Automated and Predictive Methods to Update Road Condition Reporting

Synthesis Report

research for winter highway maintenance

CTC & Associates LLC

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16. Abstract

Most state departments of transportation (DOTs) use traveler information systems such as 511 to communicate winter road conditions to the public. These systems have traditionally relied on field observations and manual updates, but emerging technologies, including automation, predictive modeling and artificial intelligence, may help agencies provide more timely, accurate and actionable road condition information. To better understand current practices and emerging approaches, this project explored how Clear Roads member states update winter road condition reports, with a focus on the use of automated and predictive tools. To keep the project relevant to member agencies, the scope focused specifically on public-facing winter road condition reporting rather than broader winter maintenance decision-making. A survey of state DOTs gathered information about current reporting workflows, traveler information systems, data sources, automation efforts and predictive tools. A review of relevant literature examined traditional reporting practices, automated and predictive approaches, connected vehicle and crowdsourced data sources, and commercial tools and platforms. Findings indicate that while many agencies continue to rely on manual or hybrid workflows, interest in automation and predictive technologies is growing. Common challenges include data integration, validation, staffing limitations and translating predictive outputs into clear and reliable public-facing information.

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List of Abbreviations and Acronyms

AI	artificial intelligence
AMSIG	American Signal Company
API	application programming interface
ATIS	advanced traveler information services
AVL	automatic vehicle location
CARS	Condition Acquisition and Reporting System
CARWIS	Conversational AI for Road Weather Information Systems
CATT LAB	Center for Advanced Transportation Technology Laboratory
CCTV	closed-circuit television
CNN	convolutional neural network
CV	connected vehicle
DMS	dynamic message sign
DOT	department of transportation
EDC	Every Day Counts
ESS	environmental sensor station
FHWA	Federal Highway Administration
GIS	geographic information system
IMO	integrating mobile observations
IRIS	Intelligent Roadway Information System (Minnesota TMS)
ITS	intelligent transportation systems
IVR	interactive voice response
LRRB	Local Road Research Board (Minnesota)
MDSS	maintenance decision support system
MnDOT	Minnesota Department of Transportation
MTC	Metropolitan Transportation Commission
NCAR	National Center for Atmospheric Research
NIK	Nested Indicator Kriging
NLP	natural language processing
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NYSDOT	New York State DOT
PF-MDSS	pooled fund MDSS
RCRS	road condition reporting system
RITA	Research and Innovative Technology Administration
RSC	road surface condition
RWIS	road weather information system
SIMS	Snow and Ice Management System (Massachusetts DOT)
SMS	short message service (text messaging)

TMC	transportation management center
TMS	traffic management system
TSMO	transportation systems management and operations
USDOT	U.S. Department of Transportation
VAMS	value added meteorological services
VDOT	Virginia Department of Transportation
VII	vehicle infrastructure integration
VMS	variable message sign
VSL	variable speed limit
WRM	winter road maintenance
WWRCI	winter weather road condition index
WYDOT	Wyoming Department of Transportation

Executive Summary

Most snow and ice states use a traveler information system, such as 511, to keep the public updated on road conditions during winter weather events. These systems have traditionally relied on field staff to observe and manually enter road condition updates, but emerging technologies, including automation, predictive modeling and artificial intelligence (AI), may help agencies provide more timely, accurate and actionable road condition information.

To better understand current practices and emerging approaches, Clear Roads initiated a research effort to explore how member states currently update winter road condition reports, with a focus on the role of automated and predictive tools in use or being considered.

To keep this project relevant to Clear Roads member states, the scope focused on winter road condition reporting and traveler information systems rather than broader winter maintenance decision-making. A survey of member states gathered information on reporting workflows, data sources and systems, the use of automation and predictive tools in public-facing reporting, and challenges to adoption. A literature search of relevant research and related resources supplemented the survey findings.

Survey Findings

The survey received 20 responses from 17 member states: Arizona, Idaho, Kansas, Massachusetts, Michigan, Minnesota, Montana, Nebraska, New Jersey, New York, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, Utah and Washington.

The survey covered three major topic areas:

- Current practices for updating winter road conditions
- The use of or interest in automated tools and approaches
- The use of or interest in predictive tools and approaches

Survey questions are provided in Appendix A.

Current Practices

Most responding agencies continue to rely primarily on manual observation and reporting by field staff to update winter road condition reports.

Fourteen of the 17 responding states use a 511 traveler information system to provide winter road condition updates, while eight states use a non-511 website, app, short message service (SMS) or phone line to update the public. Additionally, 13 states use social media, and 14 states use variable message signs (VMS). While some states use a traveler information platform built in-house, many use vendors, including Arcadis, Castle Rock, Ver-Mac, Iteris and American Signal Company (AMSIG).

As shown in Table ES1, most systems remain centered on manual input, with road weather information system (RWIS) and camera data used as supporting tools. Practices vary in terms of system development, responsibility for updates and reporting frequency.

Table ES1. Summary of Current Practices for Updating Winter Road Condition Reports

Category	Common Practices	Key Insights
Traveler Information Platforms	• 511 systems • Non-511 platforms (websites, apps, SMS (text messaging), phone) • Social media • Variable message signs	Most agencies use multiple communication channels to reach the public, with 511 systems serving as the primary platform, supplemented by social media and roadside messaging.
System Development	• Vendor-supported systems • In-house platforms	Many agencies rely on vendor-supported systems, although some maintain in-house solutions, depending on resources and needs.
Primary Data Sources	• Field observations • RWIS data • Traffic cameras	Road condition reporting remains heavily dependent on human observation, with RWIS and camera data widely used as supporting inputs.
Responsibility for Updates	• Maintenance supervisors • Central transportation management center (TMC) staff • Regional TMC staff • Snowplow operators	Responsibility is distributed across roles, but most often led by maintenance and TMC staff.
Update Frequency	• Real-time updates • Every two hours • Twice daily	Update frequency varies widely, but most agencies report more frequent updates as conditions change during active weather events, rather than following a fixed schedule.

