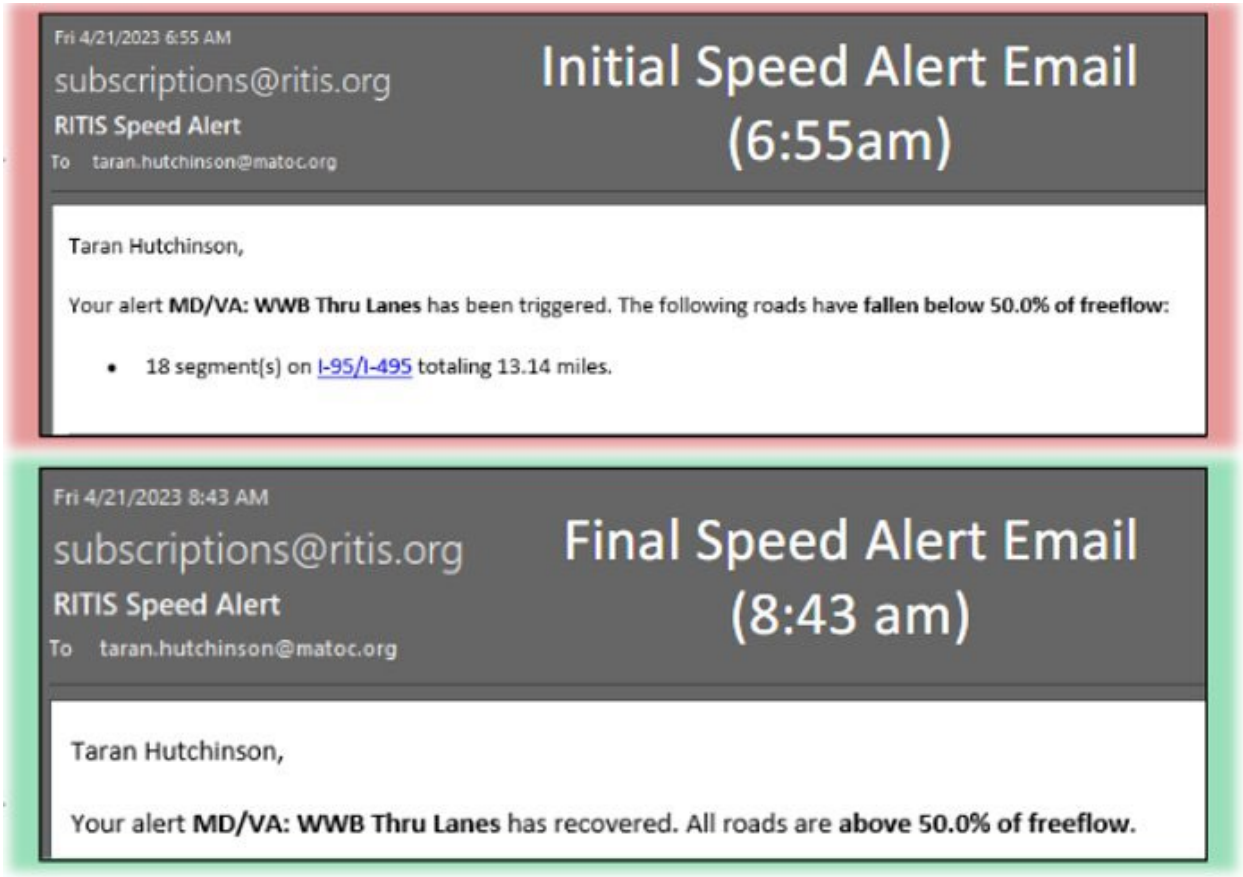


Figure 6. Maryland established a mechanism for staff to receive alerts based on RITIS speed data values, such as when travel speeds on segments are below 50% free flow speed (top) and when they have recovered to be above 50% free flow speed (bottom) (Source: Maryland DOT)

4.3 Massachusetts

At the Phase I initial workshop, Massachusetts DOT participants presented their current activities to measure performance. Massachusetts's LOS is safety based. If the roads are slippery, they are treated. Massachusetts does not have a specific number of hours in which roadways should be cleared, as their response is reactionary, using resources to treat the roads until they are clear. Road conditions are reported every two hours in 'Road & Weather' (R&W) reports. These reports also capture the costs based on equipment and individuals working on an event.

Massachusetts looks at grip levels as a treatment indicator. Unfortunately, each fixed location RWIS station represents approximately 300 lane miles. RWIS stations are not the best way to measure the grip on the roadways because they cannot accurately indicate if a whole area or specific segment of a road needs treatment. To gather better grip data, Massachusetts investigated mobile RWIS stations. The mobile RWIS stations are more accurate and show significant savings in salt usage. Most of the time, supervisors are in their vehicle and will determine what areas need treatment by looking at real time data.

Massachusetts is divided into six districts with various sub-districts. All decisions regarding deployment of equipment are made at the district level. Most of the equipment within the state is hired out and when it is needed to treat an event, each depot will ensure that it has adequate resources to treat the storm. An event begins when winter crews are activated, as this is where they start

capturing costs related to an event. Whenever a crew begins an activity, resource usage is put into the Massachusetts DOT system. If there is snow and ice activation from three or more districts, the Boston snow and ice storm desk opens as the event is then considered a 'major event.'

At the Phase I initial workshop, Massachusetts participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Massachusetts is interested in using their mobile RWIS tools to set parameters related to severity and assessing the correlation between the two. They have also executed research based on perceived grip and using this information to salt the roads as needed.
- **PM 2 – Recovery Current and Potential Use.** Massachusetts does not have a specific recovery time. Given that most of the resources Massachusetts uses for winter weather are contractors, they ensure that contractors do not go home until the job is finished. Every two hours, someone must enter the R&W conditions that are present in each area. Thinking about the recovery time, Massachusetts could use the end of precipitation to the submittal of the final R&W as the recovery period, as R&Ws are submitted once roadway conditions have been addressed and there will be no more precipitation. Massachusetts is interested in measuring the interval from the end of precipitation to when the roads are cleared from curb to curb.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Massachusetts looks at the cost at the end of the season, broken into subcategories including materials, vendor costs, overtime paid, etc. Gathering data from each district, Massachusetts compares the amount spent in the districts. Knowing the variation in lane miles and weather each district experiences allows the Department to determine what the outliers are, if any exist, and what the story is behind the outliers. Massachusetts DOT looked at the correlation between pre-wetting and treatments per lane mile per inch, which can be seen in Figure 7.

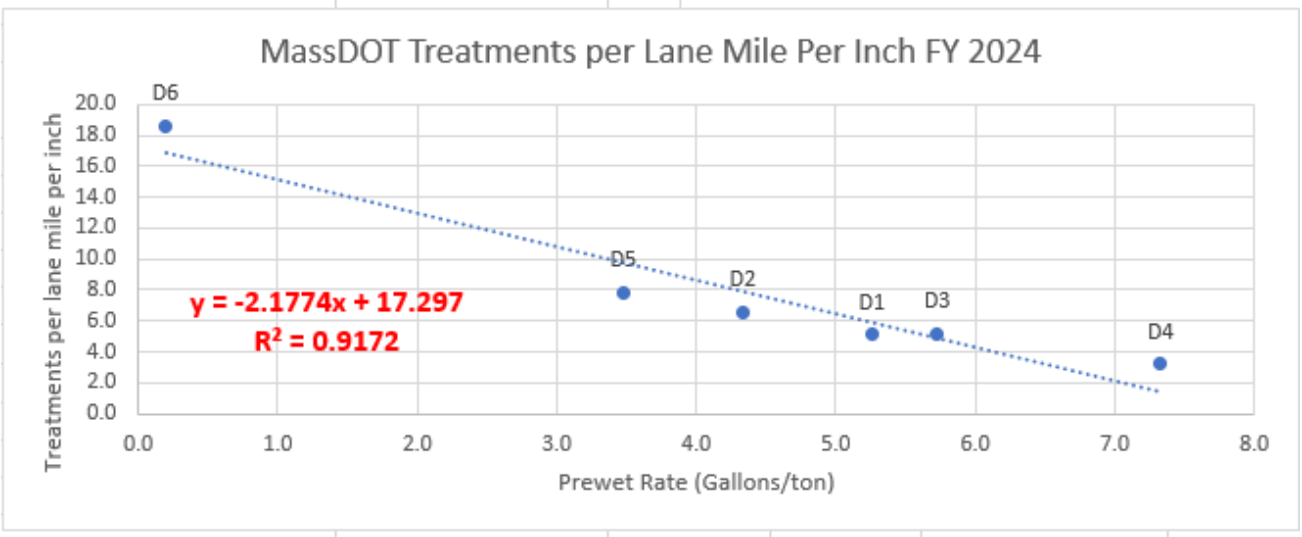


Figure 7. Massachusetts DOT Correlation Between Pre-Wetting and Treatments. (Source: Massachusetts DOT)

Through the correlational study, Massachusetts DOT determined that the more they pre-wet roadways, the less salt they use. In terms of resource usage, ice events require more materials than

snowfall. Massachusetts DOT also looked at the correlation between winter severity and salt usage, generating three different regressions as seen in Figure 8.

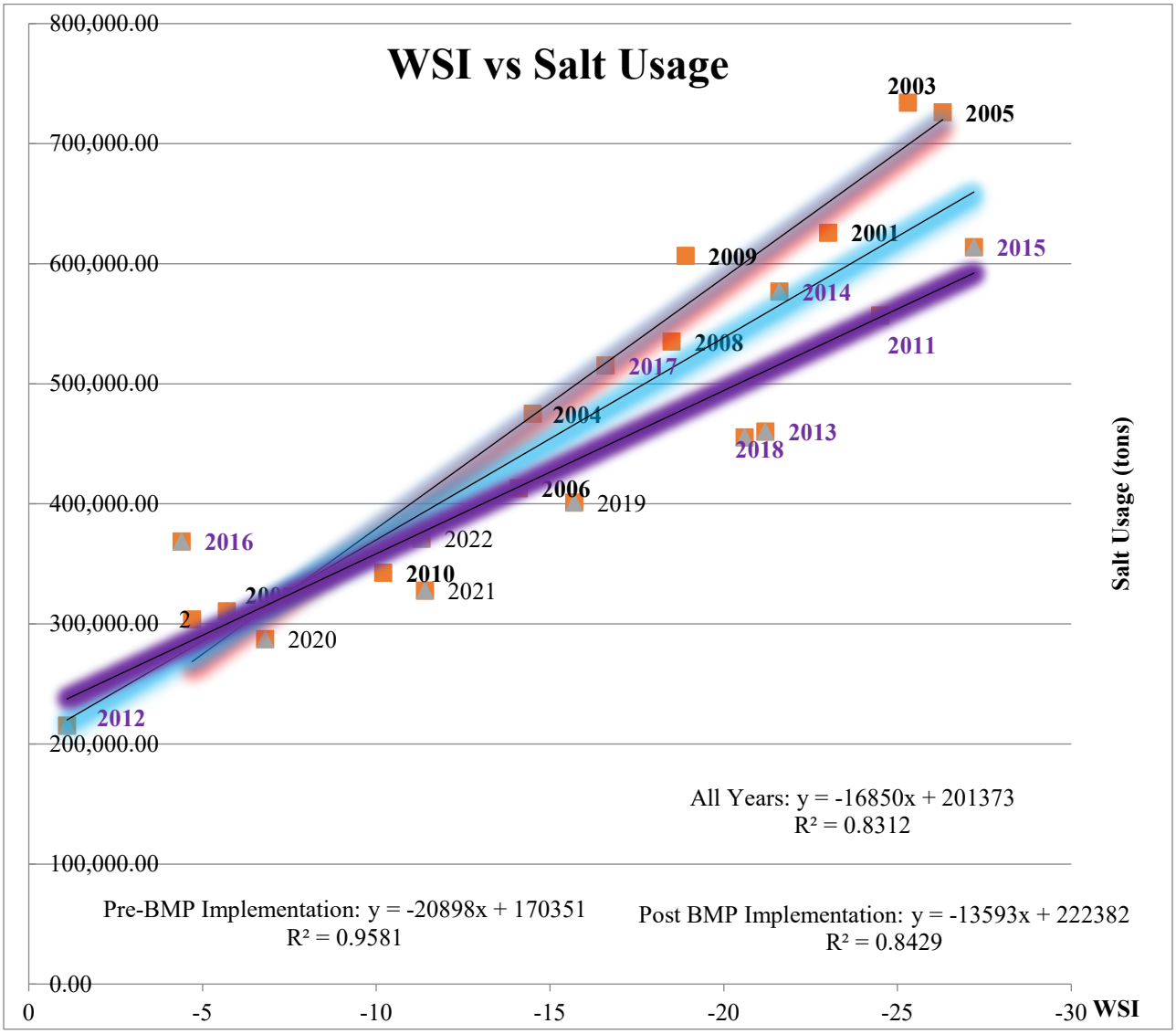


Figure 8. Massachusetts DOT's Correlation Between WSI and Salt Usage. (Source: Massachusetts DOT)

The top regression line speaks to 2001-2010 data, where Massachusetts DOT was not as efficient with their salting methodologies. The purple regression line speaks to the 2011-2022 data, where Massachusetts DOT implemented the use of modern Best Management Practices (BMPs), such as pretreating, prewetting salt, and ground speed control that delivers consistent salt application. The blue regression line shows all the data and will be compared against the labor hours spent. In the Massachusetts DOT WSI, they include the number of days below freezing, which factors into the WSI (instead of simply factoring in snowfall). Ideally, Massachusetts DOT would like to include an assessment of freezing rain in the WSI. The current WSI model (Boselly Index) only encompasses freezing rain in that temperatures were below freezing for such events, so those days were considered ones with “frost potential”.

Some of these were translated into actions for Massachusetts to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the

Phase I follow-up workshop are presented in Table 6. Figure 9 and Figure 10 present additional findings identified by Massachusetts DOT.

Table 6. Massachusetts DOT Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Related PMs	Progress and Findings
Recovery and Level of Service	
Identify a priority corridor to develop a standard on level of services and recovery measure. o Define corridor boundaries. o Create a standardized report that pulls together speed, friction, and manual observations into the winter event timeline. o Report back on process followed and repeatability on other corridors and roads	• Successfully examined performance metrics based on grip and speed, however the hours required to manually assemble and compare these hinder efforts to provide these on an ongoing basis
Agency Efficiency and Environmental Stewardship	
Look at the linkage between labor cost and WSI	• Successfully determined correlation between Winter Severity and contractor hours • Successfully determined correlation between contractor hours and salt usage • Successfully conducted excellent storm-level tracking of costs and labor • Winter Performance Index (WPI) depends on wind sensor data from RWIS

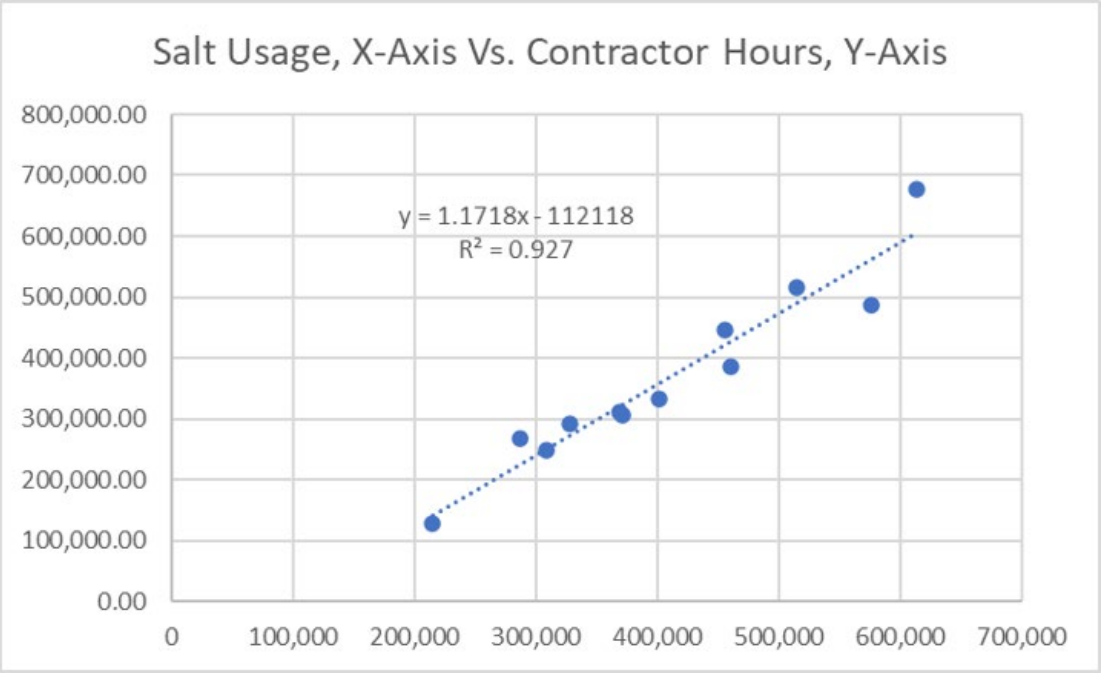


Figure 9. Massachusetts documented the correlation between salt use and contractor hours for winter weather events. (Source: Massachusetts DOT)

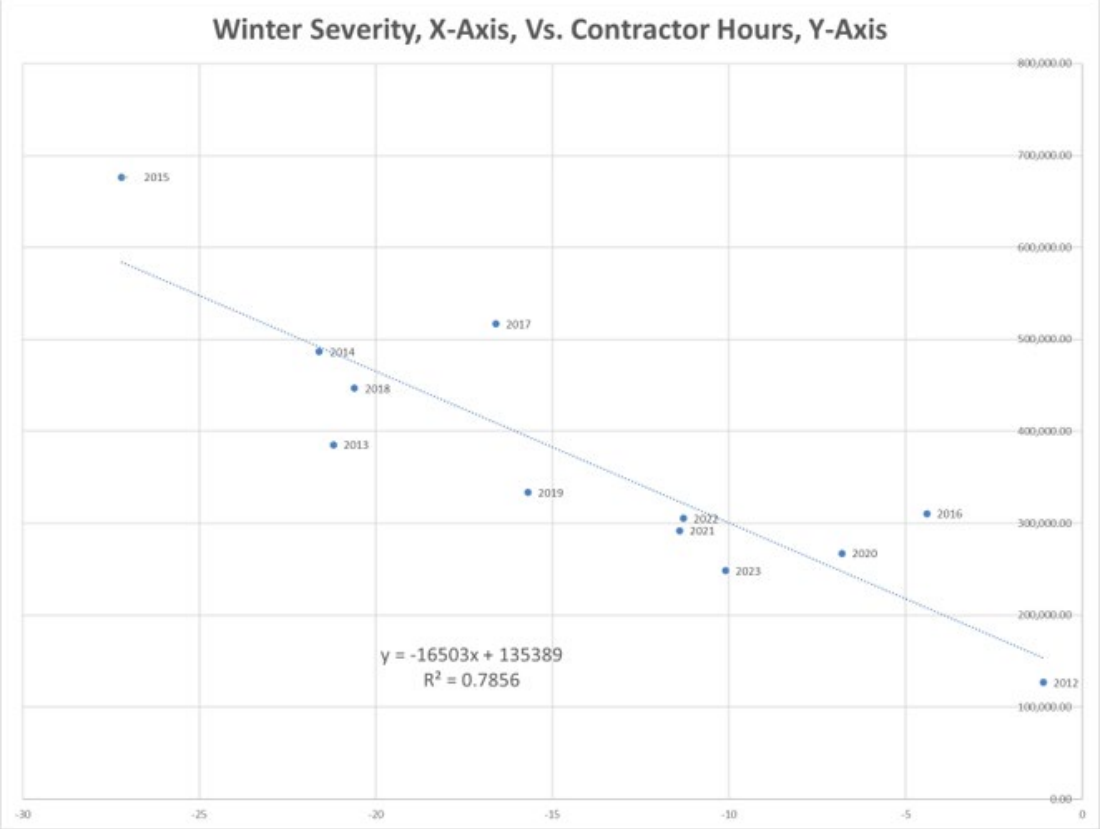


Figure 10. Massachusetts documented the correlation between annual winter severity and contractor hours. (Source: Massachusetts DOT)

4.4 New Hampshire

At the Phase I initial workshop, New Hampshire DOT participants presented their current activities to measure performance. New Hampshire's Snow and Ice Policy drives all winter weather decisions. Once precipitation accumulation exceeds one inch per hour, more measures are taken in response. Like other States, plow cycle time is based on the classification level of the road. The targeted time to recovery is based on a travel time cycle, but this is done informally. New Hampshire has a seasonal severity index that is used for winter seasons defined from November to March and has used a system for at least twenty years to keep track of costs for each event. New Hampshire mentioned that their snow and ice approach is trying to equitably balance the three-legged stool between budget, safety/mobility, and environmental impact.

New Hampshire has a good handle on outputs of winter weather response (e.g., salt used, miles plowed), but would like to make progress on measuring the level of services and return to posted speed (note that New Hampshire DOT did not use return to normal speed in order to not measure effectiveness on anything above the posted speed). Salt usage has been tracked for over eighty years, so the state will keep tracking this data to show the continuous trend of decreasing salt usage. In terms of measuring outcomes, New Hampshire used the 'Idaho Performance Measure model' for two winter seasons and saw great outcomes. Unfortunately, this model requires significant manual data entry, which takes time that the state does not have. If there is a way to automate this process, New Hampshire would be interested in tailoring this to their state.

At the Phase I initial workshop, New Hampshire participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** New Hampshire would like to assess the use of friction as a measure of LOS if they could find a less labor-intensive way to pull in data. To use speeds in defining LOS, New Hampshire would also like to perform a 'truth test' to determine if probe-data based speed measurements and grip correlate using this winter. More broadly, New Hampshire proposed that because most of the states involved in workshop 1 are members of the Clear Roads Pooled Fund Study, to potentially propose a project to create an approach to collate probe-data based speeds for events. The data is there but it is a time-consuming and ad-hoc process to analyze it. If there were common ways to leverage agency-procured speed data to assess level of service, a lot of agencies would benefit. Once all data is pulled automatically into one system, a tool such as PowerBI could be leveraged to generate additional reports and show data trends. Other States expressed interest in supporting this Clear Roads effort.
- **PM 2 – Recovery Current and Potential Use.** New Hampshire is hesitant in providing a number for recovery time, but also recognizes that the snow and ice policy should be like the recovery and cycle time. Storm severity is another factor that plays into recovery time. Looking at the grip and travel speed would prove good data to tell a story on if there are adequate resources, if more could be done, or if there is a unique storm that comes through. New Hampshire wants to move towards recovery time through grip sensors, speed, or field observations. The State would also like to use speed to determine when a storm starts and ends, which will help them better track recovery time. New Hampshire is interested in pursuing methods using 'big data' and hopes to be able to automize processes to reduce the amount of manual effort required to get results. Another focus that New Hampshire expressed interest in was the ability to get a handle on how to measure storm severity.
- **PM 3 – Reliability Current and Potential Use.** New Hampshire is already using the RITIS to measure the TTI on freight corridors. Although this has not been provided for weather previously, it would be easy to gather the probe data to look at this performance measure.
- **PM 4a and 4b – Fatalities and Injuries Current and Potential Use.** Participants recognized the value of measuring fatalities and injuries but noted a significant lack of control over these measures, as they are influenced by a variety of factors including driver capabilities and awareness. New Hampshire State Police provide New Hampshire DOT information on the number of crashes every hour of a storm, but this data is not used in performance measurement for New Hampshire DOT.
- **PM 5 – Customer Satisfaction Current and Potential Use.** New Hampshire noted that they previously had a survey process, where they attended the county fair and asked customers how they would spend a dollar on the New Hampshire DOT programs. The snow and ice program at the DOT was at the top of the list for funding each year this survey was conducted.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** New Hampshire also has been tracking their use of salt annually with the use of a WSI to normalize the data. Using the WSI, a formula that provides the winter severity and the quantity of materials that should be used based on the severity, the state began to plot salt usage and the WSI, which can be seen below in Figure 11.

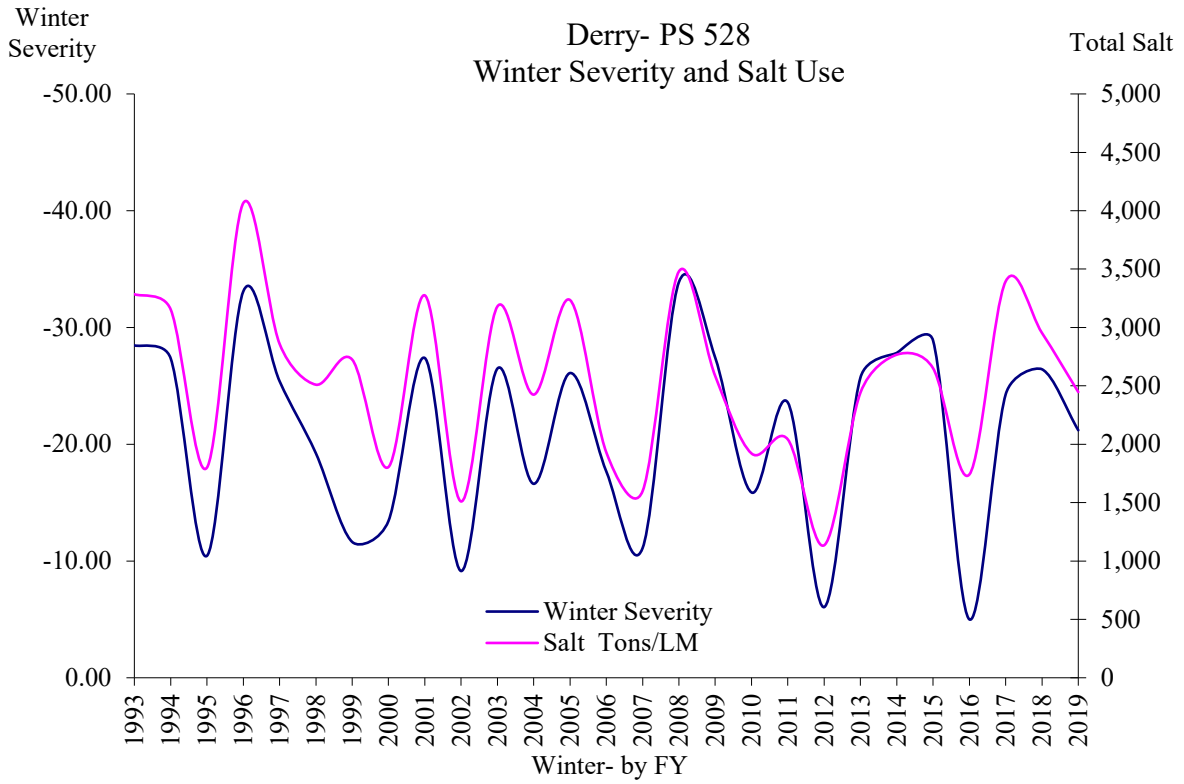


Figure 11. Weather Severity and Salt Usage in New Hampshire (FY = Fiscal Year) (Source: New Hampshire DOT)

Figure 11 demonstrates where a large ice storm occurred that caused a separation in the correlation between WSI and salt usage (i.e.,1998-1999 winter season). Unfortunately, in New Hampshire, the WSI does not take ice storms into account, which is why the ice storm caused the WSI and salt usage to not correlate. Overall, the graphic showing winter severity correlated with salt usage has shown that there has been an average of 20% reduction in salt usage over time.

Some of these focus areas were translated into actions for New Hampshire to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the Phase I follow-up workshop are presented in Table 7.

Table 7. New Hampshire DOT Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Actions for 2022-2023	Progress and Findings
Recovery and Level of Service	

• Identify a priority corridor to develop a standard report on level of services and recovery measures.
  ○ Define corridor boundaries.
  ○ Create a standardized report that pulls together speed, friction, and manual observations into the winter event timeline.
  ○ Report back on process followed and repeatability on other corridors and roads
	• Successfully leveraged third-party speed probe data to assess level of service.
	  ○ Two locations were selected along priority corridors for a study to develop a standard report on level of services and recovery measures.
	• Successfully defined a performance criterion during an event to be the goal of maintaining travel speeds at 70% of the posted speed limit.
	• No clear correlation was identified between grip and speed data, particularly after the first 1-2 storms of the winter season.
	• Regarding a "return to normal" performance measure, the "normal" speed in New Hampshire is higher than the speed limit and 70% of this value should be used to determine when "return to normal" is reached.
	• Next steps are to develop a business model, understand costs, and under what conditions (e.g., time of day, traffic volume) the performance measure may be most applicable

Reliability	
Check with RITIS to see if they can correlate reliability metrics with weather timelines to define storm start and end times	• New Hampshire ended up focusing more on speed and grip correlations and did not end up exploring the use of reliability metrics. However, New Hampshire has access to probe data which can generate these measures and correlate them to event timelines.

New Hampshire used road weather data and third-party speed data to graphically depict performance, as shown in Figure 12, Figure 13, Figure 14, and Figure 15 below. Because "normal" speeds in New Hampshire are higher than the speed limit, a performance goal of 70% of the speed limit (45 mph on freeways) was selected.

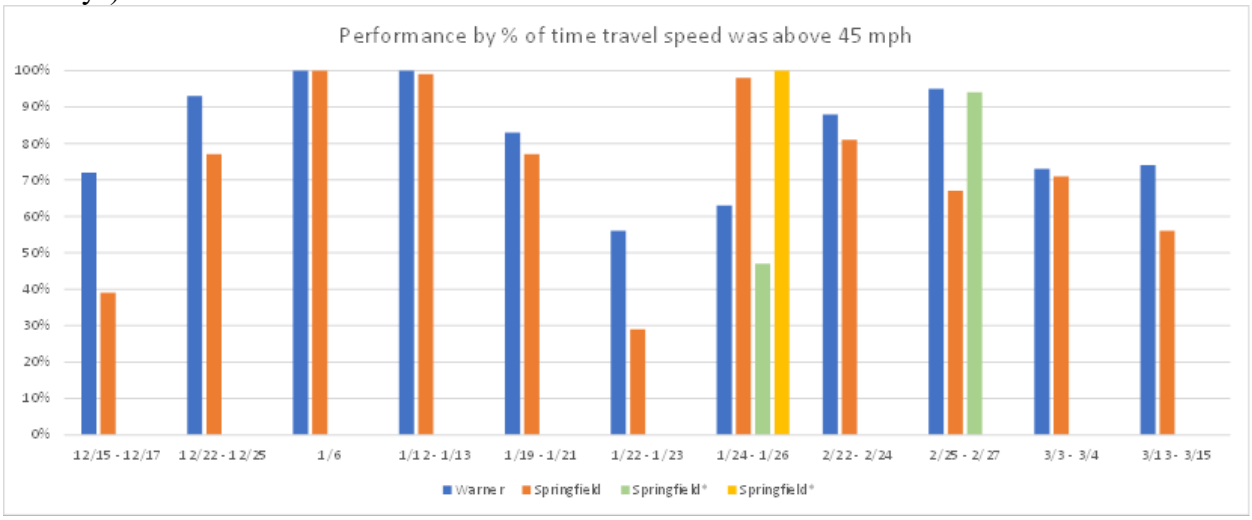


Figure 12. New Hampshire measured performance as a percentage of time that travel speeds were above the performance goal of 45 mph (which is 70% of the posted speed limit) at various locations during winter weather events during the winter season. (Source: New Hampshire DOT)

Figure 13. For a February winter weather event, New Hampshire depicted travel speeds against the speed limit and 45 mph performance goal. (Source: New Hampshire DOT)

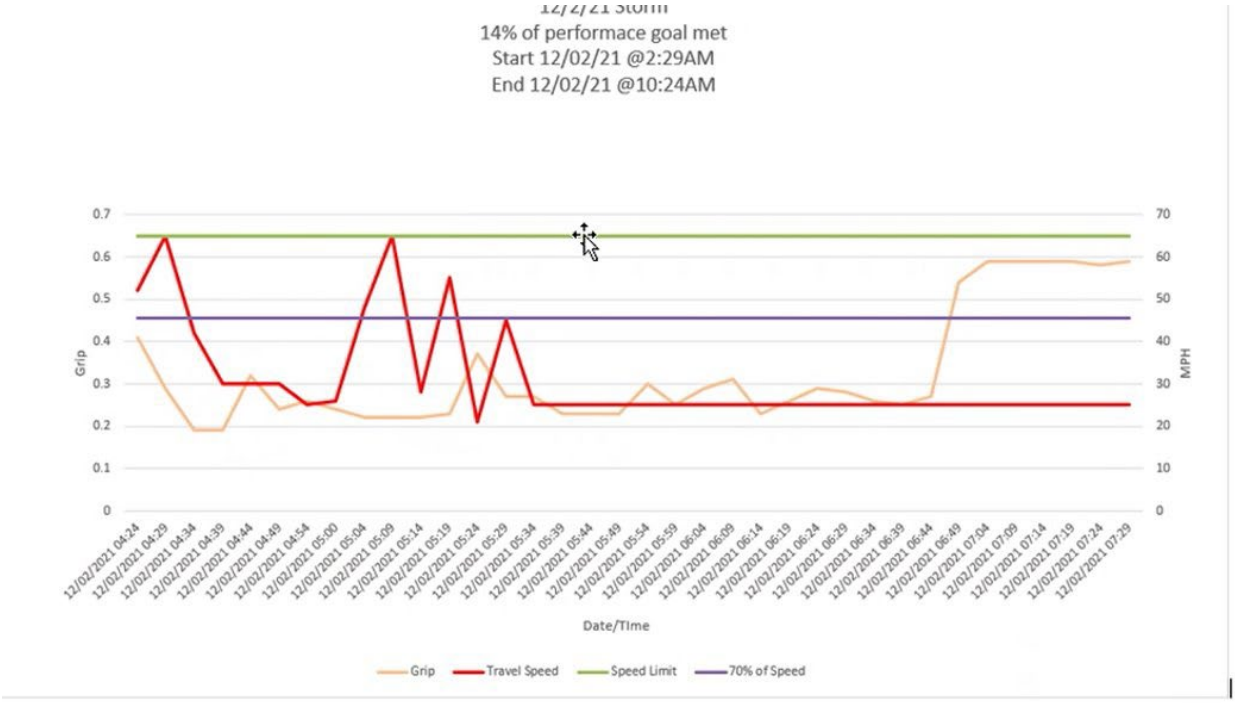


Figure 14. For this December winter weather event, New Hampshire graphed travel speed and grip alongside the speed limit and 45 mph performance goal; while grip does not appear to be correlated with travel speeds, it is possible that this is due to low traffic volumes at these times of day. (Source: New Hampshire DOT)

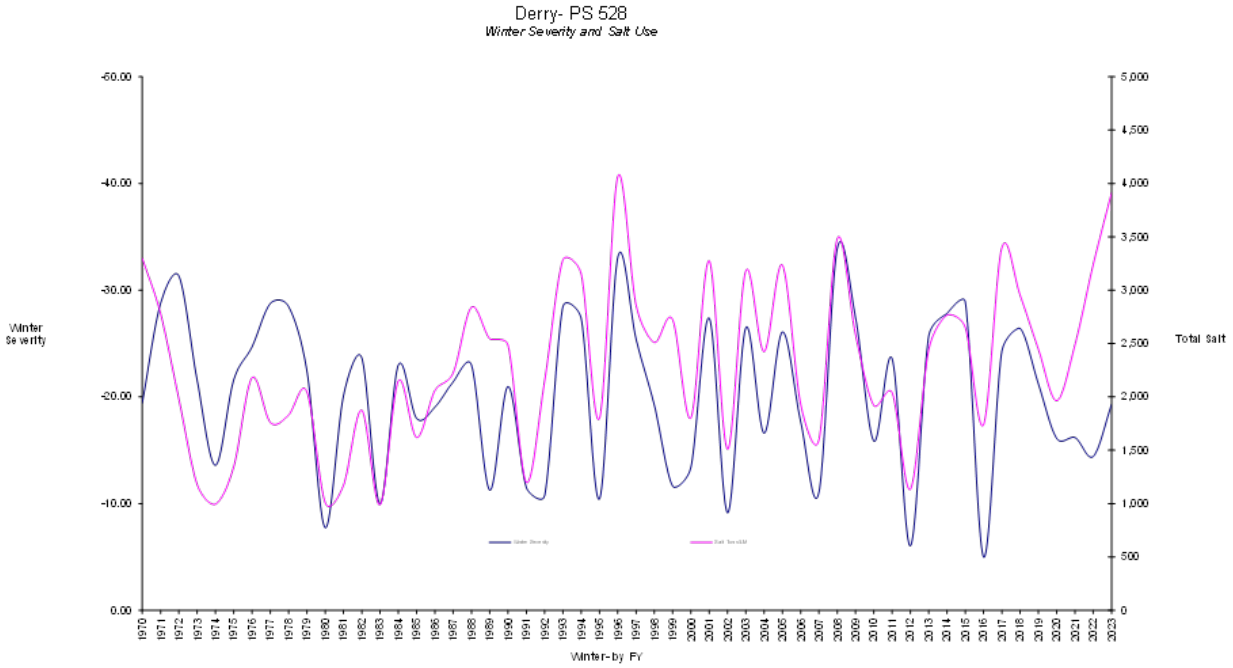


Figure 15. New Hampshire illustrated the year-by-year winter severity (blue) alongside salt use (pink) .(Source: New Hampshire DOT)

Figure 14 above represents the results of the comparison of speed data to pavement grip as an experiment to test the relationship between grip and travel speeds in order to understand if travel speeds could be a performance metric for grip. NHDOT spent considerable time assembling and comparing data following each winter event. To fully assess the relationship between traffic speed and pavement conditions (i.e., grip factor), a mostly automated process would need to be established to evaluate enough winter events in enough locations to fully understand this relationship. Figure 16 illustrates the flow of tasks NHDOT performed as well as a conceptual automated process to perform this assessment.

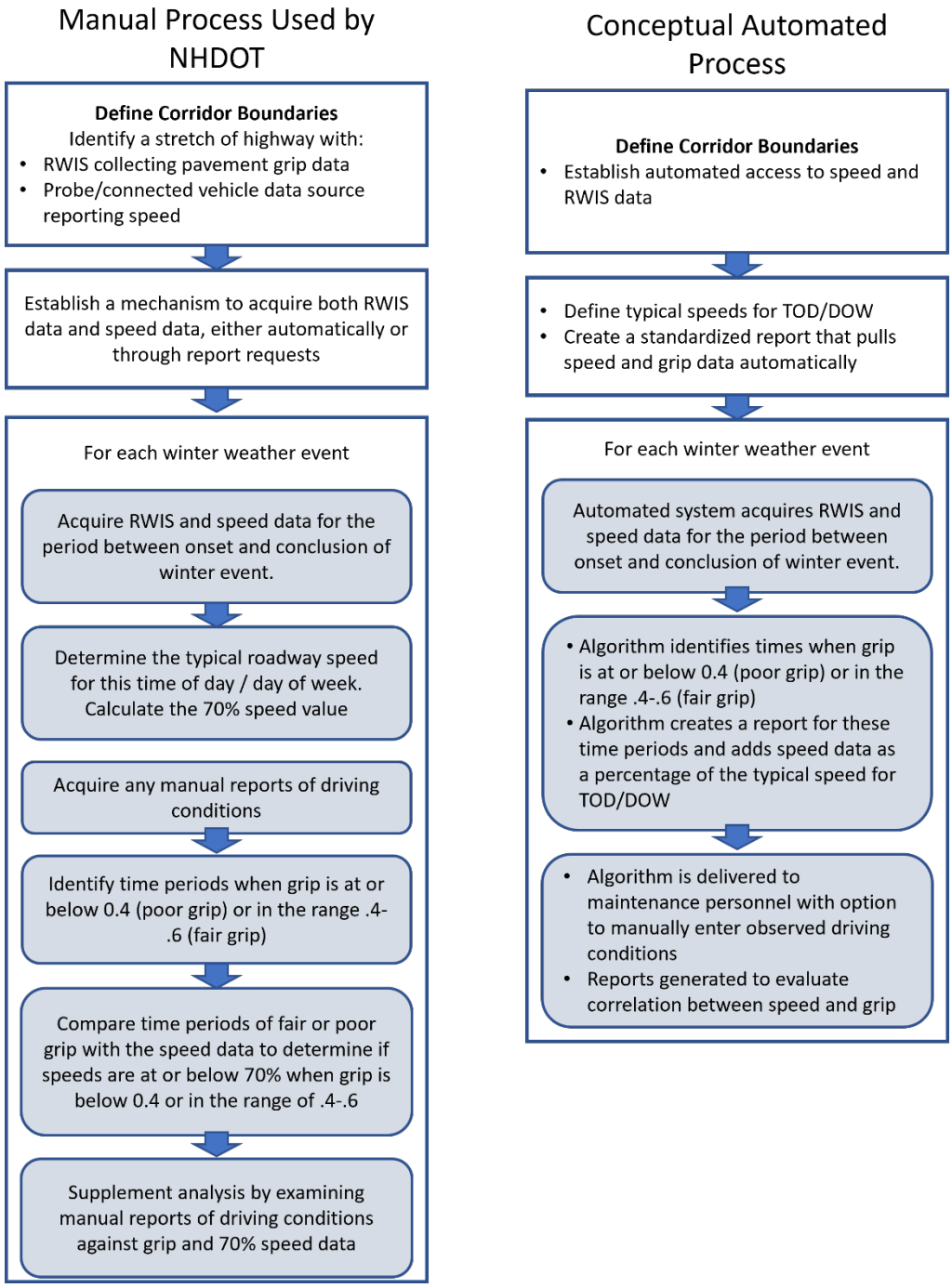


Figure 16. Flow chart depicting the manual process performed by New Hampshire DOT and conceptual alternate automated process to test the correlation between traffic speeds and pavement grip. (Source: New Hampshire DOT)

4.5 New York

At the Phase I initial workshop, New York State DOT participants presented their current activities to measure performance. New York operates on a regional basis, with ten snow and ice regions. Region 11 is New York City which is independently operated and maintained by the New York City Department of Sanitation and the New York City Department of Transportation. Cycle times vary based on the level of road, where interstates have the shortest cycle time. Unfortunately, given the reduced staff, cycle times on the lower priority roads are often doubled. New York does not have a target time for return to normal operations. Looking at the lake effect in the State, it would be hard to determine what a feasible time for resuming operations would be. New York also has insufficient staffing, so there would be significant pushback if the department established a timeframe for resuming normal operations. Not only would there be a lack of support from customers, but it would be difficult to determine what 'normal conditions' are for each different area.

There are Traffic Management Centers (TMCs) throughout the regions, and there is a Regional Operations Center (ROC) that is activated for large winter weather events. All events require reporting every two hours and this data rolls into the Statewide Traffic Information Integration Center (STIIC).