Automation Tools and Approaches

Five states use or are testing some form of automation to support winter road condition reporting, as shown in Table ES2, while six states are exploring or considering automated approaches, as shown in Table ES3. Six states reported no plans to pursue automation tools at this time.

Table ES2. Automated Tools in Use or Testing

Tool	State
RWIS + Maintenance Decision Support System (MDSS) Integration	Minnesota, Oregon, South Dakota
AVL-Integrated Snowplows	Minnesota, South Dakota
AI/Image Recognition (Pilot)	New York, Oregon
Automated 511 Triggers	Minnesota
Workflow Automation	Oklahoma
Automated Traffic Control (Variable Speed Limit)	South Dakota

Reported challenges associated with automated solutions include:

- Accuracy issues (manual overrides needed).
- Overrides not consistently cleared.
- Localized conditions are missed.

- Insufficient detail in reported conditions.
- User interface challenges.

Table ES3. States Exploring Automation Solutions

State	Tool or Approach
Arizona	MD30, Wx Horizon
Idaho	Agency RWIS cameras and friction data
New Jersey	Virtual RWIS
Pennsylvania	RWIS feeding message boards for snow squalls; variable speed limits
Utah	NIRA Dynamics
Washington	RWIS-controlled VMS

Factors driving agencies' interest in automated methods for updating winter road condition reports include:

- Accuracy, latency and density of rural reports.
- Accurate data.
- Timely delivery of information.
- Virtual weather forecasting.

Predictive Tools and Approaches

Six states use or are testing predictive tools to support winter road condition reporting, as shown in Table ES4, while five states are considering exploring predictive approaches, as shown in Table ES5. Six states reported no current plans to pursue predictive technologies.

Table ES4. Predictive Approaches in Use or Testing

Predictive Approach	State
RWIS-Integrated Modeling	Arizona, Michigan, South Dakota, Texas
MDSS	Michigan, South Dakota, Texas
Forecast-Based Modeling Using AI or Machine Learning	Arizona, Pennsylvania
In-House Meteorology	Utah
Commercial Forecasting	South Dakota

Reported challenges associated with predictive solutions include:

- Accuracy.
- Limited number of RWIS stations.
- System functionality.

Table ES5. States Exploring Predictive Solutions

State	Tool or Approach
Idaho	Friction sensors

State	Tool or Approach
Oklahoma	RWIS sites send notifications to applicable maintenance supervisors when bridge deck temperatures fall below a certain threshold
Oregon	• Virtual RWIS (Pikalert) • MDSS and forecasting tools
Washington	RWIS-based approaches

Factors driving agencies' interest in predictive solutions for updating winter road condition reports include:

- Better preparation and responsiveness to snow/ice events.
- Increased frequency of reporting and reducing staff efforts to gather and report information.
- Timely delivery of information to travelers.

Findings From the Literature

The examination of relevant literature identified research and resources related to winter road condition reporting, automation, prediction and supporting technologies. The literature emphasizes the importance of combining multiple data sources, including RWIS, vehicle-based sensors, connected vehicle data, maintenance activity, weather forecasts and other real-time inputs.

Research also highlights the potential of automated and predictive approaches to improve the timeliness and consistency of road condition updates. However, these tools depend on reliable data, clear validation methods and integration with existing systems. Several resources also point to the importance of human oversight, particularly when automated outputs are used to inform public-facing updates.

The literature search is organized into six categories:

Traditional Reporting Workflows

Publications in this category describe established agency practices for collecting, updating and sharing winter road condition information, including 511 systems, traveler information guidance and agency support materials.

Mobile and Field-Based Data Collection

Resources in this category focus on vehicle-based and field-deployed tools used to collect road condition information closer to the source. Publications include project reports and federal guidance describing snowplow camera integration, mobile observations, and other approaches to supplement RWIS and manual reporting.

Automation and System Integration

This category includes guidance, technical reports and research publications addressing how road weather data, decision-support tools and traveler information systems can be linked. These resources emphasize RWIS standards, MDSS specifications, and standardized road condition frameworks that support more automated and efficient workflows.

Artificial Intelligence and Predictive Modeling

The literature in this category includes journal articles, conference papers and project summaries exploring the use of AI, machine learning, and predictive models for road condition detection and forecasting. Resources focus on camera-based road surface classification, model performance, decision-support platforms and emerging communication tools.

Connected Vehicle and Emerging Data Sources

This category examines the use of connected vehicle technologies, vehicle-based observations and other emerging transportation data sources for road weather management. These publications include federal case studies, Aurora Program reports and weather/transportation research.

Crowdsourced and Third-Party Data

The publications in this category describe how agencies are using or evaluating data generated outside of traditional DOT systems, including crowdsourced reports, smartphone applications and private-sector data platforms. Resources include federal guidance, comparison reports and state research syntheses.

Key Themes and Future Considerations

Common themes identified through the survey and examination of literature include:

- Agencies continue to face challenges capturing localized and rapidly changing road conditions, particularly across large or rural networks.
- Standardized methods for validating automated and predictive road condition information remain limited.
- Many agencies use RWIS, decision support tools, 511 systems and vendor platforms in parallel rather than as part of a unified workflow.
- Staffing, funding and technical expertise challenges can limit agencies' ability to implement and maintain automated or predictive systems.
- Predictive tools are more commonly used for internal decision-making than for public-facing road condition reporting.

Findings from this synthesis suggest several areas agencies and research organizations may wish to explore further, including:

- Expanding RWIS networks and incorporating additional data sources, such as vehicle-based sensors and connected vehicle data, to improve data quality and coverage.
- Developing validation frameworks with clear methods, metrics and performance thresholds for evaluating automated and predictive outputs.
- Improving system integration and interoperability among RWIS, decision support tools and traveler information platforms.
- Conducting additional pilot testing and evaluation to better understand tool performance, limitations and appropriate use cases before broader implementation.
- Exploring methods for translating forecasts and model outputs into clear, reliable and actionable traveler information for public-facing systems.
- Supporting continued peer exchange, shared pilot experiences and collaborative research related to automated and predictive reporting tools.

1 Introduction

1.1 Background

State transportation agencies must provide timely and accurate information about winter road conditions to support safe travel during snow and ice events. Because conditions can change rapidly across locations and over short periods of time, maintaining up-to-date traveler information is critical for public safety.

Most snow and ice states use traveler information systems, such as 511, to keep the public updated on road conditions during winter weather events. These systems typically rely on field staff, including maintenance personnel and snowplow operators, to observe and manually input road conditions. While effective, this approach can be resource-intensive and difficult to scale, particularly during widespread or fast-moving weather events.

Emerging technologies, including automation, predictive modeling and artificial intelligence (AI), offer potential for improving the timeliness, consistency and efficiency of winter road condition reporting. These tools may support or enhance existing reporting processes, though their adoption and effectiveness vary across agencies.

This synthesis examines current practices reported by surveyed state transportation agencies to update winter road condition reports, with a focus on the role of automation and predictive tools. In addition, an examination of literature identified completed and ongoing research related to automation, predictive modeling and winter road condition reporting.

1.2 Organization of This Synthesis Report

Chapter 2 presents detailed findings from the survey of practice, organized into three topic areas:

- Current practices for updating winter road condition reports
- Automation tools and approaches
- Predictive tools and approaches

Findings include tools in use or being explored, as well as associated challenges, barriers, effectiveness, validation practices and advice from responding state departments of transportation (DOTs). Chapter 3 presents findings from a search of publicly available domestic research and resources, highlighting current practices and emerging trends. The examination of literature is organized into six topic areas:

- Traditional reporting workflows
- Mobile and field-based data collection
- Automation and system integration
- Artificial intelligence and predictive modeling
- Connected vehicle and emerging data sources
- Crowdsourced and third-party data

Chapter 4 identifies key gaps and potential next steps based on the survey and literature findings. Survey questions are provided in Appendix A.

2 Survey of Practice

An online survey was distributed to Clear Roads member states. The survey received 20 responses from 17 member states:

- Arizona
- Idaho
- Kansas (2 responses)
- Massachusetts
- Michigan
- Minnesota
- Montana
- Nebraska
- New Jersey
- New York
- Oklahoma
- Oregon
- Pennsylvania
- South Dakota (3 responses)
- Texas
- Utah
- Washington

Survey findings are highlighted below in three topic areas:

- Current practices for updating winter road condition reports
- Automation tools and approaches
- Predictive tools and approaches

Overall, responses reflect a range of practices across agencies, from largely manual workflows to more integrated and increasingly automated systems. Most agencies continue to rely on field observations and manual reporting processes, supplemented by road weather information system (RWIS) data, camera data and traveler information platforms.

Automation and predictive tools are typically used to augment, rather than replace, existing workflows. Agencies are incorporating additional data sources, system integrations and emerging technologies to improve timeliness, spatial coverage and decision-making, while maintaining human oversight.

The sections that follow describe current practices, as well as the tools and approaches agencies are using or exploring to support more automated and predictive road condition reporting.

2.1 Current Practices for Updating Winter Road Condition Reports

Agencies rely on a combination of traveler information platforms, field observations, RWIS and camera data, and staff workflows to collect, verify and share road condition information. These practices vary in terms of system development, responsibility for updates and reporting frequency. Summarized below are responding agencies' experiences with:

- Traveler information systems
- Traveler information platforms
- Data shared with the public
- Expanding access to current road conditions
- Responsibility for updates
- Update frequency

Traveler Information Systems

States generally use multiple communication channels, rather than a single system, to deliver winter road condition information to travelers. While 511 systems serve as the primary public-facing tool, many agencies supplement these with social media, websites and variable message signs (VMS) to expand reach and provide timely updates. Table 1 summarizes the traveler information systems used by responding states.