New York State DOT continues to invest in data collection from their snowplows. Forward facing cameras are being installed on snowplow trucks to provide additional data on road conditions. Air and road temperature are also available in trucks to gather data on conditions.

Given the diversity in weather across the state, it is difficult to define operational objectives. Long Island is an outlier and is often hard to staff for winter maintenance. The easiest way to assign personnel in Long Island is to keep trailers on the island until the storm is over. Other areas impacted by the lake effect have less predictable weather and are therefore harder to staff. To try and forecast weather, New York has two Mesonet weather stations installed in each county. The state has a contract with the University of New York at Albany that provides forecasting to help with predicting events. Another technology New York is looking into is artificial intelligence to process images from traffic cameras to determine road conditions.

At the Phase I initial workshop, New York participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** New York expressed interest in using friction as a predictor of roadway conditions, as speed is not always the best indicator of conditions in their state. There is often significant traffic volume behind snowplows, that when looking at speed data incorrectly describes the status of the roadways as covered. New York is also interested in looking at roadway segments in each region to determine the level of service. This would help address the abnormalities in conditions in areas such as Long Island versus areas impacted by the lake effect.
- **PM 2 – Recovery Current and Potential Use.** New York is interested in looking at defining specific criteria for road recovery times and capturing data on when they reach bare pavement on each type of roadway (desired versus actual recovery times). Instead of New York setting the same recovery times for all roads, they can set different time thresholds for various levels of roads, which could vary by Region within the State. Having access to this data would help justify additional resources needed like the need for more staff. New York is also interested in looking at the recovery time on weekdays versus weekends and tie this to when they should

have more staff on the roads. New York is looking at using artificial intelligence (AI) and traffic cameras to determine what the roadway conditions are.

- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use by State.** New York is working on a figure like New Hampshire but struggles with manual data entry. With manual data entry, errors can skew the data significantly. New York also does not have an established WSI.

Some of these were translated into actions for New York to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the Phase I follow-up workshop are presented in Table 8.

Table 8. New York State DOT Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Actions for 2022-2023	Progress and Findings
Recovery and Level of Service	
• Explore the potential for CCTV cameras and AI to be used in determining recovery time. • Work with University of New York Albany to develop a road weather dashboard that relies on National Performance Management Research Data Set (NPRMDS) data and maintenance data	• Successfully explored use of CCTV cameras for road condition reporting, and currently finalizing the algorithm to make it operational. o Camera images are taken every 5 minutes from 2400 sites. o Successfully worked with University of New York Albany where researchers develop AI algorithms to recognize camera images compared to human determined conditions. This "training" of the AI enables automated processing of camera images and determination of driving conditions. o The University of Albany is currently exploring the use of Mesonet data to supplement the image processing procedures and increase accuracy of the AI processes. o Next steps include integrating mobile cameras into operations and Agile MMS • Need to update the WSI using Mesonet data, since current WSI is based on limited data. • Need to emphasize the return on investment (RoI) in investments
Agency Efficiency and Environmental Stewardship	
Explore the use of automatic vehicle location (AVL) for automated reporting of material applications and plow activities.	• Successfully deployed Roadwatch sensors and AVL in plow trucks

New York worked with meteorologists at the University of New York at Albany as part of a project funded by the National Science Foundation to explore an artificial intelligence learning process that can be applied to real-world problems, specifically with a focus on using traffic cameras for automated detection of road conditions, as illustrated in Figure 17. Image snapshots taken every 5 minutes at 2400 camera sites are available to support this process. The project helped in labelling the data (i.e., telling the model what snowy or wet roads look like) and resulted in six total classes: severe snow, snow, wet, dry, poor visibility, or obstructed (i.e., conditions cannot be observed or identified).

Figure 17. Illustration of road conditions as viewed from traffic cameras. (Source: New York State DOT)

A "Codebook" was developed to define and set rules for labeling to ensure consistency, reproducibility, and trustworthiness. Additionally, New York State Mesonet was used for supplemental information to aid in the labeling process; for example, awareness of the number of days or hours since the previous precipitation can help the machine learning determine the label (i.e., if there has been no rain for 5 days, the label is most likely dry pavement). When the resulting process was tested on new images not used in training, the accuracy of output labels drops to about 72%. This emphasizes the need for a lot of data to train machine learning, and Mesonet has a lot more data that can be used in the future to improve outcomes and create new tools. A goal would be for the generated outputs to help inform road condition information that is currently presented on 511NY, shown in Figure 18.

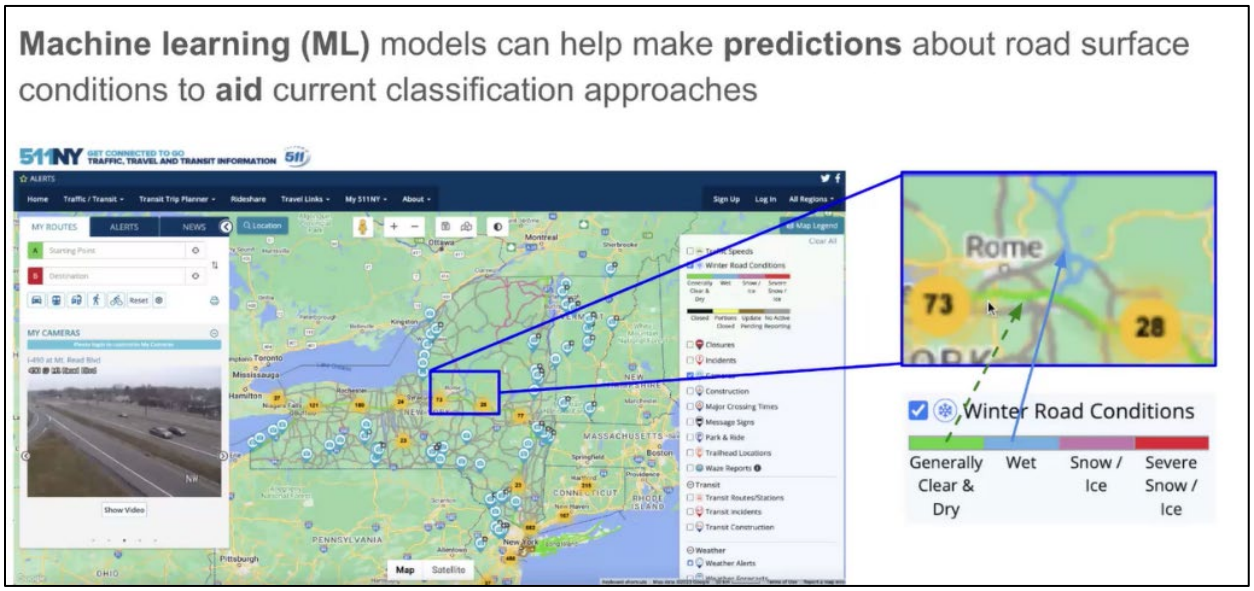


Figure 18. Illustration of road surface conditions presented on 511ny.org that can be supported by machine learning models. (Source: New York State DOT)

4.6 Vermont

At the Phase I initial workshop, Vermont participants presented their current activities to measure performance. Vermont also determines LOS based on the classification of roadway, with the highest level being interstate major collectors with a target recovery time of four hours. Roads that are classified as lower priority have a longer time in terms of goals for bare pavement, where some will not be cleared after 24 hours, although this is more anecdotal and not captured in any of the State documentation.

Vermont noted that customers will provide feedback if roadways are not cleared in a manner that meets customer expectations. The public also provides feedback on environmental factors such as the amount of salt used to treat the roadways. Unfortunately, the budget and environmental factors often go hand in hand, as more environmentally friendly options for treating the road are more expensive.

Vermont uses AWSSI to provide a data driven severity index that is used in conjunction with operations response labor hours and material usage to help determine the overall effectiveness of the response to an event. The use of AWSSI in Vermont helps to determine the relationship between severity of storm and resource usage. AWSSI does not have the capabilities to provide accurate information on events like freezing rain.

Vermont described a research effort conducted by the University of Vermont and published in 2019 entitled "Snow and Ice Control Performance Measurement: Comparing "Grip," Traffic Speed Distributions and Safety Outcomes During Winter Storms." This research compared a grip measure with the average distribution deviation measure used by the Vermont Transportation Agency, which measures changes in the distribution of vehicle speeds during and after winter weather events. The project concluded that the two measures were poorly correlated and, while independently useful, could not be used as a proxy for one another.

At the Phase I initial workshop, Vermont participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Vermont is also using grip sensors to measure friction. Currently, Vermont looks at their data on a shed or district-based level. They are interested in looking at specific segments and corridors to better tell a story on why the data is the way it is. Vermont would also like to pursue measures like those that Idaho established, focusing on data-driven quantitative input rather than subjective and qualitative input.
- **PM 2 – Recovery Current and Potential Use.** Vermont has expectations that high priority routes will be cleared as soon as possible, once the storm is over. Low volume routes may have one-third bare pavement the next working day after a storm. Vermont's goals are to never leave a lane unplowed and pour all resources necessary into a roadway to ensure that it is open as soon as possible. Garage supervisors in the state have an application on their phone that lets them know about the grip. Using this information and looking at the RWIS camera, they can deploy resources on an as needed basis. Vermont could potentially use this data to populate variable message boards with nearby road conditions, advising drivers to slow down. With the help of Vaisala's grip reporting, Vermont can request information on a storm including the number of days the storm impacted an area. Pulling this into PowerBI and removing the nighttime hours could be beneficial.
- **PM 4a and 4b – Fatalities and Injuries Current and Potential Use.** Participants recognized the value of measuring fatalities and injuries but noted a significant lack of control over these

measures, as they are influenced by a variety of factors including driver capabilities and awareness. Vermont compares the fatalities during the winter and summer and ends up seeing more fatalities and accidents in the summer months, so they are not interested in tracking this performance measure.

- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Vermont has the data to measure efficiency, however, due to shifts in specific resources used, they have not been able to measure the resources used in a consistent manner. In the 1980s, Vermont was using liquid calcium chloride, which would burn the snow off roadways and eat away at trucks. Since shifting to liquid magnesium chloride and liquid salt, Vermont has been able to look at best management practices and determine efficiency on a minor scale. One issue that Vermont presented was the inability to know how to recalibrate their system given a change in mixture.

Some of these were translated into actions for Vermont to pursue for the 2022-2023 winter season. These actions identified during the Phase I initial workshop and the findings shared during the Phase I follow-up workshop are presented in Table 9. Additionally, the Vermont winter maintenance dashboard is shown in Figure 19.

Table 9. Vermont Transportation Agency Actions for 2022-2023 Identified during the Phase I Initial Workshop and the Progress and Findings Shared during the Phase I Follow-Up Workshop for Each Related Performance Measure

Actions for 2022-2023	Progress and Findings
Recovery and Level of Service	
Translate Excel spreadsheet into a PowerBI dashboard to allow for easier calculations of service and recovery related measures	• Following the Phase I initial workshop, a big emphasis of the past year has been re-energizing an earlier initiated research project with the University of Vermont regarding return to normal speed: o After determining that travel speeds tend to NOT decrease as grip decreases until the first crash is observed, research focused back on grip factors and a clearer understanding that there is not one performance measure (or data metric) that provides sufficient information. • Successfully operate a robust and updated RWIS network that provides friction values that can be validated with a re-engineered grip factor. • Next steps include engaging University of Vermont and building more capabilities with event and storm severity into existing dashboards. • Need to translate research success into operational dashboards
Agency Efficiency and Environmental Stewardship	
Correlate AWSSI to salt use in an equation that can be used to project expected salt use and costs	• Successfully examined impacts of capital projects for snow and ice control • Need to reintroduce a winter performance index or winter severity index into operations (e.g., using costs or overtime hours) instead of an anecdotal approach

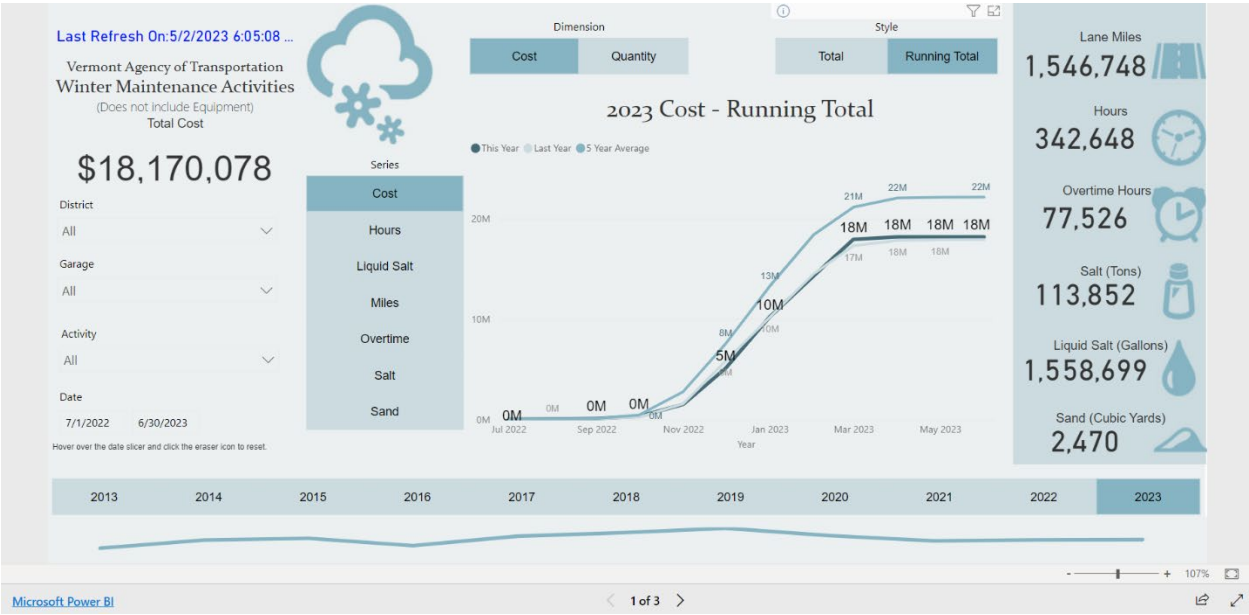


Figure 19. The Vermont Agency of Transportation dashboard of Winter Maintenance Activities. (Source: Vermont Agency of Transportation)

4.7 Arizona

At the Phase II initial workshop, Arizona participants presented their current activities to measure performance. Arizona defines start and end times of a winter event in terms of maintenance actions, beginning when plows and winter staff are responsive for an incoming storm and typically ending when staff return to their normal operations. Current performance measures for snow and ice control are based on Automatic Vehicle Location (AVL) and snowplows.

Arizona focuses on black and wet pavement, mostly on priority routes (based on Average Daily Traffic (ADT)), with Interstates always having the highest priority to stay black and wet. The LOS will change based on what storm is occurring, and the agency may opt to keep one lane open and expand from there. Arizona is not a chain law state.

Arizona has five priority routings, beginning with Interstates and then decreasing from there. The agency conducts road closures, mostly when they are shut by a crash. Arizona pre-stages equipment at possible closure points, and low-level roads have seasonal closures.

At the Phase II initial workshop, Arizona participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Arizona is interested in understanding event start/end times, using Vaisala reporting (Mass spreadsheet), increasing workflow automation (data to dashboard), conducting a RITIS demo (that other states, including Nevada, Oregon, and Wisconsin would like to join), and developing AVL performance measures.
- **PM 2 – Recovery Current and Potential Use.** Arizona acknowledged that there is a public perception of where speeds should be, but the maintenance perspective is that an event ends when the DOT stops treating. Arizona is interested in understanding event start/end times for tracking both recovery and LOS, as described above for LOS.

Some of these were translated into actions for Arizona to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 10. Additionally, a dashboard Arizona developed by overlaying speed, friction, and weather data to understand roadway performance is shown in Figure 20.

Table 10. Arizona DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Recovery and Level of Service	
• Begin LOS exploration, perhaps using RITIS for speed values (and other RITIS features). Participate in RITIS introduction, understand what is available, use small sample of North District (I-40) to test how well it works, and incorporate a RITIS dashboard. • Incorporate WSI into recovery time analysis, explore incorporating grip and speeds and AVL data together. Explore if AVL feed can be incorporated into RITIS as well. • Explore "After Action Reports" (AAR) from RITIS and can pull these into the AAR reports.	• Utilizing RWIS and RITIS data to establish a baseline for traffic speed recovery. o Wanted to establish data-based goals to better understand performance measures in the future. o Current measures include AVL-pre-wet, speeds, spinner speeds, road temps, and WSI/salt usage. Used the New Hampshire spreadsheet for WSI. o Manually created a table for time below to time above 50 mph. o Discovered anomalies where grip would dip down briefly, which helped identify bad sensors. o Identified value in viewing speed, friction, and weather data together for corridors and tracking them to adequately describe roadway performance. o Now exploring how to build intelligence and insights from this approach.

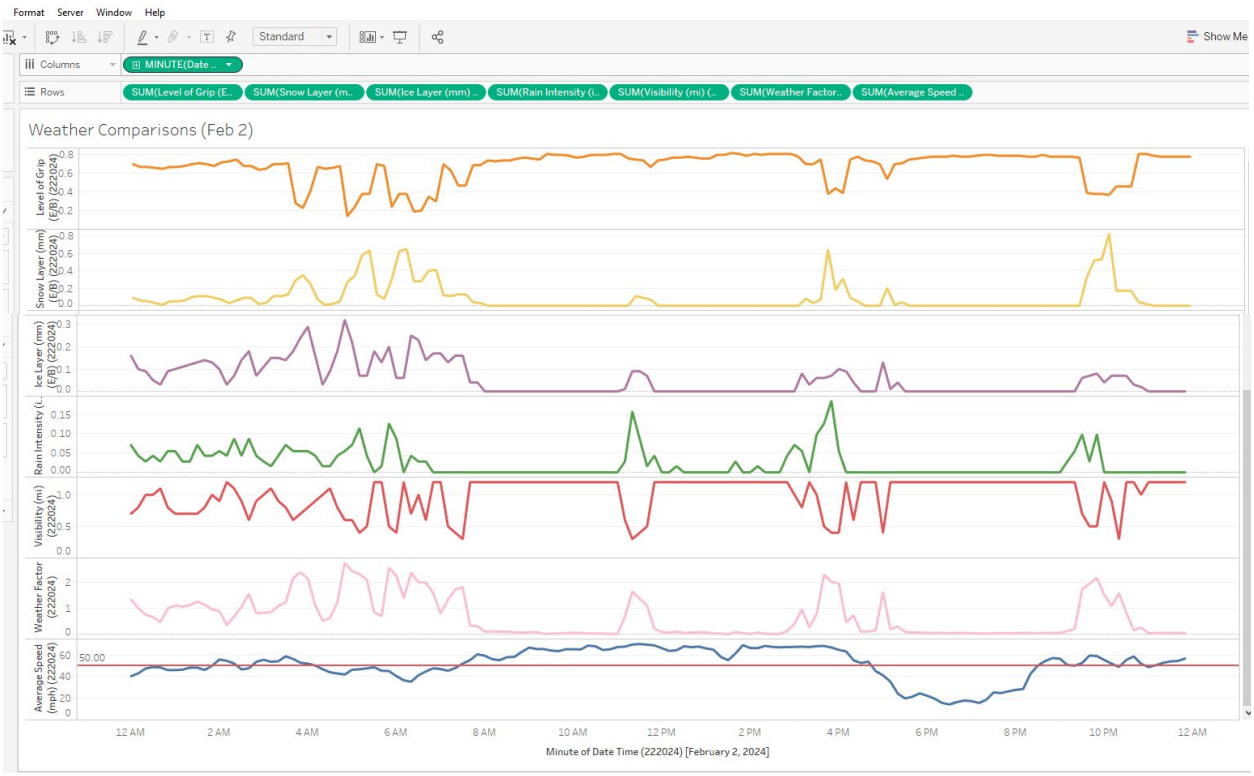


Figure 20. Arizona developed a performance measure by overlaying speed, friction, and weather data to understand roadway performance. (Source: Arizona DOT)

4.8 Iowa

At the Phase II initial workshop, Iowa participants presented their current activities to measure performance. Iowa defines a winter event in terms of start and end times based on when moisture starts impacting the pavement and ending when moisture stops building up on the pavement. However, "cleanup" may persist for days beyond the end of storm. Frost, refreeze, and blowing snow are considered storm event types, even though they are not "precipitation". Iowa also notes that times from crew out to crew in are tracked, but that is a different measurement from storm start/end.

Iowa's current performance measures for snow and ice control include:

- Time to normal driving, from end of event (requirement is 24 hours for A and B roads).
- Time to wheel path, from end of event (C Roads require wheel path bare in 24 hours).
- A salt target dashboard tracks salt use vs. expected salt use (target is <100%).

In Iowa, time to normal varies by District; there is some agreement regarding the frequency of plow cycles (e.g., Interstate every 90 minutes, other roads every 3 hours). For short storms, it is easier to meet expectations, but becomes unrealistic for long storms. Operational objectives are flexible based on the type and duration of storm (e.g., for the most severe storms, success may be not having to close roads). The goal for meeting performance for return to normal is 98% of storms, so if one storm is not met, the overall goal is not met. Philosophically, Iowa notes that as an agency, "We don't close roads, roads close themselves" due to incidents or the volume of snow. Iowa occasionally restricts towing operations in severe weather to prevent tow scene safety complications when roads are already very slick or visibility poor; these restrictions are put in place county by county, as needed.