Table 1. Traveler Information Systems Used by Respondents

State	511 (Mobile App)	511 (SMS Text Message Alerts)	511 (Telephone)	511 (Website)	Non-511 Website, App, Text Alerts or Phone Line	Social Media	Variable Message Signs
Arizona	√	√	√	√		√	√
Idaho	√	√	√	√			√
Kansas (Engineer)	√	√	√	√		√	√
Kansas (Public Service)	√	√	√	√		√	√
Massachusetts	√	√	√	√	√		
Michigan				√			√
Minnesota	√	√	√	√	√	√	√
Montana	√	√	√	√		√	
Nebraska	√	√	√	√		√	√
New Jersey	√	√	√	√	√	√	√
New York	√	√	√	√		√	√
Oklahoma					√	√	√
Oregon			√	√		√	√
Pennsylvania	√	√	√	√		√	√
South Dakota (ITS)	√	√	√	√		√	√
South Dakota (Region Engineer)	√	√	√	√		√	√
South Dakota (Winter Maintenance Engineer)	√	√	√	√	√	√	√
Texas					√		
Utah	√	√	√	√	√	√	√
Washington					√	√	√
Total	**15**	**15**	**16**	**17**	**8**	**16**	**17**

Several respondents offered additional information about traveler information systems used in their state:

- *Massachusetts.* VMS may describe general conditions to expect, but it is not tied to RWIS.
- *New Jersey.* Also uses voice assistants such as Siri, Alexa and Google Home.
- *Washington.* Receives National Oceanic and Atmospheric Administration (NOAA) weather alerts as part of the Pathfinder group.

Traveler Information Platforms

States use a mix of in-house and vendor-supported platforms to manage and distribute traveler information. In-house systems are typically developed to meet agency-specific needs, while vendor-supported platforms often integrate traveler information, weather data and field equipment. Table 2 summarizes in-house platforms; Table 3 highlights vendor-supported platforms used by responding states. Additional information on select products and vendors is provided in Section 2.4.

Table 2. In-House Traveler Information Platforms

State	Platform
Arizona	AZ511; Facebook
Massachusetts	Mass511 system, connected to MassDOT Snow and Ice Management System (SIMS)
Michigan	Mi Drive (public traveler information map)
Oklahoma	Oklahoma Road Condition Map; OKSnowPlows.org
Oregon	TripCheck
New York	511NY
Texas	DriveTexas; Highway Condition Reporting System; Wireless Emergency Alert text alerts; 1-800 public line
Washington	Real-time travel map; mobile app; NOAA collaboration; social media

Table 3. Vendor-Supported Traveler Information Platforms

State	Platform/Product	Vendor
Idaho	Idaho 511	Arcadis
Kansas	KanDrive	Castle Rock
Minnesota	511MN (Condition Acquisition and Reporting System, or CARS)	Castle Rock
Montana	Product suite	Iteris
Nebraska	Nebraska 511 (CARS)	Castle Rock
New Jersey	Voice assistant platform	TRANSCOM
Oregon	Social media	X (formerly Twitter)
Pennsylvania	511PA	Arcadis
Pennsylvania	Portable message boards	Ver-Mac and AMSIG
Pennsylvania	Permanent message boards	Daktronics
South Dakota	SD511	Iteris/DTN
South Dakota	Roadway Management System	Iteris
Utah	TraveliQ	Arcadis

In Minnesota, the agency's manual efforts also include social media and integration with the TMS (IRIS) for dynamic message sign messaging.

Data Shared With the Public

Agencies share a wide range of information with the public during winter weather events. As shown in Table 4, the most commonly reported data include closures, surface conditions and camera imagery, while supplemental information, such as snowplow locations and forecasts, is used to enhance situational awareness for travelers.

Table 4. Road Condition Information Shared During Winter Weather Events

State (Respondent)	Active Snowplow Locations	Plow Camera Photos	Stationary Webcams	Road Weather Information System Information	Closures or Restricted Travel	Forecasted Conditions or Alerts	Surface Condition (e.g., wet, icy, snow-covered)	Travel Difficulty or Driving Advisories
Arizona		√	√		√	√	√	√
Idaho			√	√	√	√	√	
Kansas (Engineer)			√	√	√		√	√
Kansas (Public Service)			√	√	√		√	√
Massachusetts			√		√		√	√
Michigan	√	√			√			√
Minnesota	√	√	√		√		√	
Montana		√		√	√		√	√
Nebraska	√	√	√	√	√	√	√	√
New Jersey			√		√			√
New York			√		√		√	√
Oklahoma	√	√	√	√	√		√	
Oregon			√	√	√		√	√
Pennsylvania	√		√	√	√	√	√	√
South Dakota (ITS)			√	√	√	√	√	√
South Dakota (Region Engineer)			√	√	√		√	√
South Dakota (Winter Maintenance Engineer)		√	√	√	√	√	√	√
Texas			√		√	√	√	√
Utah	√		√	√	√	√	√	√
Washington			√	√	√	√	√	√
Total	**6**	**7**	**18**	**13**	**20**	**9**	**18**	**17**

Several respondents reported additional information that is shared with the public:

- *Michigan.* Current speed and parking information.
- *Oregon.* Chain requirements.
- *South Dakota.* Commercial vehicle restrictions.

Expanding Access to Current Road Conditions

Four responding states provide access to neighboring state road conditions within their traveler information systems. New York's system includes a layer that can be turned on or off to view other states' road conditions, while Oklahoma, Kansas and Montana display links to adjoining states' 511 systems.

Responsibility for Updates

The parties responsible for updating road condition reports varies across states but typically involves a combination of maintenance staff and transportation management center (TMC) personnel, as shown in Table 5. In most cases, these roles work collaboratively, with field staff providing observations and TMC staff managing data entry and public dissemination. Other responsible parties reported by respondents include county radio room operators, maintenance workers, district and state emergency operation centers, and contract meteorologists.

Table 5. Responsibility for Updates

Responsible Party	State
Maintenance Supervisors	Idaho, Kansas, Massachusetts, Minnesota, Nebraska, New York, Oklahoma, South Dakota, Texas, Utah, Washington
Central TMC Staff	Arizona, Idaho, Kansas, Montana, Nebraska, New Jersey, Oklahoma, Oregon
Regional TMC Staff	Arizona, Minnesota, New Jersey, New York, Oklahoma, Pennsylvania, Washington
Snowplow Operators	Idaho, Kansas, Minnesota, Montana, South Dakota, Utah
County Radio Room Operators	Pennsylvania
Maintenance Workers; Area and Regional Supervisors/Engineers	South Dakota
District and State Emergency Operations Center; Travel Division	Texas
Contract Meteorologists	Utah

Update Frequency

Six states update road condition reports in real time, while the remaining states vary widely in their update schedules. Most states report more frequent updating during active weather events, typically as conditions change. The Michigan and Minnesota respondents did not provide a response. Table 6 details state practices for updating frequency and timing.

Table 6. Frequency and Timing of Updates

State	In Real Time	Every Two Hours	Twice Daily	Details of Update Frequency
Arizona				During significant weather events as conditions change; less frequently during minor events.
Idaho			√	Not provided

State	In Real Time	Every Two Hours	Twice Daily	Details of Update Frequency
Kansas	√			Every four hours, as conditions change; generally try to update at 5:30 am, 11:30 am and 3:30 pm.
Massachusetts		√		Every two hours (even hours), approximately 150 depots report observed atmospheric and road weather conditions from the previous two hours. Conditions are color-coded on the 511 maps.
Montana	√			Not provided
Nebraska	√			Not provided
New Jersey	√			Not provided
New York				As conditions change, with a four-hour limit.
Oklahoma				Combination of real time, as conditions change, and four mandatory reporting times throughout the day.
Oregon				Five times daily for specified locations (snow zones).
Pennsylvania		√		Not provided
South Dakota				A minimum of three times per day Monday through Friday and twice daily on Saturday, Sunday and holidays. Updates also occur following initial maintenance activities and as conditions change.
Texas	√			Not provided
Utah				Up to every three hours or as conditions change.
Washington	√			Not provided
Total	**6**	**2**	**1**	

2.2 Automation Tools and Approaches

Eleven responding states reported using, testing or exploring some form of automation to support winter road condition reporting. Six states reported that they have no plans to pursue automation tools at this time.

Overall, automation is most often applied to specific components of the reporting process, such as data collection, integration or formatting, rather than fully replacing manual condition reporting. Agencies commonly integrate data from sources such as automatic vehicle location (AVL)-equipped snowplows, RWIS and maintenance decision support systems (MDSS) to support more efficient workflows. More advanced approaches, including AI-based image recognition, are being explored but are generally in early stages of development.

Summarized below are responding agencies' experiences with:

- Automation tools and approaches in use
- Validation of automated tools
- Exploring automation solutions

Automation Tools and Approaches in Use

Five states are currently using or testing automation tools to support winter road condition reporting. These approaches fall into several categories, including data integration, partial workflow automation and early-stage AI applications. In most cases, these tools support specific elements of the reporting workflow, such as data collection or standardization, while human staff continue to review, adjust and approve final outputs.

While some agencies are exploring more advanced capabilities, such as AI-based image recognition, these tools are not yet widely used for direct reporting and are typically limited to testing or pilot applications. Table 7 presents the tools or approaches states are currently using or testing, including the challenges associated with the tools and their effectiveness.

Table 7. States Using or Testing Automation Tools

State	Tool or Approach	Challenge	Effectiveness
Minnesota	• AVL-integrated snowplows • RWIS + MDSS integration • Automated 511 triggers	• Automated conditions are not always accurate, so overrides are available. • Clearing overrides can be challenging for some users. • Conditions can be localized, and local bad spots may not be identified by the systems.	Somewhat effective
New York	Automated detection of road conditions from DOT cameras with AI (University of Albany National Science Foundation grant-funded project). See the May 2023 Overview of NYSDOT and SUNY Albany Project for more information about this project.	Have not yet automated reporting	Very effective
Oklahoma	Partial automation for compiling reports in a uniform format across eight field districts.	• Senior staff often wants more detailed condition information than what the field districts are reporting. • The interface isn't as user-friendly as it should be.	Somewhat effective
Oregon	• RWIS + MDSS integration • Limited image recognition using Pikalert	Not reported	Too early to tell
South Dakota	• AVL-integrated snowplows • RWIS + MDSS integration • Automated variable speed limit	Not reported	Not reported

Automation systems typically rely on integrating multiple data sources, including AVL data from snowplows, RWIS observations, MDSS outputs and, in some cases, camera imagery. These inputs are used to generate suggested road condition updates or to standardize reporting across regions. However, human review remains a critical component, as automated outputs are often adjusted or overridden to reflect localized conditions. In some cases, automation is limited to specific workflow components. For example, Oklahoma reported using partial automation to compile road condition reports into a uniform format across its eight field districts, rather than automating condition detection or reporting.

State Spotlight: Minnesota

Minnesota DOT integrates AVL-equipped snowplows with RWIS and MDSS data to support automated reporting and 511 triggers. The system improves efficiency by streamlining data collection. However, staff report that automated conditions are not always accurate and require manual overrides, particularly for localized conditions.

Validation of Automated Tools

Few states reported formal validation processes for automated tools. Two states (Oklahoma and Oregon) do not currently validate the accuracy of automated tools, while two states (Minnesota and South Dakota) did not report.

New York State DOT described a validation approach that includes field verification, comparison with snowplow camera images, review by TMC or operations staff, and post-event analysis. The agency emphasized that automated tools, particularly those incorporating AI, should include a “human in the loop” to ensure accuracy and reliability.