At the Phase II initial workshop, Iowa participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Iowa may collect cycle time as a proxy for level of service.
- **PM 2 – Recovery Current and Potential Use.** Iowa would like to automate recovery calculations similar to how North Dakota does this.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Iowa will trial a storm index to help tell the story. After big events, the agency receives many inquiries about what happened and the budget status. For a "level 5" storm, the agency could articulate what is expected and then compare that with usage information as it becomes available. Seasonal severity is not really appropriate for this. Although the index is not a performance measure, Iowa notes it will support performance management. A storm index may also be able to estimate the "Tina Scale" of the storm (i.e., the time it occurs, what occurs, duration, etc.), and may help predict storm impact in advance.

Some of these were translated into actions for Iowa to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 11. Additionally, a winter event forecast index developed by Iowa that considers a variety of factors to predict the impact is shown in Figure 21.

Table 11. Iowa DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Level of Service	
• Consider collecting cycle time as a proxy for LOS by exploring Travel Map like Missouri: look at AVL capabilities. • Explore multi purposes: for field staff, LOS statistical analyses, and communication to the public.	• Considering collecting cycle time as a proxy for LOS by exploring Travel Map like Missouri.
Agency Efficiency	
Trial and initiate storm index development with a goal of using it this winter.	• Developing a new, predictive index to help forecast event impact as a communication tool to stakeholders (e.g., maintenance, supervisors, NWS, law enforcement) to help anticipate the effectiveness of planned or available snow response by comparing with previous weather events. o Considers statewide vs. regional impacts, accommodates holidays, first event for a season, rate of snow, wind, ice, sky cover after storm stops (e.g., if sunny the index number will erode quicker). o May help in planning meetings with State Police and others in advance of a weather event to understand the timing/duration of impacts (e.g., Troopers could better plan where to stage vehicles). o Currently with Information Technology (IT) department to implement access to Iowa DOT staff.
Recovery	
• Explore use of ATR speeds to automate recovery calculations (similar to North Dakota). • Possibly add expected speeds (due to weather) to the North Dakota algorithms to allow viewers to see how treatment improved travel.	• Beginning to explore use of ATR speeds to automate recovery calculations.

Storm	Category Unit	Code	Value	Notes
Snow Rate	<0.25/hr	A	1	snow_rate or snow total/hours
	0.25-0.5/hr.	B	2	
	0.5-1.5/hr.	C	3	
	1.5+	D	5	
Blowing/drifting pote	previous snow >3, winds >15	A	0.5	From previous rolling 24hr?
	previous snow >6, winds>25	B	1	
	previous snow > 10, winds >35	C	3	
	previous snow > 12, winds >45	D	5	
Non-snow Hours	Freezing drizzle/frz fog	A	2	precip_type/WS
	Freezing rain/sleet	B	4	
	Road Frost	C	0.5	
Rain start bonus	Per switch	A	2	precip_type/WS
Long Duration bonus	multiplier, after first 24	A	105%	
	multiplier, after first 48	B	115%	

Driver impact	Category Unit	Code	Value
Weighted miles	per mile, per hour	A	0.001
coverage bonus	50-75% garages	A	105%
	>75% impacted	B	110%

Events	Category Unit	Code	Value	
Major Holiday?	Per day, multiplier	A	140%	
Rush hour?	per hour multiplier	A	110%	
Seasonal Exposure	First/second event,	A	110%	manual?

Post storm Erosion	Category Unit	Code	Value	Notes
Pave Temps	30-32+	A	70%	XML/RWIS
	25-30	B	75%	
	17-25	C	80%	
	10 to 17	D	85%	
	0-10	E	90%	
	<0	F	95%	
Sun	Sunny	A	75%	In XML... AWOS?
	Light clouds	B	85%	
	Overcast	C	90%	
	Night	D	95%	

Figure 21. Iowa developed a winter event forecast index that considers a variety of factors to predict the impact, including the forecasted weather conditions (top), time of the event (bottom left), extent of the impact (center left), and post-event conditions (bottom right). (Source: Iowa DOT)

4.9 Minnesota

At the Phase II initial workshop, Minnesota participants presented their current activities to measure performance. In Minnesota, a winter event "begins" when labor, equipment and material (LEM) resources are first utilized, including pre-treating. An event "ends" when bare lane is achieved and maintained for 6 hours. If an event stops and restarts within 6 hours, it is a continuation of the initial event. Current performance measures for snow and ice control include:

- Road Salt Liquid/Solid Ratio (i.e., want it to be big)
- Percentage Frequency of Meeting Bare Lane
- Miles of Snow Fence

Minnesota DOT's primary objective is based on return to bare lane after a storm, with varying priority based on traffic volume. Bare lane is used as the proxy for that measure, and the agency would like to be able to use a return to travel speed measure instead. In the Metro area, Minnesota DOT works to keep high volume roads wet with bare lane 0-3 hours after storm, with the longest time

being 9-36 hours on low volume roads. Operationally, the agency sometimes uses a mantra of "Get one wheel path open".

Coverage in metro and major freeways is 24 hours, but lower volume roads may not be treated overnight. Additionally, events do not get cancelled and road closures do not happen in the Twin Cities Metro Area, except when incidents occur. Minnesota DOT is the only state agency that may close a highway, except for incidents when the Minnesota State Patrol can also close the highway. Minnesota DOT's mission is to "maintain a safe, reliable, transportation system". Currently, the agency uses "lag" measures but is also looking at "lead" measures. For example: how much brine/liquid is being applied to the road to prepare for storms (ratio of liquid to solid). There are indications that increased liquid is showing positive results. Minnesota, Iowa, South Dakota, and Nebraska all conduct a pre-winter coordination call to discuss actions to prepare for storms and to reopen/recover from storms.

At the Phase II initial workshop, Minnesota DOT participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Minnesota is interested in moving to GeoTab to track cycle times as part of AVL implementation. Most of the program is based on cycle times. External conditions like a jack-knifed semi-truck impacts this, so it is more variable than is desired.
- **PM 2 – Recovery Current and Potential Use.** Minnesota would like to switch to an automated way to measure recovery (possibly speed vs. bare pavement).
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Minnesota noted that using more liquid is leading to better utilization of salt. While the transition to liquid as a measure is currently only shared seasonally, the agency would like to have this measure available on a monthly basis; this measure does not make sense for each event.

Some of these were translated into actions for Minnesota to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 12. Additionally, Minnesota DOT uses dashboards to display winter severity and measures for snow and ice clearance and public satisfaction are shown in Figure 22 and Figure 23. Measures that Minnesota calculates for brine-salt ratio for gallons of liquid brine used versus tons of salt are depicted in Figure 24 and Figure 25.

Table 12. Minnesota DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Level of Service	
Explore implementing GeoTab reporting similar to Missouri to track cycle times in the metro area (different reseller than Missouri GeoTab). Possibly look at speed data available in the metro area to potentially help the switch from bare lane to speed maintained. Note: through Federal Highway Administration (FHWA) there is a group of AVL users regardless of reseller. Ask GeoTab contact about "Citizen Insight" add-on.	• Examining cycle times for internal performance measure for management and planning. o Planning to investigate implementing something similar to the Missouri DOT dashboard to have data more easily accessible.
Recovery	

Consider a switch to automated way of recovery (possibly speed vs. bare pavement). Explore modeling an approach off the North Dakota product to track speeds at selected locations and compare to start/end storms from MDSS. Further understand if/what the role of automation plays for removing subjectivity.	• Developing a new measure based on return to travel speed (RTTS).
	  o Learned how North Dakota effectively uses ATR speed data, which is an underutilized data source but provides good enough information to generate a clear statewide picture of what is happening without a need for probe data.
	  o Learned from observing Missouri's dashboard.
	  o Use available MDSS, NWS, and RWIS weather data.
	• Use available ATR, WIM, RWIS, and probe (Iteris) speed data.

Agency Efficiency and Environmental Stewardship	

Continue to encourage transition to liquid application over salt, as well as other innovative practices.	• The performance measure for liquid to solid ratio remains effective.
	  o Rose from 54 gallons per ton to 85 gallons per ton over the season, with some Districts >100 gallons per ton.
	  o Using brine may save up to 30% of salt than if salt alone were used, resulting in a cost savings that can be calculated.
	  o Plans to determine environmental effect regarding lakes and salt run off given lower salt usage when brine is used instead; potential national significance to demonstrate environmental impacts.
	• Continue nature-based solutions like paying farmers to not harvest several rows of corn or place haybales adjacent to highway to be a temporary snow fence –potential long-term performance implications and can predict benefits of snow fence by the number of miles.

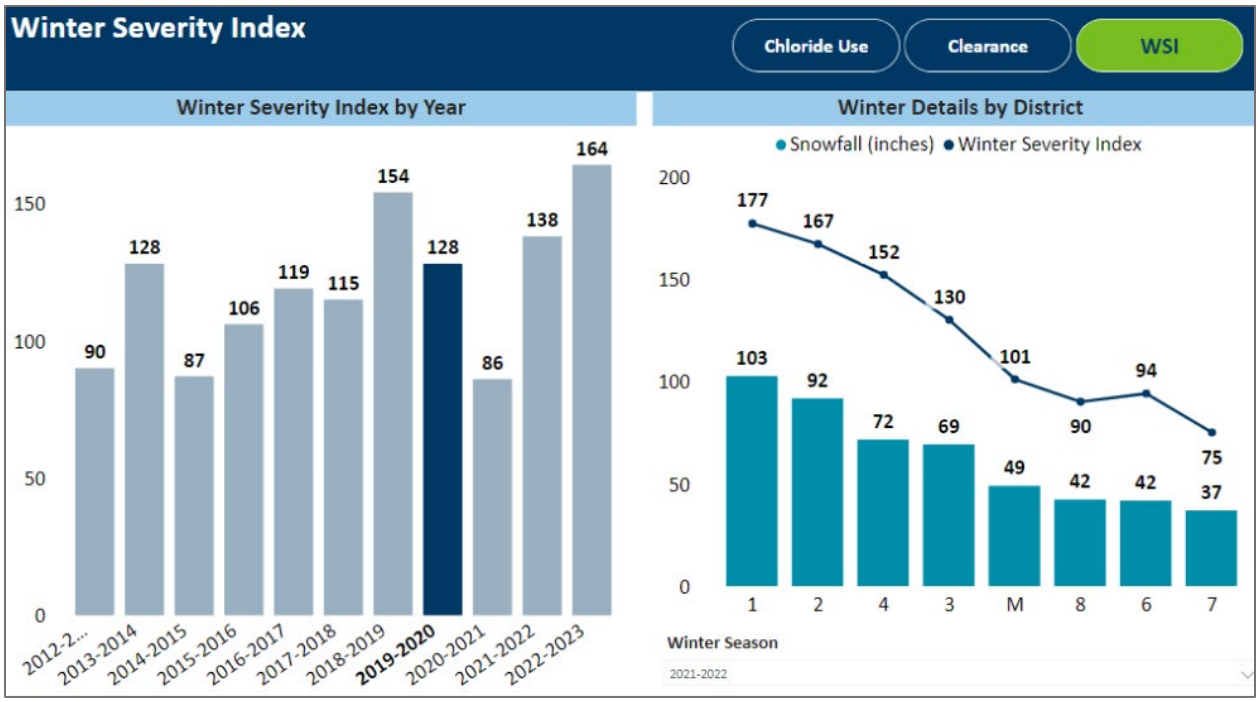


Figure 22. Minnesota uses a dashboard that displays winter severity index by year for the state and by District, as well as snowfall amounts for each winter season. (Source: Minnesota DOT)

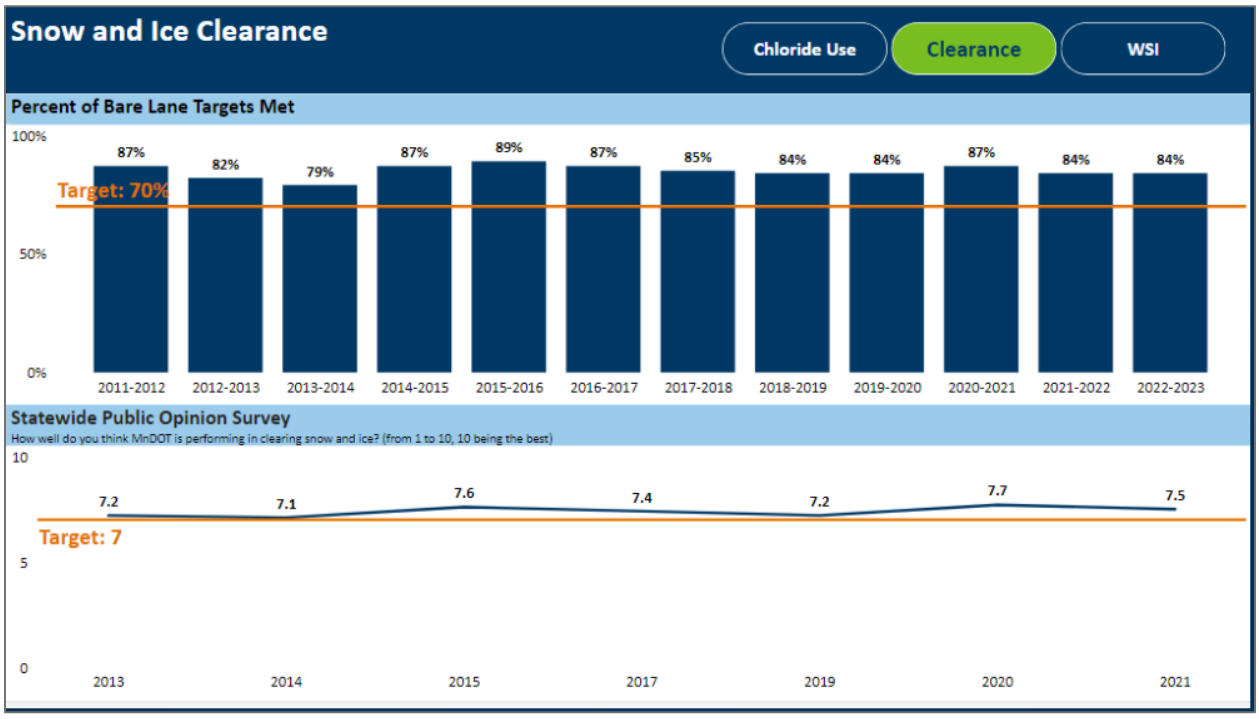


Figure 23. Minnesota uses a dashboard that displays measures for snow and ice clearance based on percent of bare lane targets met and public opinion surveys for each year. (Source: Minnesota DOT)

Unit Of Measure Name	(All)					
Resource Name	(All)					
Sum of Gals / Ton	Column Labels					
Row Labels	2019	2020	2021	2022	2023	2024
D1-Duluth	15	14	32	32	44	91
D2-Bemidji	19	21	22	20	29	52
D3-Baxter	27	34	38	40	55	80
D4-Detroit Lakes	86	106	188	177	182	215
D6-Rochester	16	24	33	36	44	71
D7-Mankato	46	86	97	132	102	119
D8-Willmar	22	22	25	43	55	81
Metro District	12	14	16	19	28	61
Grand Total	23	31	41	43	54	85

Figure 24. Minnesota calculates a brine-salt ratio for each District based on the gallons of liquid brine used versus tons of salt. (Source: Minnesota DOT)

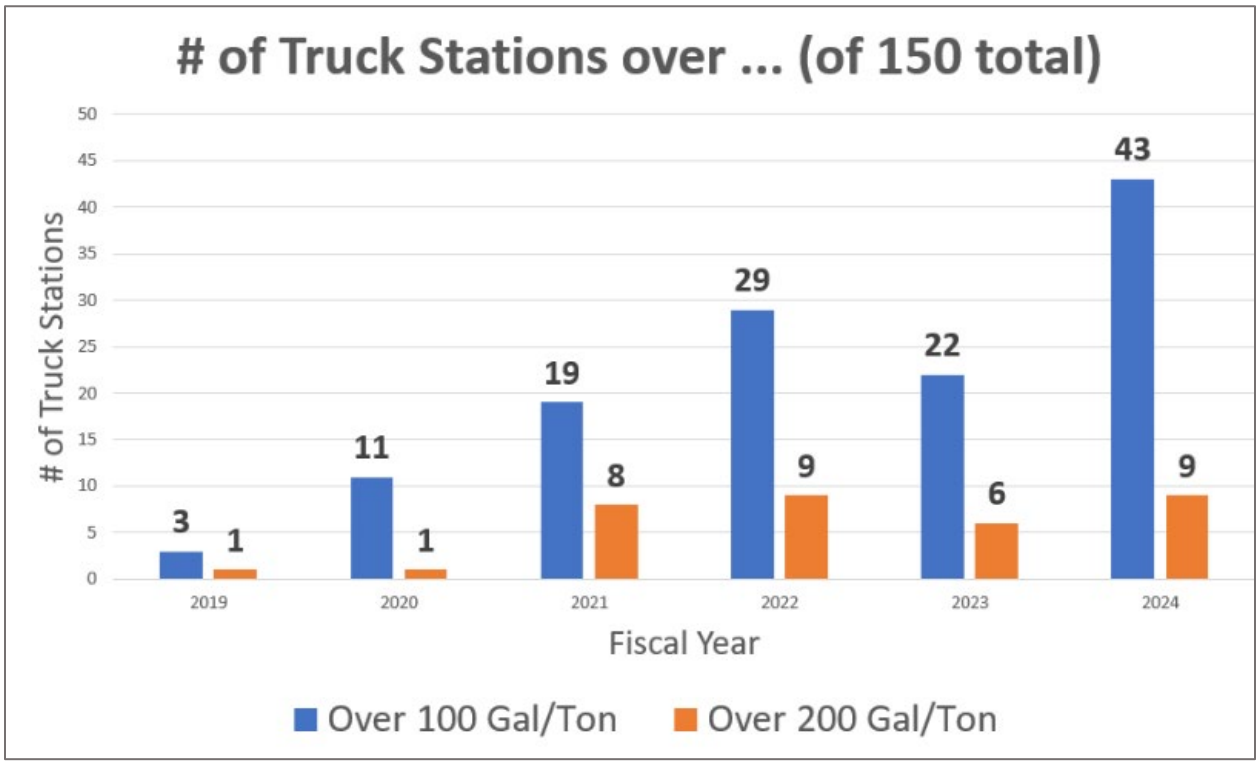


Figure 25. Minnesota calculates a brine-salt ratio for each District and truck station based on the gallons of liquid brine used versus tons of salt. (Source: Minnesota DOT)

4.10 Missouri

At the Phase II initial workshop, Missouri participants presented their current activities to measure performance. Missouri does not have an official definition of what constitutes a winter event. Instead, the DOT continuously monitors road conditions and updates these regularly on the DOT Traveler Information Map available on the agency website. Unofficially, Missouri defines a winter event as anytime roadways are impacted and the condition on the traveler information map changes

from "clear" to either: mostly clear, partly covered, covered or closed. The DOT then defines the end of the event as the time when roadways are returned back to a clear condition.

Missouri's current performance measure is the time to return a roadway back to a clear condition from end of precipitation. Times are not measured while precipitation is still falling, but is measured from when a storm ends. Missouri's Engineering Policy Guide for Snow and Ice Control Operations is available online. This Guide includes pictures of roadway conditions that show each of the defined roadway conditions: clear, mostly clear, partly covered and covered, as shown in Figure 26.

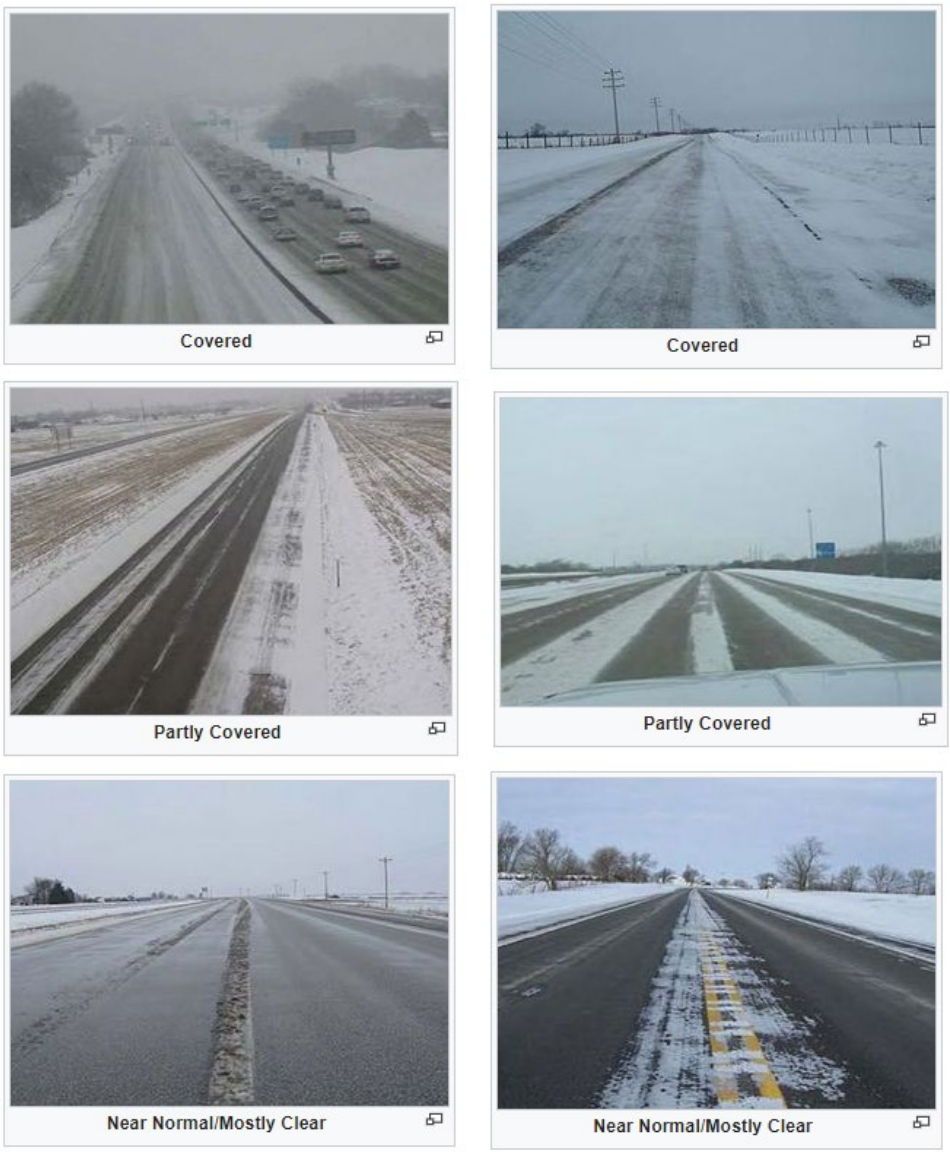


Figure 26. Images of Missouri DOT's defined roadway conditions. (Source: Missouri DOT)

Missouri noted a difference in overall operational objectives and LOS. The DOT's overall objective is to return to normal: there is not a stated time of these objectives, instead because all storms are different, the goal is as soon as possible and Level of Service ties in to this. For each storm, a 48 hour call forecast involving highway patrol is set up to discuss resources available, the need to shift resources, etc., to support messaging to media and talking points. These calls help to understand staffing available/challenges and how it relates to each storm.

Missouri focuses on routes that impact most travelers (i.e., continuous operations routes). The external agency objective is to educate the public and media to set and manage expectations (e.g., lower-level routes (400 and below) are non-continuous, but the main DOT focus is on continuous routes). The agency will try to get to other non-continuous routes and treat hills, corners, intersections but not attempt to get to normal until after priority 1 routes. The internal agency objective is to return to normal as soon as possible.

Additionally, transportation management centers (TMCs) in the Kansas City, St. Louis, and Springfield areas use dynamic message signs (DMS) to message "winter weather expected, be advised" to reduce the number of vehicles on the road as much as possible.

At the Phase II initial workshop, Missouri participants expressed interest in the following performance measures as focus areas:

- **PM 4a and 4b – Fatalities and Injuries Current and Potential Use.** Missouri will explore crash changes.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Missouri plans to continue development of a WSI using their Titan App.

Some of these were translated into actions for Missouri to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 13. Additionally, dashboards from the Titan App that Missouri are shown in Figure 27 and Figure 28.

Table 13. Missouri DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Agency Efficiency and Environmental Stewardship	
Continue development of WSI using Titan App. Explore University of Missouri report on crash changes. Work with Arizona and Kentucky who have advanced this.	• Developed the Titan app that includes a severity index which relates monetized impacts of a weather event on safety, mobility, and recovery costs. o Normalized statewide by county using biggest events and associated costs. o Dashboard shows average costs and can see geographic impact of individual events compared to baseline. o Costs include pre-treatment and other costs to the public incurred during the event even though an event start time is from the end of precipitation. o Working to make maintenance costs available in an API for closer to real-time analysis and to support implementation of "day after" action items for materials, safety, and level of service. • Exploring artificial intelligence (AI) functions on forward facing truck cameras to automatically capture road condition information (e.g., clear conditions).
Safety	
Explore University of Missouri report on crash changes.	• Included the monetized safety impacts in the Titan app severity index using crash costs. o Examined the change in number of crashes during an event using the number of crashes on a clear weather day within one week of the event as a baseline.

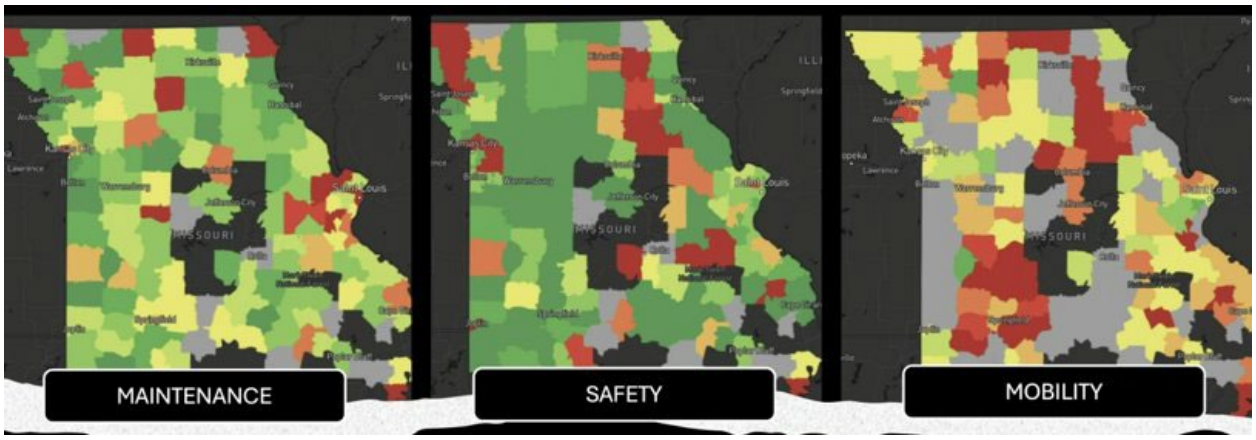


Figure 27. Missouri developed the Titan app which includes a severity index that generates monetized impacts of a weather event by county. (Source: Missouri DOT)

Figure 28. The Missouri Titan app includes a dashboard that shows impacts of a weather event by county. (Source: Missouri DOT)

4.11 Nevada

At the Phase II initial workshop, Nevada participants presented their current activities to measure performance. Nevada DOT does not have a formal definition of a winter weather event. Instead, all events are correlated to the impact on the road, or the action taken by maintenance. Weather would correlate to the reason for the event. For example, if a road is closed due to snow, the event would be labeled “Road Closure”, and the reason would be “Winter Weather Conditions”. All events are tracked in several systems including:

- *Spillman CAD* – Legal repository for event info, shared platform with Nevada State Police.
- *511* – Public Traveler Information, event record stored in the Nevada Data Exchange (NDEX).
- *Enterprise Asset Management System (EAMS)* – Maintenance activity log. Maintenance activities are assigned to crews and completed once completed.

- *Nevada Data Exchange (NDEX)* – Traffic Operations data base and archiving for all traffic records pertaining to event information and intelligent transportation system (ITS) device data.

Currently, Nevada DOT is furthest along with deployment of AVL and fleet telematics, which can measure the following:

- Lights
- Wiper Blades
- Plow Up/Down
- Spreader Rates (if calibrated correctly)
- Route/Path Frequency

Nevada DOT also has a large network of Road Weather Information Sensors (RWIS) that can measure a variety of information such as:

- Air Temperature
- Pavement Temperature
- Wind Speed and Direction
- Precipitation
- Humidity
- Barometric Pressure
- Visibility

In Nevada, route prioritization basis is not ADT; some lower volume need to be kept open for accessibility and continuous routes are continuously plowed until they reach black. Nevada implements chain controls that correspond with California (i.e., R1 – snow tires required; R2 – chains or four-wheel drive required; R3 – chains and four-wheel drive required but would typically close road). Each District has its own snow plan for how to prioritize and address a storm.

Nevada finds the largest benefit is providing the data to the National Weather Service (NWS), which then helps them provide DOT maintenance staff with more accurate weather predictions. Nevada DOT has even started formally working with NWS for new RWIS deployments so that they can provide input on sensor location for better readings.

At the Phase II initial workshop, Nevada participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** .
- **PM 2 – Recovery Current and Potential Use.** Nevada is interested in exploring recovery, perhaps starting with closures to measure how long it takes to advance from closed to open.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Nevada Districts already track costs for salt and labor, and headquarters would like to get this information from all three Districts to create trends. Additionally, Nevada would like to focus on how to make the most of AVL.

Some of these were translated into actions for Nevada to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 14. Additionally, Figure 29 shows the findings from Nevada's efforts to manually calculate a value for recovery time.

Table 14. Nevada DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Recovery	

Explore improving, starting with closures, how long it takes to advance from closed to open. During the meeting, explored technology / data options and was able to pull up ATRs, pulled up RWIS, showed 11 hours to return to normal. Will pick an ATR in urban area and ATR in rural area. Conduct analysis manually, show to management. Explore using Power BI to automate this.	• Successfully developed a measure for Recovery Time using available ATR and precipitation data.
	  ○ Compared events for average clearance time and grouping by severity using a severity index from the NWS.
	  ○ Significant work would be required to automate the process for continued monitoring of this performance measure and insights would be more useful as a dashboard to compare multiple routes at a time, see historical trends throughout the year, and trends from season to season.
	• Despite inconclusive insights from this experiment, the performance measure did prompt questions that would not have otherwise been asked, which demonstrates usefulness for telling a story to request funding or resources.

Agency Efficiency and Environmental Stewardship	
• Explore Headquarters pulling District costs for salt and labor to create trends. First step is getting all the data from all three Districts. • Focus on how to make most of AVL. Explore recently awarded AVL project to determine state of AVL, how data can be obtained, and what is possible. Share the Missouri DOT example of tracking the plow coverage internally (red/green map of where plows have been). Explore potential to implement similar.	• Still examining this for future winter seasons.

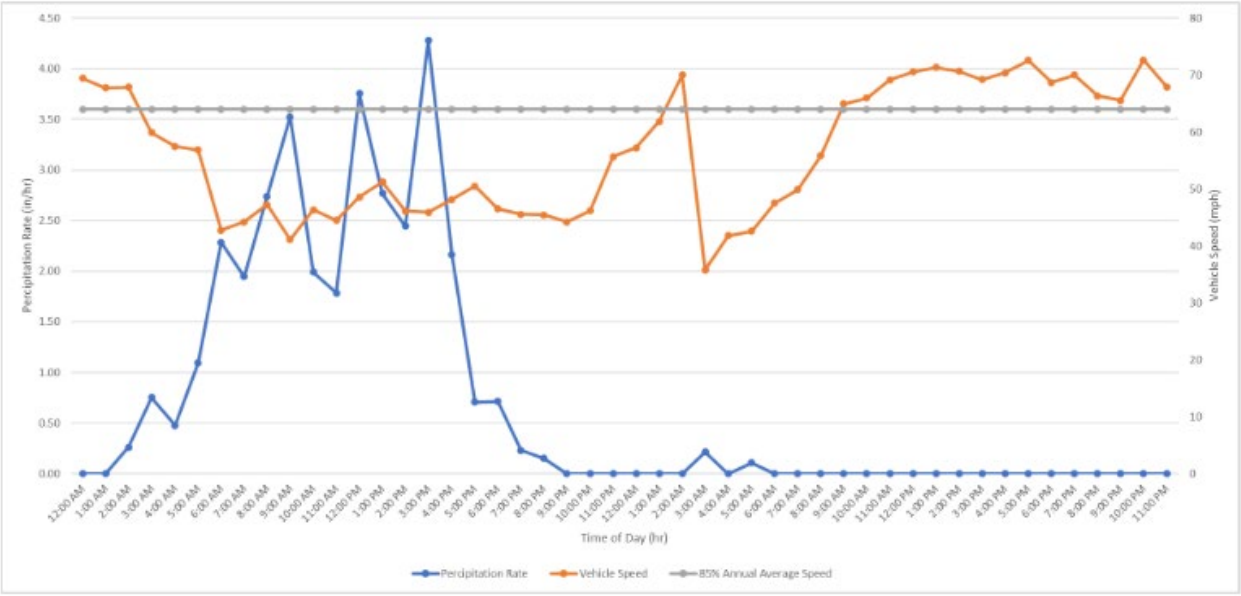


Figure 29. Nevada normalized data to hourly averages in Excel and manually calculated a value for recovery time. (Source: Nevada DOT)

4.12 North Dakota

At the Phase II initial workshop, North Dakota participants presented their current activities to measure performance. North Dakota uses a WSI from Clear Roads. The timeframes for the same areas are totaled to calculate a seasonal total; this is calculated from the MDSS. Winter Severity is calculated as:

- 0.50 x (average annual snowfall in inches) +
- 0.05 x (annual duration of snowfall in hours) +
- 0.05 x (annual duration of blowing snow in hours) +
- 0.10 x (annual duration of freezing rain in hours)

Current performance measures used in North Dakota, illustrated in Figure 30 and Figure 31, include:

- Speed Recovery: statewide average shown on public dashboards for a mix of roadway classes. This is calculated at 73 locations statewide, including 66 ATR and 7 ESS.
- Clear Roads Winter Severity Index: provides a measure of winter severity
- Snow and Ice Costs: monthly summaries are sent to all District administration and executive management. The agency is working to automate this measure.
- Snow and Ice Material Usage: monthly summaries are sent to all District administration and executive management.
- Hours Charged to Winter Maintenance (hours per lane mile): this is a measure of "work smarter not harder" and monthly summaries are sent to all District administration and executive management.
- Road closures: tracked by length, duration, and classification.

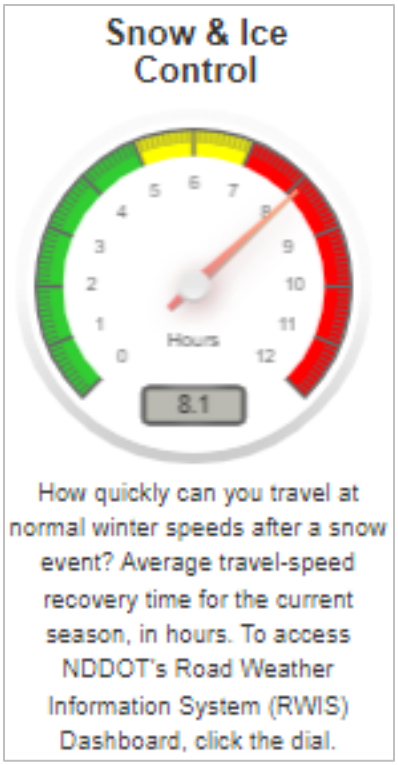
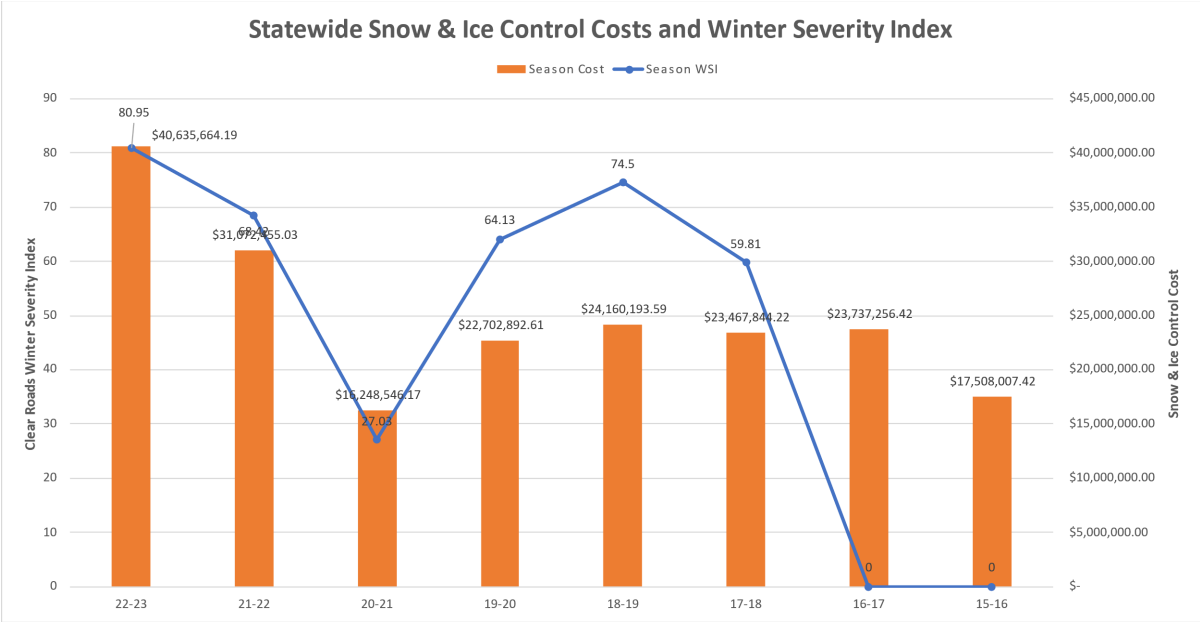


Figure 30. North Dakota dashboard. (Source: North Dakota DOT)



Notes on graph: North Dakota did not start using WSI until 2017-18 hence zeros under the two years. Axis scales for Seasonal WSI and costs are default and do not imply a strict correlation.

Figure 31. North Dakota snow and ice control costs and WSI. (Source: North Dakota DOT)

North Dakota uses six levels of service (e.g., ranging from 1 for "Metro" to 6 for low volume, two-lane roadways). The agency defines recovery time for all plowable snow (i.e., packed or ice can remain) removed after active event. These objectives are not tracked by the agency. North Dakota does not have 24 hours plow activities, but Fargo, Minot, and Bismarck have skeleton operations 24/7 with additional operators recently added to extend the hours of service in other communities.

Interstate closures happen every year, and the agency has gates that close. Closures remain in place until the agency can get out there to clear the roadway. The DOT can close a road anywhere anytime using barricades, and State Patrol can close a road for any emergency. Speed recovery has been examined using speed sensors.

Storm events are defined by the criteria shown in Figure 32.

Storm Trigger Requirements:

NDDOT Storm Category.	Description	Precipitation	Duration	Wind Speed
1	Snow Accumulation	≥ 2"	All	All
2	Freezing Rain	All	All	All
3	High Winds	≥ Trace	≥ 2 hours	≥ 35 mph

- When weather conditions meet at least one of the above three Storm Categories, the weather event is to be considered a storm.

Storm Expiration Requirements:

NDDOT Storm Category.	Description	Precipitation	Duration	Wind Speed
1	Snow Accumulation	< Trace	All	< 35 mph
2	Freezing Rain		All	
3	High Winds		All	

- When weather conditions meet all three of the above Storm Categories the storm is to be considered finished (meeting all Precipitation, Duration and Wind Speed requirements).

Figure 32. North Dakota criteria for defining storm events. (Source: North Dakota DOT)

At the Phase II initial workshop, North Dakota participants expressed interest in exploring various performance measures:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Potential exploration of friction and speed relationships.
- **PM 2 – Recovery Current and Potential Use.** North Dakota has been and planned to continue to explore friction and speed relationships for recovery and LOS analyses building from their existing dashboards.
- **PM 4a and 4b – Fatalities and Injuries Current and Potential Use.** North Dakota will examine fatalities alongside winter severity, as well as crashes as a substitution for fatalities.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** North Dakota is measuring labor costs for winter maintenance already, both with and without labor. North Dakota would like to pursue snow fences and implementing Minnesota's liquid to solid ratio performance measure.

Some of these were translated into actions for North Dakota during the Phase II follow-up workshop to pursue for the 2023-2024 winter season. Specifically these actions were to develop measures with speed as an indicator for recovery time automate storm start/stop criteria, and integrate speeds from ATR, non-intrusive speed detection, and WIMs for recovery and level of service; implement Minnesota's brine vs. salt ratio performance measure, continue automation efforts, and explore cumulative severity calculations for agency efficiency and environmental stewardship; and examine fatalities/crashes vs. winter severity as a reliable substitution for fatalities for safety. These actions and the findings shared are presented in Table 15.

Additionally, North Dakota uses a cost-tracking tool to monitor snow and ice control costs, including labor costs, as shown in Figure 33 and Figure 34. Year-over-year winter severity and cost tracking help in assessing and improving performance, as depicted in Figure 35 and Figure 36.

In conclusion, North Dakota's performance measures provide comprehensive insights into winter maintenance operations, focusing on recovery times, agency efficiency, and environmental stewardship. The integration of speed and friction data, coupled with measures such as the brine-salt ratio, helps optimize resource use and improve overall service levels during winter events. The ongoing implementation and exploration of these measures aim to enhance the efficiency and effectiveness of North Dakota DOT's winter maintenance strategies.