Exploring Automation Solutions

Six states are considering automation tools but have not yet implemented them. These efforts reflect growing interest in improving reporting efficiency, though agencies continue to face barriers related to cost, staffing, system integration and data accuracy.

Table 8 summarizes the tools under consideration, the primary barriers to implementation and the drivers of interest in these technologies. Selected tools are further described in Section 2.4, Commercial Products and Vendors.

Table 8. Automation Solutions Under Consideration

State	Tool or Approach	Primary Barrier	Driver of Interest
Arizona	MD30, Wx Horizon	Budget	Virtual weather forecasting.
Idaho	Agency RWIS cameras and friction data	Staffing	More up-to-date and accurate data.
New Jersey	Virtual RWIS	Software accuracy, procurement, advanced traffic management system integration	Accurate and timely delivery of conditions.

State	Tool or Approach	Primary Barrier	Driver of Interest
Pennsylvania	RWIS feeding message boards for snow squalls; variable speed limits	Budget, IT protocols, accuracy	Not reported
Utah	NIRA Dynamics	Time, budget, integration	Accuracy, latency and density of rural reports.
Washington	RWIS-controlled VMS	Budget	Need to provide timely traveler information.

State Spotlight: New York

New York State DOT is testing AI-based image recognition to assess road conditions using traffic camera data. While the system shows promise, it has not yet been deployed for automated reporting, and the agency emphasized the need for a "human in the loop" to validate outputs.

To learn more, see Section 3.4, Artificial Intelligence and Predictive Modeling for publications describing this research, including:

- *Improving Generalizability of Road Condition Classification Models for Department of Transportation Camera Images*
- *Overview of NYSDOT and SUNY Albany Project: Automated Detection of Road Conditions From DOT Cameras With AI*
- *Classifying Road Surface Conditions With Self-Trained Artificial Intelligence*

2.3 Predictive Tools and Approaches

Unlike automation tools, which focus on streamlining the reporting process, predictive tools are primarily used to anticipate future conditions and support operational decision-making.

Six responding states reported using or testing predictive tools to support winter road condition reporting, while five states are considering predictive approaches. Six states indicated no current plans to pursue predictive technologies.

Predictive tools are most commonly used to support maintenance decision-making and situational awareness, rather than to directly generate public-facing road condition reports.

Summarized below are responding agencies' experiences with:

- Predictive tools and approaches in use
- Data sources for predictive tools
- Validation of predictive tools
- Challenges and limitations with predictive tools
- Advice for other agencies
- Exploring predictive solutions

Predictive Tools and Approaches in Use

Predictive tools used by responding states fall into several categories, including MDSS platforms, RWIS-integrated modeling, forecast-based tools and in-house meteorological analysis.

Current approaches rely heavily on forecast-based models and RWIS-integrated systems, with limited use of advanced predictive analytics. Most approaches combine weather forecast data with observed conditions to estimate future road conditions and support operational decision-making. MDSS platforms are among the most widely used tools, providing treatment recommendations and short-term forecasts based on weather and pavement data. More advanced approaches, such as machine learning–based forecasting, are being tested in a limited number of states but are not yet widely adopted.

States reported mixed perceptions of predictive tool effectiveness, with some indicating strong performance and others noting that tools remain in early stages of evaluation. Although no states reported formal or standardized methods for measuring effectiveness, Texas DOT reported that this year, the agency has implemented predictive MDSS and hopes to gather more information from it.

Table 9 presents the predictive tools or approaches states are currently using or testing, including the challenges associated with the tools and their effectiveness.

Table 9. States Using or Testing Predictive Tools

State	Tool	Challenge	Effectiveness
Arizona	• Forecast-based modeling using machine learning or AI • RWIS-integrated modeling	Not reported	Too early to tell
Michigan	• MDSS • RWIS-integrated modeling	Accuracy	Very effective
Pennsylvania	Forecast-based modeling using machine learning or AI	Accuracy	Somewhat effective
South Dakota	• MDSS • RWIS-integrated modeling • Commercial forecasting	Accuracy	Very/somewhat effective
Texas	• MDSS • RWIS-integrated modeling	Limited number of RWIS stations	Too early to tell
Utah	In-house meteorologist using manual tools	Accuracy and functionality	Very effective

State Spotlight: Utah

Utah DOT relies on in-house meteorologists using manual forecasting tools to support winter road condition reporting. While effective, this approach requires specialized expertise and may present staffing and budget challenges for other agencies.

Data Sources for Predictive Tools

RWIS and weather forecast data form the foundation of most predictive tools, with additional data sources used to improve accuracy where available. As shown in Table 10, states also incorporate AVL data, camera imagery and other inputs to support predictive capabilities.

Table 10. Data Sources Used for Predictive Tools by State

Data Source	State
Weather Forecast Data	Arizona, Michigan, Pennsylvania, South Dakota, Texas, Utah
RWIS	Arizona, Michigan, South Dakota, Texas, Utah
AVL Data	Arizona, Michigan, South Dakota, Utah
Vehicle-Mounted Sensors	Arizona, Michigan, South Dakota, Texas
Plow Camera Imagery	Arizona, Michigan, South Dakota
Crowdsourced Traffic or Condition Reports	South Dakota, Utah

Validation of Predictive Tools

Validation practices for predictive tools vary across states. Five states have not attempted to formally measure the effectiveness of predictive tools.

As shown in Table 11, common validation approaches include field verification, comparison with camera or visual data, and review by TMC or operations staff. As with automation tools, these practices are not yet standardized and remain an area for further development.