Table 15. North Dakota DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

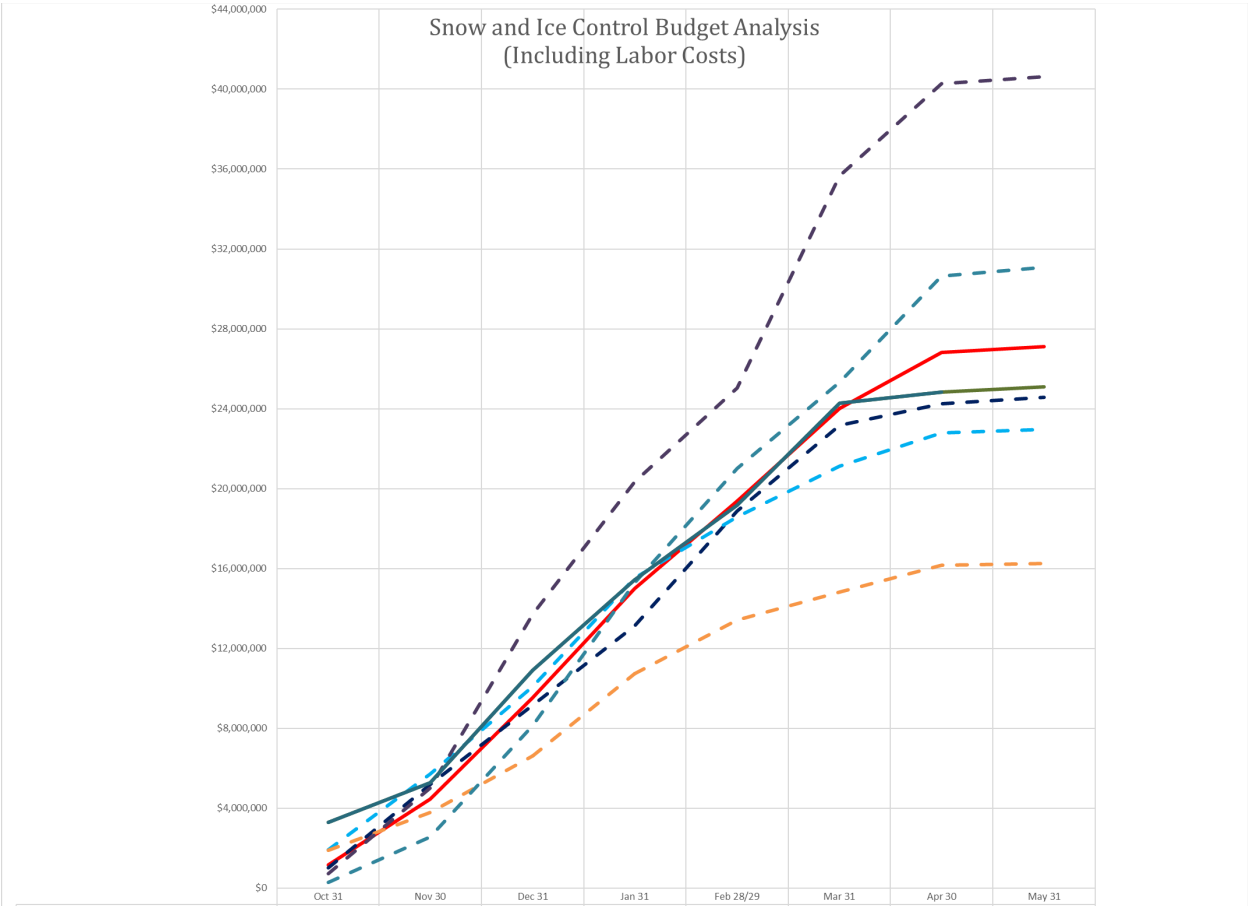
Actions for 2023-2024	Progress and Findings
Recovery and Level of Service	

For friction and speed relationships, explore further automating the friction portion to do a comparison (two graphs now). Explore the option of calculating recovery time with this.	• Develop measure with Speed as an indicator for Recovery Time.
	  ○ Procuring AVL to use Iowa's performance measure.
	  ○ Use MDSS to automate start/stop of storm with select criteria.
	  ○ Get speeds from ATR, non-intrusive speed detection, and WIMs all into tool.
	  ○ Friction included given uncertainty that speed recovery would be adequate.
	  ○ Public likely would understand speed better than friction.

Agency Efficiency and Environmental Stewardship	
• Explore salt liquid/solid ratio (frequency of comparison, etc.). Have the data, will explore options for assembling and analyzing. Note: Minnesota showed benefits in small trial, then had to make a paradigm shift in storage, production, trucks etc. • Explore cumulative severity calculations based on Iowa (and Iowa "how to"). • Explore output related performance measures to include costs.	• Continuing to implement automation. • Working with North Dakota State University to work toward AI solutions. • Working to implement Minnesota brine vs. salt ratio performance measure in order to use less salt and achieve cost savings.
Safety	
Explore fatalities/crashes vs. winter severity as a substitution for fatalities. How reliable is the crash data (based on check boxes).	• Still examining this for future winter seasons.

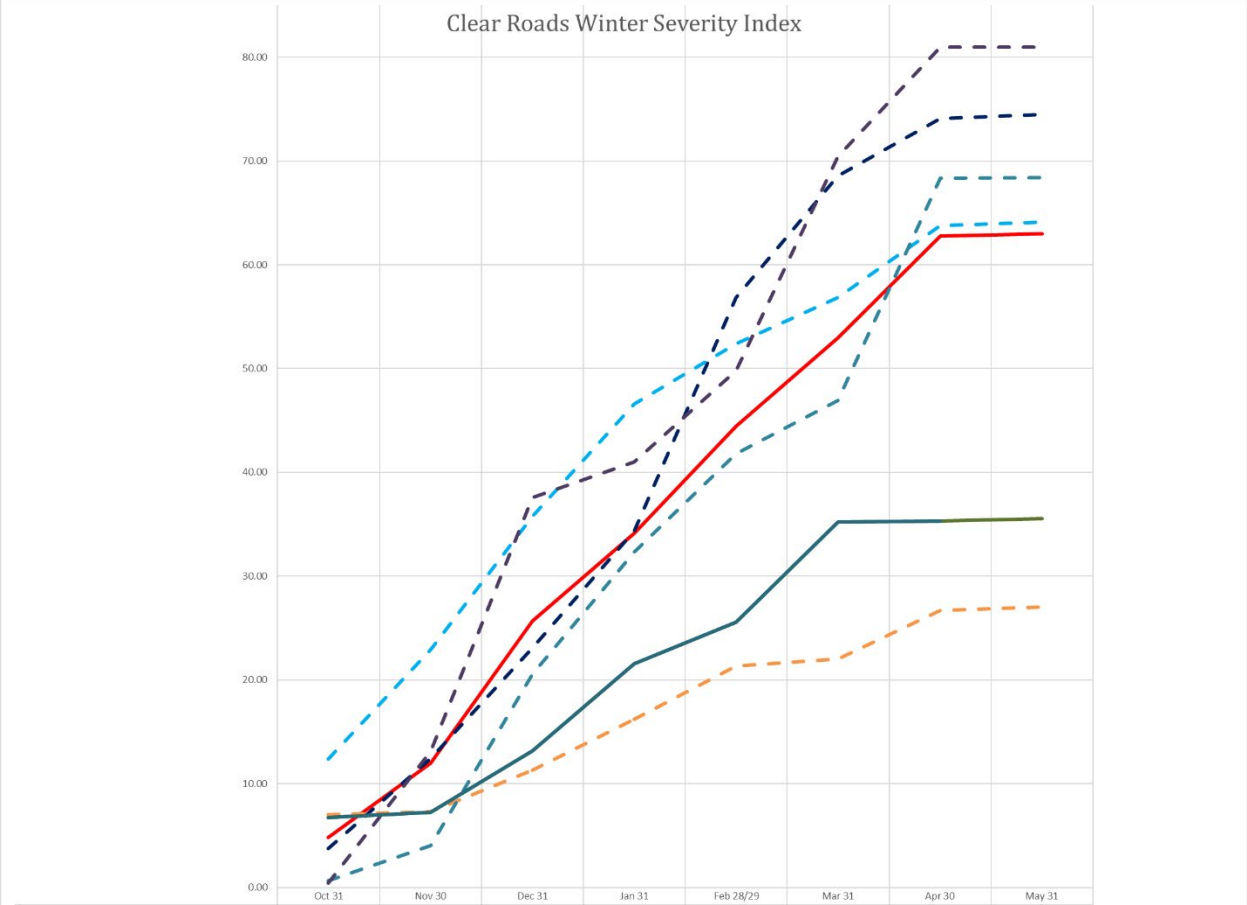
	Expenditures	Biennium to Date Spent	Total Available Budget	% of Budget Used
801110	*Salaries and Wages*			
512010	Shift Differential	$130,326	$412,000	32%
513005	Temporary Salaries	$48,675	$205,038	24%
514005	Overtime	$1,711,579	$3,187,492	54%
	Salaries and Wages - Sub Total	**$1,890,579**	**$3,804,530**	**50%**
80130	*Operating Expenses*			
521045	Motor/ Aircraft Pool	$6,729,375	$16,960,489	40%
521046	Motor Pool Replacement Exp	$2,142,240	$3,490,361	61%
534180	Salt	$6,863,041	$9,000,000	76%
534181	Anti-Icing Chemical	$1,551,914	$2,000,000	78%
534185	Sand	$155,914	$1,100,000	14%
	Operating Expenses - Sub Total	**$17,442,483**	**$32,550,850**	**54%**
	Expenditures - Total	**$19,333,063**	**$36,355,380**	**53%**
	Budget Remaining - Total		**$17,022,317**	

Figure 33. North Dakota uses a cost-tracking tool. (Source: North Dakota DOT)



	Oct 31	Nov 30	Dec 31	Jan 31	Feb 28/29	Mar 31	Apr 30	May 31
Running 5 Year Average	$1,166,702	$4,443,812	$9,541,256	$15,006,254	$19,382,057	$24,020,266	$26,827,274	$27,099,165
2018-2019	$1,019,141	$5,184,912	$9,149,463	$13,134,427	$18,872,545	$23,155,143	$24,259,967	$24,571,203
2019-2020	$1,931,047	$5,698,081	$10,081,646	$15,516,793	$18,577,472	$21,125,960	$22,786,062	$22,967,955
2020-2021	$1,875,231	$3,784,278	$6,629,460	$10,738,831	$13,427,027	$14,813,745	$16,174,442	$16,248,546
2021-2022	$294,876	$2,551,135	$8,133,804	$15,297,862	$21,007,654	$25,339,942	$30,637,724	$31,072,455
2022-2023	$713,216	$5,000,656	$13,711,909	$20,343,354	$25,025,587	$35,666,538	$40,278,174	$40,635,664
Actual 23-24 Oct-May plus 5 year average winter	$3,281,114	$5,274,461	$10,895,438	$15,425,723	$19,167,651	$24,271,286	$24,827,967	$25,099,858
2023-2024	$3,281,114	$5,274,461	$10,895,438	$15,425,723	$19,167,651	$24,271,286	$24,827,967	

Figure 34. North Dakota tracks year-over-year snow and ice control budget costs with (and also without) labor costs by month. (Source: North Dakota DOT)



	Oct 31	Nov 30	Dec 31	Jan 31	Feb 28/29	Mar 31	Apr 30	May 31
Running 5 Year Average	4.86	11.97	25.67	34.12	44.42	52.95	62.77	63.01
2018-2019	3.77	12.46	23.11	34.38	56.84	68.54	74.09	74.50
2019-2020	12.37	22.92	35.77	46.61	52.37	56.82	63.77	64.13
2020-2021	7.05	7.31	11.32	16.24	21.32	22.04	26.68	27.03
2021-2022	0.66	4.02	20.57	32.35	41.78	46.90	68.34	68.42
2022-2023	0.43	13.14	37.57	41.02	49.81	70.43	80.95	80.95
Actual 23-24 Oct-May plus 5 year average winter	6.76	7.23	13.15	21.55	25.55	35.21	35.32	35.56
2023-2024	6.76	7.23	13.15	21.55	25.55	35.21	35.32	

Figure 35. North Dakota tracks year-over-year winter severity each month through the winter season. (Source: North Dakota DOT)

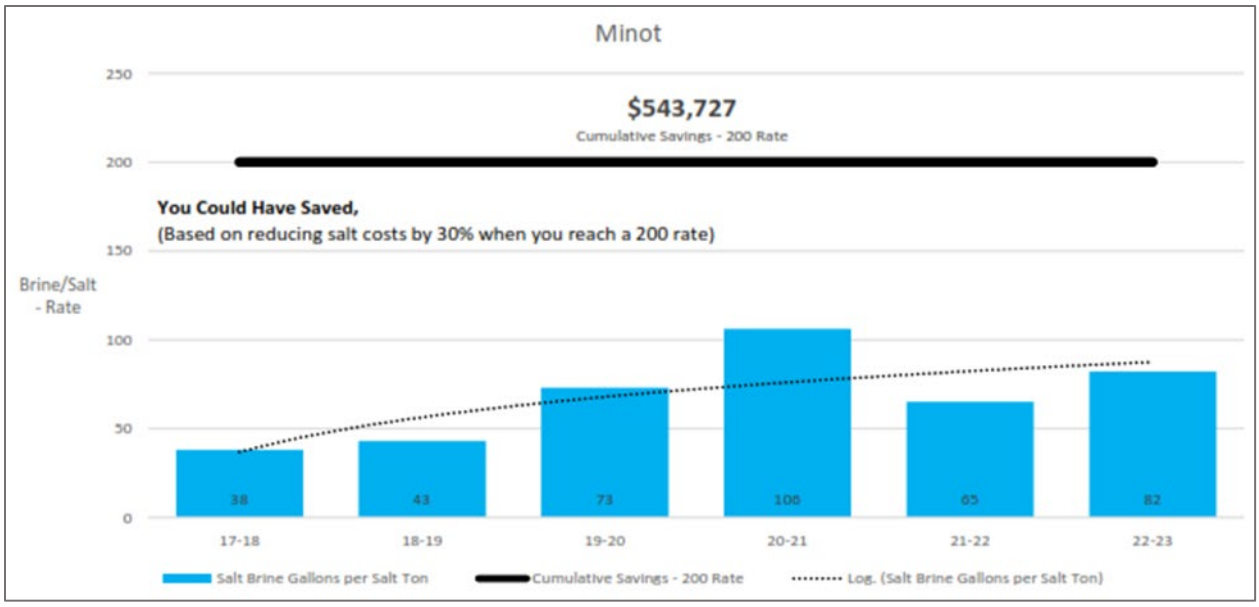


Figure 36. North Dakota calculates a brine-salt ratio for each District based on the gallons of liquid brine used versus tons of salt and generates a value of potential cost savings if more brine had been used. (Source: North Dakota DOT)

4.13 Oregon

At the Phase II initial workshop, Oregon participants presented their current activities to measure performance. The Oregon Department of Transportation does not have a definition for a winter event, or performance measures for snow and ice control. Instead, the agency relies on the defined levels of service and desired conditions. Specifically, Oregon has five defined LOS goals for level of effort and road expectations. For example, for LOS A: bare pavement is obtained as soon as practical and overtime is expected; for LOS B: bare pavement is obtained as soon as practical and overtime may be used. Other LOS see less overtime and a reduced goal for pavement condition. Oregon does have some seasonal closures.

At the Phase II initial workshop, Oregon participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Oregon already defines LOS for certain roads and what materials are used on those. The agency could examine if it is using those materials and could focus on areas with full telematics.
- **PM 2 – Recovery Current and Potential Use.** Oregon already defines LOS for certain roads and what materials are used on those. The agency could examine if recovery could be an additional measure used and explore various available data sources.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Oregon would like to examine a Winter Storm Severity Index (WSSI) by using RITIS to download and compile data to compute a WSSI. The agency could then possibly compare WSSI to overtime costs and material usage.

Some of these were translated into actions for Oregon to pursue for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 16.

Table 16. Oregon DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Recovery and Level of Service	
• Evaluate use of telematics to determine if meeting materials use goals and if statewide expansion might open opportunities. What are we getting from telematics? How can we use it? • Currently using PikAlerts. Explore how the data could be used for performance management: What data are we getting? Does it make sense and is it reliable? Are we saving it? How can it be used for storm severity? Review and consider Iowa's use of PikAlerts. Note: Iowa is attaching PikAlerts to crash reports (e.g., work zone with weather on top). Also, if PikAlert data shows worse conditions than perceived by staff, use that to send alert to supervisors. • Explore RITIS data available to Oregon and consider possible uses. • Explore what RWIS data is available and saved.	• Initiated a process to develop performance measures with available data that would be useful and tell a story. o Identified data gaps, which helped to strategize for how to examine historical winter events. o Identified a lot of available data, which is stored in different places and has not been comprehensively examined. o Identified benefits, challenges, and how data can be used. • Identified the need to pull data together in one place for a big picture view that can help to tell a story without asking multiple individuals to assemble data for each winter storm. o Focused on a segment on I-84 to examine road condition reports, resource allocation specific to LOS B, AVL/telematics data in Geotab, Pikalert, and RITIS data. o Next winter will be an opportunity to operationalize performance measure.
Agency Efficiency and Environmental Stewardship	
• For winter severity index, select one location/maintenance area. Explore salt use and liquid/solid ratio. • Research Arizona's approach to pre-wetting pavement. • Explore the weather severity approaches used in Iowa.	• Better understanding of what is available and how to proceed to improve processes and performance measurement in the future to move to a more performance-based operations approach.

4.14 Wisconsin

At the Phase II initial workshop, Wisconsin participants presented their current activities to measure performance. Wisconsin records the beginning and end of storm events based on the weekly report submitted by the patrol superintendent in each county. Current performance measures for snow and ice control include 'Percent of Bare/Wet Pavement'. This measure is based on 'Time to Bare/Wet Pavement', which is the time it takes from the end of the winter storm/precipitation until the roads return to the condition they were in before the storm. This number is reported under the 'Mobility' category with the title 'Winter Response'.

In Wisconsin, all state-maintained highways are divided into two categories of coverage, 18-hour roads and 24-hour roads. For segments belonging to the 18-hour category, winter maintenance crews are instructed not to perform winter maintenance activities between 10pm and 4am unless hazardous conditions warrant, while for segments belonging to the 24-hour category, maintenance crew can be assigned to work around the clock, as needed, during a winter storm event.

Wisconsin designated two different time frame expectations for the two coverage categories. 18-hour roads are expected to be cleared within six hours after the end of a storm, while 24-hour roads are expected to be cleared within four hours after the end of a storm. All counties in the state are assigned to one of two groups. One group of counties reports and declares the time it took for them to achieve

bare/wet pavement status on all their 18-hour roads only, while the other group of counties reports and declares the time it took for them to achieve bare/wet pavement status on all their 24-hour roads only.

Percent of bare/wet pavement is the percentage of time to achieve bare/wet pavement declared by the counties within the designated time frame. A target of 70% is set. For all the counties in the 24-hour group, if the counties declared the roads as bare/wet within four hours, 70% of the time, then winter maintenance meets the target. With the same rule, if the counties in the 18-hour group declared the roads as bare/wet within six hours, 70% of the time, then winter maintenance meets the target.

The primary concerns with this approach are that it is difficult to understand. This is caused by the multiple layers of measure, based initially on self-reported and subjective data, and that the 70% is a target instead of a threshold value.

A key difference compared to the other States is the role of the counties versus the State. The DOT hires all 72 counties to do winter maintenance; the counties decide how to do it (e.g., brine vs. salt). Some internal measures (not shared with the public) include comparing brine/salt use per lane miles between counties normalized by WSI. Finally, counties (and the state) use MDSS (Maintenance Decision Support System), which was purchased for the counties to leverage.

At the Phase II initial workshop, Wisconsin participants expressed interest in the following performance measures as focus areas:

- **PM 1 – Level of Service (LOS) During Event Current and Potential Use.** Wisconsin may more deeply explore MDSS capabilities to understand what other weather data may be available. For example, the agency may remove subjective data of end time of storm and calculate when trucks report to home base as a less subjective measure (drivers do make a decision of when to come back); Wisconsin will look at numbers to see if this makes sense. Wisconsin would also like to examine dashboards like North Dakota uses.
- **PM 2 – Recovery Current and Potential Use.** Wisconsin may more deeply explore MDSS capabilities as described in PM1 to understand what other weather data may be available to remove subjective data of end time of storm and calculate when trucks report to home base, for instance. Likewise, Wisconsin wants to examine dashboards like North Dakota uses and modernize their databases used for material reporting from the countries.
- **PM 6 – Agency Efficiency and PM 7 – Environmental Stewardship Current and Potential Use.** Wisconsin has other measures (e.g., total lane costs, maintenance costs), and would like to add the liquid to solid ratio as a new performance measure, potentially going back several years.

Some of these were translated into actions for the 2023-2024 winter season. These actions identified during the Phase II initial workshop and the findings shared during the Phase II follow-up workshop are presented in Table 17. Wisconsin developed a list of potential ATR sites with RWIS nearby to better understand event impacts on traffic flow (Figure 37) and examined data that allow staff to better understand event traffic impacts (Figure 38). Additionally, Wisconsin developed a dashboard mock-up to better understand event impacts by specific location as shown in Figure 39. Figure 40 illustrates how Wisconsin uses a 70% target for bare-wet conditions after winter storm events for 18- and 24-hour roadways, which is not to be exceeded (i.e., potentially utilizing more resources and higher costs than necessary) or underperformed (i.e., need to utilize more resources to improve road conditions). Finally, Figure 41 illustrates how Wisconsin tracks winter severity by county, and tracks salt use, cost per lane mile, and the MDSS severity index.

Table 17. Wisconsin DOT Actions for 2023-2024 Identified during the Phase II Initial Workshop and the Progress and Findings Shared during the Phase II Follow-Up Workshop for Each Related Performance Measure

Actions for 2023-2024	Progress and Findings
Recovery and Level of Service	
• Explore MDSS and other weather data to better leverage available data like AVL data, storm data reported by counties. Explore a pilot in county. Start small with 1-2 measures/reports. • Explore MDSS and what North Dakota is doing with storm start/end times to remove subjective data for end time. • Look into RITIS to understand what is available in Wisconsin.	• Explored how to build on Mobility, Accountability, Preservation, Safety, Service as part of an ongoing project focused on setting performance measures, gathering relevant data, and communicating progress to the public. • Have target to achieve clear roads within 4-6 hours after events using "percent that bare-wet conditions are met after winter storm events" for 24- and 18-hour roads. • Use an MDSS formula for winter severity and calculate goal for clearance. • Started exploring how to take leverage multiple data sources that are already available: AVL, MDSS, RWIS, ATR, and storm data reported by counties. o Plan to correlate MDSS, AVL, and RWIS data to ATR data next winter. • Gained awareness of possibilities to improve in performance measures in potential new project. o Plan to explore use of MDSS data to mark the start/end of a storm next season. o Plan to explore automating data extraction in the next season.
Agency Efficiency and Environmental Stewardship	
Have other measures (e.g., total lane costs, maintenance costs), like the liquid to solid ratio as a measure. Maybe go back several years. Send the severity "how to".	• Piloted a new Storm Report database and dashboard that allows search by county name and geographic values to get faster understanding of event impacts and costs. o Has modernized data storage, is automated, and has more simplified report generation than the previous process. o Easier data access for analysis; available in cloud, but can download a files.

County	City	RWIS Site	RWIS Site Info	ATR Site	ATR Site Info	MDSS Route	MDSS Route Info
Waukesha	Pewaukee	101011	I-94 EB @ CTH F	670011	I-94 0.3 MI E OF CTH J - BUSSE RD	WI-906-1	I-94 CTH T to Milwaukee Co. line (Driving)
Dane	Monona	201087	USH 12/18 WB @ Monona Dr.	130639	USH 12/USH 18 1.0 MI E OF CTH BW	WI-3003-1	Beltline John Nolen Dr. to Stoughton Rd. (Driving)
Winnebago	Appleton	201086	I-41 @ STH 441 SB	706123	I-41 BTWN USH 10/STH 441 & CTH BB	WI-420-1	I-41 Breezewood Ln. to CTH BB (Driving)
Marathon	Wausau	101059	II-39 NB @ CTH N	370005	USH 51/STH 29 0.4 MI N OF CTH NN	WI-541-1	USH 51 No jct. Bus 51 to S jct. STH 29 (Driving)
St. Croix	Hudson	101039	I-94 WB @ St. Croix River	550006	I-94 W OF STH 35 NORTH	WI-01-1	I-94 St. Croix River to STH 35 (Driving)

Figure 37. Wisconsin developed a list of potential ATR sites with RWIS nearby to better understand event impacts on traffic flow. (Source: Wisconsin DOT)

Wisconsin DOT

Roadway Hourly Speed for 01/19/2024

Site names: 550006
County: St. Croix
Funct Class: Urban Interstate
Location: I-94 W OF STH 35 NORTH HUDSON TNSHP - HPMS

Seasonal Factor Grp: 5
Daily Factor Grp: 5
Axle Factor Grp: 5
Growth Factor Grp: 1

		0-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	TOTAL	AVG	MED	85%ile
01/19	00-01	2	0	0	0	0	0	10	12	31	88	159	181	77	12	3	575	69	70	75
	01-02	0	0	0	0	0	2	2	9	32	65	130	117	46	11	7	421	69	69	75
	02-03	2	0	0	2	0	2	3	10	18	77	114	102	53	13	4	400	69	69	76
	03-04	6	0	0	0	0	2	3	3	15	80	164	135	77	29	14	528	70	70	78
	04-05	7	0	0	0	1	0	1	14	28	123	258	263	135	53	12	895	70	70	77
	05-06	83	6	3	2	3	3	14	19	86	230	461	581	370	155	62	2,078	69	71	79
	06-07	218	11	6	8	3	7	31	72	185	500	710	826	548	184	105	3,414	66	70	78
	07-08	606	32	18	15	12	14	32	123	280	643	746	865	573	262	130	4,351	61	68	78
	08-09	458	25	11	10	7	14	35	102	279	592	942	1,001	568	149	35	4,228	62	68	76
	09-10	22	0	0	0	0	11	41	129	365	771	1,008	1,151	603	142	24	4,267	69	69	76
	10-11	8	0	0	0	5	2	52	149	367	739	1,150	1,116	506	85	13	4,192	68	68	75
	11-12	21	0	0	0	0	12	41	178	363	778	1,103	1,247	633	141	35	4,552	69	69	76
	12-13	10	3	0	1	1	11	36	153	371	799	1,158	1,425	814	163	27	4,972	69	70	77
	13-14	16	0	0	0	1	8	30	129	394	755	1,192	1,606	980	257	47	5,415	70	71	77
	14-15	11	1	0	0	2	6	29	159	464	894	1,253	1,731	1,151	310	56	6,067	70	71	78
	15-16	21	0	1	0	1	4	43	170	460	915	1,491	1,930	1,250	339	46	6,671	70	71	78
	16-17	23	3	0	0	1	2	28	210	573	975	1,458	1,937	1,264	333	53	6,880	70	70	77
	17-18	25	0	1	3	4	22	88	262	545	998	1,392	1,642	935	207	35	6,159	68	69	76
	18-19	29	0	0	1	1	16	61	198	331	613	1,068	1,290	636	129	32	4,405	69	69	76
	19-20	22	0	1	2	2	8	39	140	232	461	683	839	491	123	33	3,076	69	70	77
	20-21	30	0	1	0	1	8	28	97	178	356	523	664	398	91	27	2,402	69	70	77
	21-22	9	1	0	0	1	8	18	65	181	352	499	599	339	91	36	2,199	69	70	77
	22-23	25	2	0	2	1	2	9	70	106	241	342	408	227	45	13	1,493	68	69	76
	23-24	36	1	1	1	2	2	14	40	71	139	225	220	132	53	39	976	67	69	78
	Day	1,690	85	43	47	49	166	688	2,513	5,955	12,184	18,229	21,876	12,826	3,377	888	80,616	68	70	77

Figure 38. Wisconsin examined data that allow staff to better understand traffic impacts. (Source: Wisconsin DOT)

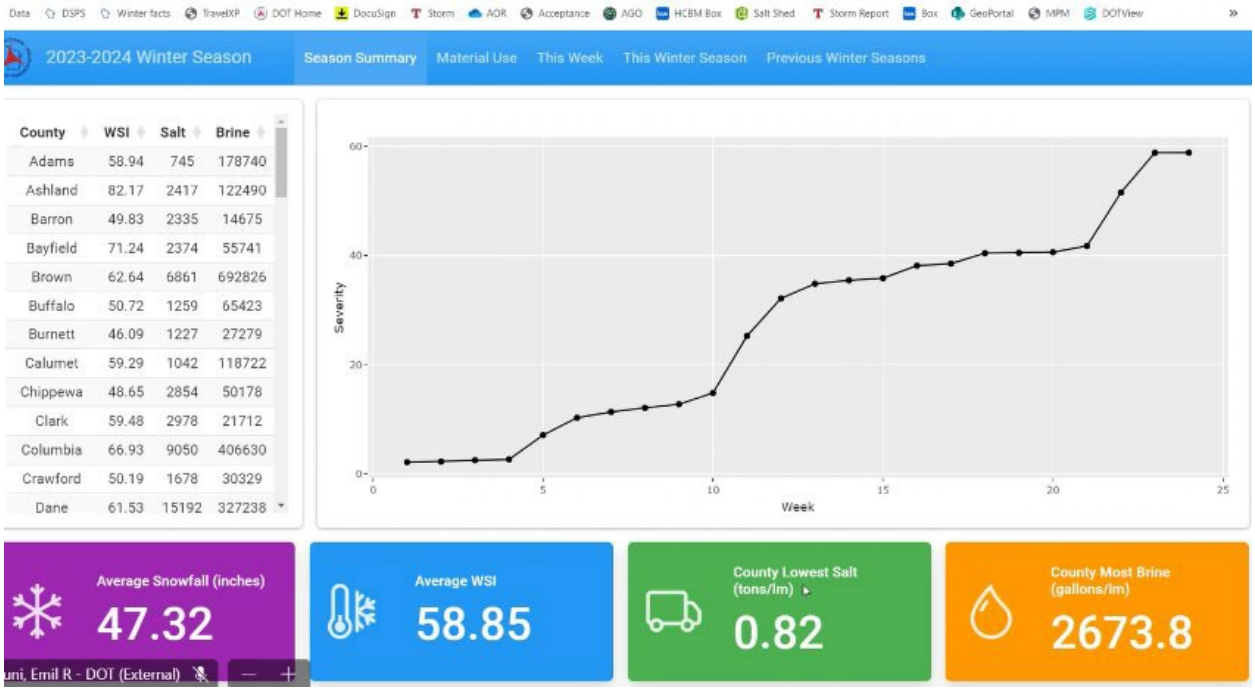


Figure 39. Wisconsin developed a dashboard mock-up to show winter season impacts by county. (Source: Wisconsin DOT)

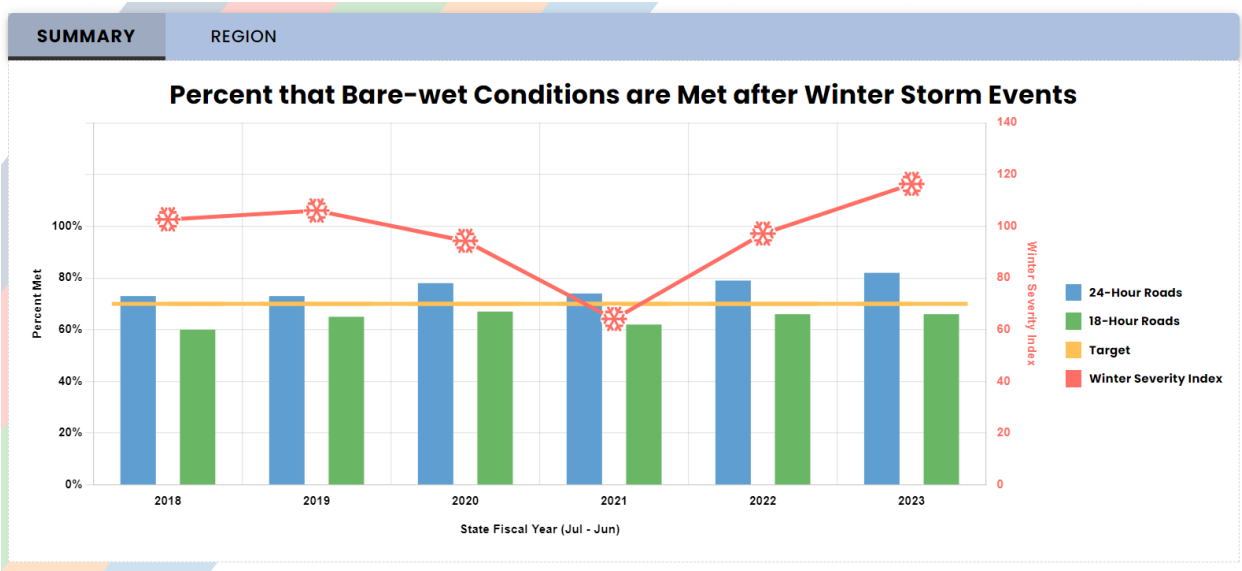


Figure 40. Wisconsin uses a 70 percent target for bare-wet conditions after winter storm events for 18- and 24-hour roadways, which is not to be exceeded (i.e., potentially utilize more resources and higher costs than necessary) or underperformed (i.e., need to utilize more resources to improve road conditions). (Source: Wisconsin DOT)

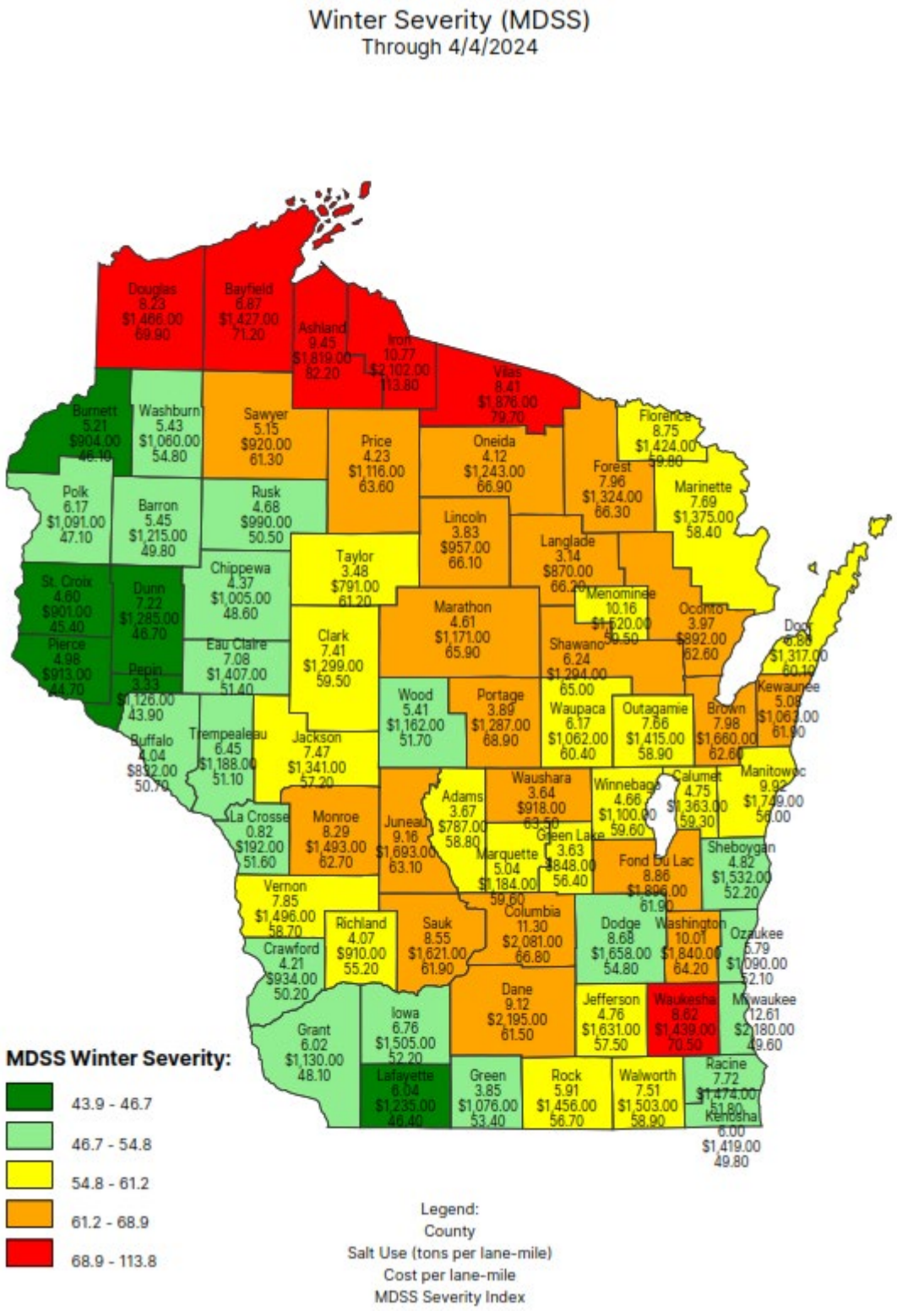


Figure 41. Wisconsin tracks winter severity by county, and tracks salt use, cost per lane mile, and the MDSS severity index. (Source: Wisconsin DOT)

CHAPTER 5. Observations from Workshop Participants

This section presents a summary of discussion items from all four workshops.

5.1 Initial Workshop Discussions

Several overarching observations were noted during the Phase I initial workshop discussions:

- **Two objectives and the related performance measures rose to the top of the list across all agencies.** 'Maintain Level of Service during event' and 'Meet recovery criteria set by the agency.' While challenging and not perfect, most States noted there is an approach to leverage their existing capabilities to determine the level of service during the event and the time it takes to resume normal operations after the event.

- **The biggest challenge noted by all states is in consistently defining an "event".** There is a lack of consistency in the timeline for defining an event. In Maine and Massachusetts, the crew define the beginning of an event when they call out crews to start preparing for a storm. In New Hampshire, an event begins when they receive a call from crew indicating that there is precipitation, or when precipitation is viewed on cameras or measured by the Road Weather Information System (RWIS). Maryland noted that there are situations where a winter event is anticipated, they dispatch crews to begin pre-treatment, and then the storm passes with no precipitation. Any measures taken to treat the roadways can be considered an event, because teams are called in to address the road conditions or prepare to address road conditions. A key part of all event timelines includes pre-treatment of the roads before an event begins, and the actions to treat the roads until normal service resumes.

- **Standardizing how an event is defined is crucial in aligning performance measures across AASHTO Region 1.** The group agreed there are five specific time stamps measurements critical to tracking winter storm performance measures:

    - **Event Start Time.** The time that an agency begins tracking an event. This may be determined by when crews are called up, or when pre-treatment or treatment of roads begins (this may be before, after, or simultaneously to precipitation start time).
    - **Precipitation Start Time.** After the event start time, the time that precipitation is observed or measured to begin.
    - **Precipitation End Time.** The time that precipitation ends. The start and end time of precipitation comprises the **precipitation time window** where precipitation is occurring. Multiple precipitation windows may occur within the overall event. The advantage of precipitation time windows is that they can be objectively captured by RWIS. This window might be better for reporting measures on levels of service during the event. The disadvantage of just relying on these windows is that it may not capture the full cost of the response (such as labor, materials spent before or after the precipitation).
    - **Event End Time.** The time that staff activities related to the storm conclude. This may be after the end of the precipitation. Typically, event windows will be longer than the precipitation windows.
    - **Return to Normal Time.** The time that the roadways have returned to bare pavement, or other qualifiers used by the agency to indicate the event caused conditions are cleared.

- However, all participants noted the significant ambiguity in specifying these times. Defining these timestamps is a major focus area **and a priority for multi-state coordination, especially between Massachusetts, New Hampshire, Maine, and Vermont.**

- Due to **staff availability constraints** and the workload of state maintenance personnel, State DOTs noted a distinct preference for automation of processes in determining performance measures. An imperfect measure that is automatically (or algorithmically) calculated based on sensor data and agency records is preferable to a more detailed measure that involves a significant amount of post-processing and manual data crunching.

- **All participating State DOTs noted strong methods of measuring resource usage** including how much labor and materials costs were incurred in response to the storm. The record-keeping especially around material usage is uniformly high across the State DOTs.

- **All participating State DOTs recognize the need for winter severity indices to understand trends in winter performance measures.** The group discussed the use of winter severity indices as well as storm severity indices. There was agreement that storm severity indices (i.e., how do storms rate against the norm or each other) would be beneficial but are more difficult to implement. A frequently used winter severity index is the Midwestern Regional Climate Center's Accumulated Winter Season Severity Index (AWSSI), and there was recognition that other and other local Winter Severity Indices (WSI) are used. Maine, Vermont, Massachusetts, and New Hampshire are using seasonal severity indices. Maryland and New York State currently do not use a severity index. Maine, Vermont, and New Hampshire do have Vaisala's RWIS dashboards which provides storm severity index. (Note: the Storm Severity Index is calculated as Storm Severity Index = WS (Max) + WEL (Max) + 300/ST (Min) where the following units are used: WS = Wind Speed (mph) WEL = Water Equivalent Layer (millimeters) ST = Surface Temperature (degrees F) [Index range is 10 to 80 for typical storm events with severe cold and high winds running as high as 500] (Source: Jensen et al, 2014). However, the States have not fully explored its use.

Participating agencies also discussed challenges and barriers to taking necessary actions before the Phase I follow-up workshop. The following list includes barriers in implementing action plans.

- **Selecting a pilot location/corridor.** Given the proximity of the states to one another and the similarity in performance measures used, it would be ideal for states to agree on a roadway that goes throughout several states to use as a pilot. This is not required but would be useful and promote collaboration among the states.

- **Developing timestamps for event start, event end, precipitation start, precipitation end, and return to normal.** There needs to be a consensus on what triggers are used to record an event's start and end and how return to normal is measured. Using RWIS, the precipitation start and end times can be easily gathered.

- **Assembling speed data.** All state transportation agencies said that they have access to probe-based speeds. They will explore the use of speed data in pilot corridors to assess the value for both LOS and recovery performance measures.

- **Assembling grip data.** All state transportation agencies have access to grip data but have not really developed a proven reporting format. There is interest in exploring the use of this for

performance measures and one possibility is for all the States using Vaisala to talk to their representative to develop a common report format.

- **Conflating data and generating reports.** Generating reports is something that can be more of a manual process. State transportation agencies will work on finding automated manners to conflate data and generate reports.

- **Assessing data and determining LOS.** Depending on the pilot location for each state transportation agency, they must determine what reasonable LOS is during an event.

- **Other institutional challenges.** These included getting internal support for this process as well as ensuring that key staff involved in this process have the time available to dedicate to improvement over the next few months.

These discussions and lessons learned from the Phase I initial workshop helped shape the format of the Phase II initial workshop. Many discussions with participants in the Phase II initial workshop mirrored discussions described above from the Phase I initial workshop. The participating agencies discussed challenges and barriers to taking necessary actions before the Phase II follow-up workshop. The overall discussion about performance management noted challenges with staffing, availability of data, and interactions with vendors, among other issues. Technical challenges identified included anticipated changes to AVL systems, approval from management, workforce challenges, and identification of funding.

Key recommendations to overcome challenges reflect those described in NCHRP Report 889 (**Error! B ookmark not defined.**) and included:

- Use weather "events" as the starting point. This allows for greater flexibility in the definition of performance measures. Consistency across the agency's jurisdiction is more important than the definition itself. Data collection, aggregation and analysis can be tied to specific points in the event timeline (before, during, and after the event ends).
- Develop both a "storm severity" and a "seasonal severity" index. The value of a performance measurement is greatly enhanced by pairing it with severity both at the event and seasonal level. The effectiveness of a severity index is simply determined by its degree of correlation with the maintenance response.
- Pick a consistent LOS and recovery criteria and how it is measured across the agency. Subjectivity is unavoidable in snow and ice performance measurement. There likely is no "correct or universally applicable" LOS or recovery standard nationally. Defining how these are measured can be made more consistent within the agency.
- Report performance information. This allows regional and county staff to compare resource use with that of their peers. DOTs develop annual performance measurement reports, fact sheets, and other publications that provide information about winter storm maintenance activities. This type of report gathers data to help agencies identify good performance as well as areas that need improvement.