Table 11. Methods Used to Validate Predictive Tools by State

Validation Method	State
Field Verification by Staff	Pennsylvania, South Dakota, Texas, Utah
Plow Cam or Visual Data Comparison	South Dakota, Texas, Utah
Post-Event Analysis or Audit	South Dakota, Texas, Utah
TMC or Operations Staff Review	Pennsylvania, Utah
No Validation	Michigan

Challenges and Limitations With Predictive Tools

Respondents identified several challenges associated with predictive tools, particularly related to weather variability and data limitations. Tables 12 and 13 summarize reported challenges related to system performance and specific weather conditions, respectively.

Table 12. Challenges Associated With Predictive Tools

Challenge	State
Accuracy	Michigan, Pennsylvania, South Dakota, Texas
Functionality	Michigan, Utah
Forecasting Visibility	South Dakota
Limited Number of RWIS	Texas
Learning Curve	Texas

Table 13. Challenges Associated With Weather Events or Road Conditions

Challenge	State
Freezing Rain/Sleet	Pennsylvania, Texas, Utah
Snow Squalls/Snow Events	Pennsylvania, Texas
Lake Effect Snow Events	Michigan
Precipitation at Borderline Temperatures	South Dakota
Storm Types	Utah

State Spotlight: Texas

In Texas, snow event forecasts are generally accurate other than the quantity, but ice events tend to be significantly more difficult to forecast — particularly in terms of location and extent.

Advice for Other Agencies

Predictive tools can support decision-making, but their effectiveness depends on how well they are integrated into agency workflows and supported by reliable data.

Agencies offered the following advice for testing or implementing predictive tools:

- *Michigan*. Understand how tools will be used before investing in a complex system that may not be utilized.
- *Pennsylvania.* Verify the information.
- *South Dakota.* Ensure user buy-in and review recommendations and results when seeking improvements in practice.
- *Utah.* Consider the benefits of an in-house meteorologist. While retaining an in-house meteorologist has advantages, including cost savings, the respondent noted that it can be challenging in regard to staffing and budget to switch to that model. Implementation approaches require a lot of thought and planning.

Exploring Predictive Solutions

Several states are exploring predictive tools but have not yet implemented them. These efforts focus on expanding data inputs and improving forecasting capabilities. Table 14 summarizes the predictive solutions under consideration, along with reported barriers to adoption and drivers of interest.

Table 14. Predictive Solutions Under Consideration

State	Tool or Approach	Primary Barrier	Driver of Interest
Idaho	Friction sensors	Not reported	Not reported
Massachusetts	RWIS provider and weather forecaster — the forecaster uses RWIS data to model road weather forecasts.	Not reported	Not reported
Oklahoma	RWIS-based alerts for maintenance supervisors when bridge deck temperatures fall below thresholds.	Sensor reliability	Being caught unprepared or inadequately responsive to a snow/ice event.
Oregon	Virtual RWIS (Pikalert), MDSS and forecasting tools.	Technical integration and proving reliability of data in variable conditions.	Increasing frequency of reporting and reducing staff effort to gather and report information.
Washington	RWIS-based approaches	Budget	Better, more timely information for the traveling public.

2.4 Commercial Products and Vendors

A range of commercial tools and vendor-supported platforms are available to support winter road condition monitoring, reporting and decision-making. These tools are typically provided by private-sector vendors and support functions such as traveler information systems, weather forecasting, data integration, field communications and predictive modeling. Many state DOTs rely on a combination of these tools, either as standalone systems or integrated within broader operational platforms.

Rather than representing a single solution, these tools are most often used together to support different parts of the road condition reporting workflow. Detailed below are key categories of commercial tools and examples of tools mentioned in the survey.

Key Categories of Commercial Tools

Products identified in the survey responses and literature can be grouped into several functional categories: traveler information and reporting platforms, weather and data providers, hardware and field device products, and platforms facilitating system integration and regional coordination.

Traveler Information and Reporting Platforms

These platforms support the collection, management and dissemination of road condition reporting information to the public through systems such as 511, mobile applications and web-based maps. They often integrate multiple data sources and provide interfaces for TMC staff to update and publish road condition reports. Examples cited in the survey include:

Castle Rock Associates, Inc.
From the website: Castle Rock is a software company specializing in Advanced Traveler Information Services (ATIS). Our customers include departments of transportations (DOTs), ministries of transport, municipal and local governments, and regional planning organizations. Castle Rock's software platform empowers the public to get travel knowledge through our interactive websites, 511 phone systems, iOS and Android mobile apps, social media and more.

Iteris, Inc.
From the website: Iteris combines leading software, hardware and services on a platform that is built to enable the future of smarter and connected transportation. The breadth of services we offer provides Iteris with a unique, 360-degree perspective as we support all phases of the intelligent transportation system (ITS) lifecycle. Iteris regularly delivers projects encompassing the entire project life cycle, from concept of operations through civil/software design to implementation, evaluation, operations and maintenance.

Arcadis N.V.
From the website: We're on a mission to support our clients in making the right decisions to navigate today's challenges and address tomorrow's uncertainties by bridging the gap between human intelligence and technology. By leveraging our design, engineering and consultancy expertise alongside our digital solutions, we offer custom products geared towards agility and resiliency to bolster business growth and shape sustainable cities around the globe. Travel-IQ, Arcadis' Advanced Traveler Information System (ATIS), enables public agencies to efficiently report and manage travel-impacting events like roadwork, accidents and special events.