5.2 Follow-Up Workshop Discussions

Overarching observations that were discussed throughout the Phase I follow-up workshop included:

- **The relationship between pavement grip and vehicle speeds is not as strong as attendees hoped.** As noted earlier, one goal between workshops was to test the hypothesis that vehicle speed data could be mechanism for assessing level of service and/or return to normal time for winter storms, effectively serving as a substitute for the use of pavement grip data. As vehicle speed data is increasingly available from multiple sources, this could improve performance management. Several states were able to assemble vehicle speed data and compare it to pavement grip data. The findings showed that, while there is a correlation, it is not as profound as was hoped. Possible explanations are that travelers tend to drive slower during the first 1-2 storms of the year, but after that, speed is impacted less. It was also noted that the 2022-2023 winter season did not have as many winter storms to compare and therefore only a small number of case studies were available to compare pavement grip to vehicle speeds.

- **Ongoing challenges with generating meaningful information from bountiful data.** Multiple states noted that they are data rich, but struggle with processing the information to create dashboards or reports that are valuable, particularly when different stakeholder groups have unique needs (e.g., maintenance supervisors versus field personnel versus the traveling public).

- **Increased automation is needed to provide better information faster.** Several states described work to automate processes to combine data from multiple sources, although a challenge remains that too much automation could overlook external factors. Dashboards were noted to be particularly useful, both for real-time actions and performance monitoring.

- **Different Messaging is needed for diverse groups.** It was expressed in the Workshop that there are at least three groups that must be considered for winter maintenance performance messaging:

    - **Maintenance Supervisors and Senior Staff.** This group has a focus on costs of response and environmental impacts. Therefore, their emphasis is on seeing cost data.

    - **Field Personnel.** This group is primarily focused on maintaining the roads. They want to see how well they are doing their jobs to make any needed changes.

    - **Traveling Public.** They want to understand what is being done responsibly with their tax contributions.

- **Ongoing challenges with reducing salt use.** Whether due to environmental concerns, costs, or other factors, states have a continued focus on reducing salt use. However, this must be balanced with safety and expectations of the traveling public.

- **Remaining Technical Issues.** Workshop attendees discussed four technical issues that still require more attention to address:

    - **Grip vs. Speeds** – The correlation between these is not as clear-cut as anticipated.

- **Storm Severity** – Several methods in play but an ideal solution that works for all has not yet been determined. It was noted that the Clear Roads Pooled Fund Study continues to advance this topic.
- **Seasonal Severity** – It was noted that seasonal severity indices have trouble accommodating freezing rain and ice.
- **Messaging based on grip factors** – There was discussion about the use of messaging (e.g., Dynamic Message Sign displays, 511 phone or web) to inform drivers when grip is low may be effective at slowing traffic when appropriate.

Discussions and lessons learned from the Phase I follow-up workshop helped shape the format of the Phase II follow-up workshop. Many discussions with participants in the Phase II follow-up workshop mirrored discussions from the Phase I follow-up workshop. However, a common theme for many attendees' action items between the Phase II initial workshop and the Phase II follow-up workshop was to explore new ways to better leverage data that was already available at the agency in order to develop effective performance measures. For example:

- Some participating agencies, like Arizona, Nevada, and Oregon have limited experience with snow and ice performance measurement. However, these agencies have access to a variety of data and used this NCHRP effort as the impetus to begin investigating what data is available and how it may be used to generate meaningful findings that can improve agency operations and efficiencies.
- Some participating agencies are more advanced in snow and ice performance measurement like Minnesota, Iowa, Wisconsin, Missouri, and North Dakota, and learned from each other to pursue development of similar snow and ice performance measures or dashboards at their agency.

Several overarching observations that were discussed throughout the Phase II follow-up workshop included:

- **Participating states use MDSS.** While New England agencies participating in the Phase I initial and follow-up workshops focused a lot on start/end times for winter weather events, the states in the Phase II initial and follow-up workshops that use MDSS did not share this focus. There was also less emphasis in the Phase II initial and follow-up workshops about costs to call additional staff for winter storm response.
- **Performance measures are very effective at telling a story.** Specifically, performance measures can be used to help justify budgets, get salt and other materials, transition to a new approach like brine that involves retrofitting trucks, and answering questions from environmental agencies and the public, for example. Performance measures are helpful for communicating decisions internally and externally.
- **Performance measures are rarely punitive.** There are few instances of performance measures being used to tell how bad an agency or specific District, maintenance garage, or staff are doing. Instead, performances measures help tell success stories, identify possible areas for improvement that may require additional resources or funding, and plan for the coming winter season.

CHAPTER 6. Lessons Learned to Inform Future Workshops and Feedback from State DOTs

This section presents a summary of lessons learned from these Workshops that can be used to inform the approach for conducting any future workshops. Lessons learned that were identified by the project team and workshop participants that were instructive for future workshops to be conducted in this project included:

- **Preparation materials were beneficial.** The survey and "read ahead" materials that were circulated before the Phase I initial workshop and the Phase II initial workshop to participants were beneficial for staff to understand the context of the workshop and reflect on current DOT practices.
- **Networking opportunities at the workshops were invaluable.** Workshop participants collectively acknowledged the advantages of having multiple in-person meetings to better engage with regional peers.
- **The collaboration between the two workshops was key for implementation.** Participants said that the "homework" and meetings conducted between the two workshops were helpful to further collaborate and exchange information. These meetings helped participants stay accountable and focused on the implementation activities that each agency identified as part of the Phase I initial workshop and the Phase II initial workshop.
- **Ability to leverage experiences of other states.** Participants from the Phase II initial workshop and the Phase II follow-up workshop specifically noted the value of learning about what has been effective in other states to apply similar practices at their own agencies. Specific examples include:
    - The strong interest from attendees in the positive benefits that Minnesota has received from their transition to increased brine use (and reduction in salt);
    - The strong interest in Iowa's predictive index and the potential to implement this in other states;
    - The strong interest in Missouri's partnership with the university to develop the Titan app and consider various factors (including crashes) in the costs of winter events.
- **Two in-person workshops facilitated the exchange of information about progress and implementation at different agencies.** The "before-after" sequence of in-person workshops provided a valuable opportunity to report back on progress and hear the challenges and lessons learned from other agencies. A workshop participant noted that a single workshop would have had limited effectiveness.
- **The overview of all Performance Measures was valuable to workshop participants.** This was conducted in the Phase I initial workshop. One participant said this was extremely important to emphasize how many ways there are to define each category of performance measures.
- **Between workshop check-in webinars were effective.** There was active participation from participants during each of the check-in webinars that occurred between workshops. Participants noted that this helped them continue to understand what neighboring states were doing to advance their performance management and was motivation to address the goals identified by each state in the Phase I initial workshop and the Phase II initial workshop.

- **Involving a border state with state DOTs participating in future workshops may be beneficial.** If possible, for example, it may be helpful to invite Maryland DOT to a workshop that Virginia DOT is invited to.
- **Agency buy-in to performance measure change is critical.** Attendees from the Phase I follow-up workshop noted that they have existing performance measures their agency is familiar with, and changes to these require approval from multiple levels. However, collaboration within this project was identified as a resource to help understand what other neighboring states are doing regarding performance management and to better understand how to improve local performance management.
- **There are risks to too much automation of performance management.** The increased data sets and innovative data collection approaches identified in both workshops (e.g., vehicle speed data, pavement grip, Automated Vehicle data from maintenance vehicles) were recognized as valuable. However, participants noted that there are risks of automating data analyses and losing the understanding of external factors. For example, a winter storm starting at 10:00 PM vs. a storm starting at 10:00 AM have different treatment approaches, material usage, and expected impacts to drivers. Simply looking at the data without ignoring the start time loses some understanding of the response activities.
- **A better understanding of the interactions of cost, level of service, and environmental impacts is needed.** Through discussions in the Phase I initial workshop and the Phase I follow-up workshop, participants agreed that performance management is about managing costs of winter storm response, maintenance of level of service of the road, and impacts to the environment through chemical treatments. For example, the level of service can be maintained very well, but at a higher cost and increased risks to the environment. Similarly, costs can be controlled, but as a result the level of service is reduced. Participants described a Venn diagram of these three factors, noting that where each factor overlaps with the others is what needs to be better understood.
- **A big challenge noted by states in AASHTO Region 1 is in consistently defining an "event."** There is a lack of consistency in the timeline for defining an event. In Maine and Massachusetts, the crew define the beginning of an event when they call out crews to start preparing for a storm. In New Hampshire, an event begins when they receive a call from the crew indicating that there is precipitation, or when precipitation is viewed on cameras or measured by the RWIS. Maryland noted that there are situations where a winter event is anticipated, they dispatch crews to begin pre-treatment, and then the storm passes with no precipitation. Any measures taken to treat the roadways can be considered an event, because teams are called in to address the road conditions or prepare to address road conditions. A key part of all event timelines includes pre-treatment of the roads before an event begins, and the actions to treat the roads until normal service resumes.

- **Standardizing how an event is defined is crucial in aligning performance measures across AASHTO Region 1.** The group agreed there are five measurements of time that are critical to tracking winter storm performance measures:

    - **Event Start Time:** The time that an agency begins tracking an event. This may be determined by when crews are called up, or when pre-treatment or treatment of roads begins (this may be before, after, or simultaneously to precipitation start time).

- **Precipitation Start Time:** After the event's start time, the time that precipitation is observed or measured to begin.
- **Precipitation End Time:** The time that precipitation ends. The start and end time of precipitation comprises the **precipitation time window** where precipitation is occurring. Multiple precipitation windows may occur within the overall event. The advantage of precipitation time windows is that they can be objectively captured by RWIS. This window might be better for reporting measures on levels of service during the event. The disadvantage of just relying on these windows is that it may not capture the full cost of the response (such as labor, materials spent before or after the precipitation).
- **Event End Time:** The time that staff activities related to the storm conclude. This may be after the end of the precipitation. Typically, event windows will be longer than the precipitation windows.
- **Return to Normal Time:** The time that the roadways have returned to bare pavement, or other qualifiers used by the agency to indicate the event caused conditions are cleared.

REFERENCES

Dowds, J., and J. Sullivan. 2019. *Snow and Ice Control Performance Measurement: Comparing "Grip," Traffic Speed Distributions and Safety Outcomes During Winter Storms."* https://vtrans.vermont.gov/sites/aot/files/planning/documents/research/publishedreports/2019-08_GRIP.pdf (as of September 11, 2024).

Jenson, D., B. Koberlein, E. Bala, and P. Bridge. 2014. *Ensuring and Quantifying Return on Investment through the Development of Winter Maintenance Performance Measures.* https://www.vaisala.com/sites/default/files/documents/WEA-RDS-G-Performace%20Measures_2014.pdf (as of September 11, 2024).

Midwestern Regional Climate Center's Accumulated Winter Season Severity Index (AWSSI). https://mrcc.purdue.edu/research/awssi (as of September 11, 2024).

Missouri Department of Transportation. *Engineering Policy Guide for Snow and Ice Control Operations.* http://epg.modot.org/index.php/133.4_Snow_and_Ice_Control_Operations (as of September 11, 2024).

Regional Integrated Transportation Information System (RITIS). https://www.ritis.org/login?r=Lw== (as of September 11, 2024).

ABBREVIATIONS AND ACRONYMS

AAR	After Action Report
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AI	Artificial Intelligence
ATR	Automatic Traffic Recorder
ATRI	American Transportation Research Institute
AVL	Automatic Vehicle Location
AWSSI	Accumulated Winter Season Severity Index
BMP	Best Management Practices
CATT Lab	Center for Advanced Transportation Technology Lab
CCTV	Closed-Circuit Television
CHART	Coordinated Highways Action Response Team
DMS	Dynamic Message Sign
DOT	Department of Transportation
EAMS	Enterprise Asset Management System
ESS	Environmental Sensor Station
FY	Fiscal Year
IT	Information Technology
ITS	Intelligent Transportation System
LOS	Level of Service
MARWIS	Mobile Advanced Road Weather Information Sensor
MDSS	Maintenance Decision Support System
MPH	Miles Per Hour
NCHRP	National Cooperative Highway Research Program
NDEX	Nevada Data Exchange
NPMRDS	National Performance Management Research Data Set
PIO	Public Information Officer
PM	Performance Measure
R&W	Road & Weather
RITIS	Regional Integrated Transportation Information System
ROC	Regional Operations Center
RoI	Return on Investment
RTTS	Return To Travel Speed
RWIS	Road Weather Information System
STIIC	Statewide Traffic Information Integration Center
TMC	Traffic Management Center
TTI	Travel Time Index
VMT	Vehicle Miles Traveled
VSL	Variable Speed Limit
VTrans	Vermont Transportation Agency
WIM	Weigh In Motion
WPI	Winter Performance Index
WSI	Weather Severity Index

Appendix A. Workshop Materials

This section includes workshop materials used for the Phase I initial workshop that were leveraged for the Phase II initial workshop and may be used to support future workshops. The following summarize the materials included in this Appendix and their respective section:

A. Draft invitation letter to proposed State DOT workshop attendees, after receiving approval from NCHRP.
B. Phase II initial and final workshop agendas, which are draft proposed agendas for future workshops.
C. State DOT Participant Read-Ahead Materials and Actions
D. Post-Workshop Evaluation
E. Workshop PowerPoint Slides

A. Draft Invitation Letter

SUBJECT LINE: **INVITATION – NCHRP Workshop for Implementation of Performance Measures in Snow and Ice Control Operations**

MESSAGE:

[Name(s)]
The National Cooperative Highway Research Program (NCHRP) is starting a project that seeks to implement findings from the NCHRP Research Report 889. This project is part of the NCHRP Implementation Support Program that provides opportunities to conduct collaborative activities to help state departments of transportation (DOTs) to implement and benefit from NCHRP studies.

As part of this project, NCHRP is seeking participation from up to six (6) state DOTs in AASHTO Region [X] for an in-person workshop to analyze and make meaningful advances in their performance measurement activities for snow and ice control that fits their needs and operational objectives.

The 1-day workshop, tentatively planned for [month] timeframe will be in a convenient location in [workshop location] given the composition of State DOTs interested in participating. The workshop will:

- Recap the findings and lessons learned from the NCHRP Research Report 889 "Performance Measures in Snow and Ice Control Operations";
- Provide an overview of the key performance measures and required data and resources used within Report 889; and
- Guide participating DOTs in identifying existing data and resources that are available to help acquire information needed to report on the performance measures.
- Identify state-specific plans for the winter of 2023 to make progress on snow and ice performance measurement.

Because this is an NCHRP Implementation Project, the emphasis of the workshop goes beyond informing attendees of the research results. The goal is that attendees of the workshop will identify one or more actions for their agency to take to improve performance measurement for winter maintenance.

Please let us know by [XX/XX]/2023 if your agency is interested in participating in this effort. NCHRP will be providing travel reimbursements for [one or two] participants per State DOT to the workshops. Once you have confirmed your interest in participating, we will follow up with the selected dates, additional information on the agenda, and travel logistics. As current funding allows for participation of up to six states, we encourage interested states to express interest as soon as possible. If more than six states express interest, the project team may be able to accommodate or may have to invite some attendees to workshops in later years.

For additional questions about this workshop, please contact Pat Zelinski, NCHRP Program Officer (pzelinski@nas.edu) and Deepak Gopalakrishna (deepak.gopalakrishna@icf.com), the Principal Investigator for this research effort.

B. Typical Agendas for Workshops

The agenda for the 1.5-day initial workshop activities is shown in Table A-18 below. The agenda for the 1-day follow-up workshop activities is shown in Table A-2 below.

Table A-18. Typical Agenda for Initial Workshop

DAY 1: INTRODUCTION TO NCHRP REPORT AND ACTION PLANNING	
8:30 AM	Introductions and Overview of Workshop Purpose
9:00 AM	Recap of NCHRP Report 889 - Topic #1: Big Picture/Key Concepts
10:00 AM	Break
10:15 AM	Round-Robin #1 – Attendees Share Current Capabilities, Processes, and Existing Performance Measure Approach • *Each participating state will describe their performance measure approach and capabilities, as identified in the Microsoft Excel Tool.* • *Primary interest in this workshop/project (e.g., what they are hoping to improve).*
11:15 AM	Recap of NCHRP Report 889 - Topic #2: Deep Dive into Performance Areas • *Report 889 included a guide for performance measures for snow and ice control.* • *This session will step through the performance measures with a focus on those shared in the round-robin.* • *Attendees will be given worksheets to fill in as the discussion progresses describing their interest, challenges with, and status of each performance measure*
12:00 PM	Lunch/Break
1:30 PM	Recap of NCHRP Report 889 Topic #2 (continued)
2:15 PM	Break

2:30 PM	Discussion on Candidate Performance Measurement Improvements
	• *Group discussion, exercises about options for changes to winter weather performance measurement*
	• *Summary of changes and expectations for next winter*
	  ○ *Candidate regional changes*
	  ○ *Individual state changes*

4:00 PM	Obstacles and Barriers to Achieving Actions. Technical and Institutional Challenges Towards Implementing Action Plans • *Data availability* • *Institutional issues* • *Others*
4:45 PM	Recap of Workshop
5:00 PM	Close Workshop

Table 19. Typical Agenda for Follow-Up Workshop

8:00 AM	Introductions and Overview of Workshop Purpose

8:30 AM	Round-Robin – Attendees Share Progress on Action Plans Created in Initial Workshop
	• *Each participating agency spend 30-45 minutes (depending on number of participating agencies) sharing:*
	  ○ *Description of progress. Findings and plans for next winter.*
	  ○ *Questions from the workshop attendees*

10:00 AM	Break
10:15 AM	Round-Robin (continued) – Attendees Share Progress on Action Plans Created in Initial Workshop
12:00 PM	Lunch/Break Working Lunch on-site
12:45 PM	Round-Robin (continued) – Attendees Share Progress on Action Plans Created in Initial Workshop
2:00 PM	Break
2:15 PM	Round-Robin (continued) – Attendees Share Progress on Action Plans Created in Initial Workshop

2:45 PM	Implementation Report
	• Challenges from last season
	• Advice to other agencies
	• Key findings identified to include in the report.
	• Plans for a chapter for each site:
	  ○ Messages states want to convey.
	  ○ Graphics/results to include from each state.
	  ○ What other activities underway that we should report on

3:30 PM	Advice for future workshops
	• Were the "read ahead" materials valuable? Would additional materials have been more helpful?
	  ○ Was the overview of all Performance Measures (conducted in the initial workshop) valuable and should it be repeated?
	  ○ What additional content should the project team prepare for the future workshops (to accomplish as much as possible in one day)?
	• What inputs from this project were most helpful (and should be carried forward to the remaining workshops)?
	• Key Takeaways attendees would offer to future workshop attendees?

3:45 PM	Recap Workshops and Progress Made
4:00 PM	Workshop Concludes

C. State DOT Participant Read-Ahead Materials and Actions

Several read-ahead materials were provided to the State DOTs attending the workshop in advance of the meeting, as was done for the initial workshops in Phase I and Phase II, and noted to be valuable by the workshop participants. The purpose of providing these materials was to familiarize the participants with the process outlined within NCHRP Report 889: "Performance Measures in Snow and Ice Control Operations." Having participants familiar with the process before the workshop helped in easier facilitation of the workshop and allowed participants to prepare for the event, gathering the information that they needed to participate successfully in the event.

Materials that were provided to the State DOTs before the initial workshops in Phase I and Phase II included:

- Electronic access to the full NCHRP Report 889 at: https://www.trb.org/NCHRP/Blurbs/178901.aspx
- A high-level overview of the report, including the 10-step approach to develop and assess performance measures in addition to key considerations when going through the process of developing and evaluating performance measures.
- Information on the relationship between the report and what would be done over the course of the workshop.
- The goals of the workshop.

The research team conducted an introductory webinar (60 minutes in duration) prior to each workshop with the participating States. The purpose of the webinar was to orient the attendees about the workshop, share information about the guide, as well as encourage participants to review their current practices prior to the workshop.

To prepare for the initial workshops in Phase I and Phase II, the research team asked that workshop participants review the read-ahead materials, in addition to completing a SurveyMonkey that was prepared by the research team. The SurveyMonkey collected information used in the workshop, prepared workshop participants for discussions at the workshop, and helped workshop participants to begin thinking about the effectiveness of their state DOT's existing snow and ice control program and feasibility of making improvements. This information included:

- **State DOT Mission and Goals.** The mission and goals of the state DOT feed directly into the process of setting operational objectives, which correlate to performance standards and measures. The impact of the snow and ice control program on the state DOT's goals is important to determine as it relates to the investment in these programs and operational practices and policies.
- **Performance Measures Currently Used at State DOT.** Familiarity with the current performance measures used at the state DOT to monitor the effectiveness of the snow and ice program will help with the facilitation of conversations on improvements to performance management programs. Additionally, an understanding of performance measures that may have been piloted or used in the past, and lessons learned from those experiences was useful for discussions.
- **Data Availability.** Understanding what data is already collected and the feasibility of modifying practices to collect additional data will inform whether the state DOT can begin to use new or modified snow and ice performance measures. Lessons learned and familiarity

with experiences in the past when maintenance staff or others were asked to collect new data may be helpful.

- **Completing Data and Performance Assessment Tool -** Participants were asked to complete the Excel-based tool created as part of NCHRP 889. This provided a baseline capability assessment for the State DOT as they participate in the workshop.