Weather and Data Providers

Weather and data vendors provide meteorological data, forecasts and decision-support tools that inform road condition reporting and winter maintenance operations. Their data are commonly integrated into agency systems or third-party platforms to support operational decision-making and traveler information updates. Examples cited in the survey include:

DTN
From the website: DTN has the most comprehensive weather expertise in the world. We deliver the most hyper-local, accurate and real-time weather intelligence available. With our intelligence, you are able to act quickly and efficiently to keep your employees, your stakeholders and your assets out of harm's way. You can rely on our forecasts to help you make confident and cost-effective decisions regarding roadway treatment plans or route planning to avoid costly delays. With DTN backing your decisions, you can reduce your risk and protect the people and products that rely on safe and open roadways.

Hardware and Field Device Products

These products include dynamic message signs, sensors and other field equipment used to communicate with travelers or collect roadway data. These tools support real-time messaging and data collection in the field. Examples cited in the survey include:

Daktronics, Inc.

From the website: Since 1988, Daktronics has led the way in DMS [dynamic message sign] product development. Vanguard products fit any ITS application and offer industry-critical reliability, legibility and serviceability.

Ver-Mac

From the website: Ver-Mac creates innovative Work Zone Safety solutions by generating and sharing real-time information through connected technologies.

American Signal Company (AMSIG)

From the website: Based in Atlanta, Georgia, AMSIG specializes in portable message signs, speed display trailers, ITS applications, CCTV [closed-circuit television] systems, Highway Advisory Radios and retrofit solutions that support safer, smarter and more efficient environments.

System Integration and Regional Coordination Platforms

Some platforms support the integration of multiple systems and data streams across agencies or regions. These tools may facilitate coordination among transportation agencies, transportation management centers and public safety organizations, particularly in large metropolitan areas or multi-agency environments. Examples cited in the survey include:

TRANSCOM

From the website: TRANSCOM is a coalition of 16 transportation and public safety agencies in the New York — New Jersey — Connecticut metropolitan region. It was created in 1986 to provide a cooperative, coordinated approach to regional transportation management.

Example Tools and Emerging Capabilities

In addition to the categories above, several tools identified in the survey and literature illustrate emerging capabilities in winter road condition monitoring and reporting. These tools highlight trends toward increased automation, expanded data sources, and improved decision support and include:

MD30 (Vaisala)

From the website: The Mobile Detector MD30 from Vaisala monitors road conditions, and transmits weather data from snowplows or any vehicle type without disruption — keeping your ground transportation or airport operations running smoothly and safely. The MD30 is compact, easy to install and cost effective even for large fleet deployment. Its quick response time and high sensitivity enable reliable mobile road condition data year-round.

NIRA Dynamics

From the website: For the infrastructure sector, we harness data from millions of connected vehicles to deliver accurate, up-to-date insights on road conditions. Our solutions, such as Road Health and Winter Road Insights, enable road owners and maintenance providers to monitor road quality in real time, prioritize repairs and optimize seasonal maintenance. This data-driven approach makes road upkeep more efficient, cost-effective and sustainable — while extending the life of the infrastructure itself.

Wx Horizon (Vaisala)

From the website: Vaisala's new Ground Cast Sensor is automatically integrated to Wx Horizon Premium which fuses local observation data with two of Vaisala's industry-leading modelling systems: its best-in-class road weather model and a weather forecasting system that improves global weather forecasts specifically designed for use in transportation.

Pikalert (University Corporation for Atmospheric Research)
From the website: With funding and support from the U.S. Department of Transportation's (USDOT) Research and Innovative Technology Administration (RITA) and direction from the Federal Highway Administration's (FHWA) Road Weather Management Program, the National Center for Atmospheric Research (NCAR) is conducting research to develop the Pikalert System that incorporates vehicle-based measurements of the road and surrounding atmosphere with other, more traditional weather data sources, and creates road and atmospheric hazard products for a variety of users.

3 Examining the Literature

This review of relevant literature summarizes publicly available research, guidance and related resources on winter road condition reporting, with an emphasis on automation, system integration, predictive modeling and emerging data sources. The resources reviewed reflect a progression from traditional reporting workflows that rely heavily on field observations to more advanced approaches that incorporate mobile observations, connected vehicle data, crowdsourcing, AI and decision-support tools. Together, the literature highlights the potential of these technologies to improve timeliness and coverage and the continuing importance of data quality, standardization, validation and human oversight.

The resources cited below are organized into six categories:

- Traditional reporting workflows
- Mobile and field-based data collection
- Automation and system integration
- Artificial intelligence and predictive modeling
- Connected vehicle and emerging data sources
- Crowdsourced and third-party data

3.1 Traditional Reporting Workflows

State DOTs typically rely on a combination of field observations, RWIS data and TMC workflows to update winter road condition reports. In many cases, maintenance staff and snowplow operators observe conditions in the field and relay this information to TMC personnel, who are responsible for updating traveler information systems such as 511. While some systems incorporate automated elements, these workflows remain largely manual and depend on human observation and communication.

The following examples illustrate how traditional reporting workflows are implemented in practice.

Best Practices for Road Condition Reporting Systems, Dean Deeter, Ginny Crowson, Tina Roelofs, Jeremy Schroeder and Deepak Gopalakrishna, Federal Highway Administration, September 2014.
https://ops.fhwa.dot.gov/publications/fhwahop14023/fhwahop14023.pdf
From the abstract: Often, the center of an agency's traveler information system is a Road Condition Reporting System (RCRS). The RCRS is frequently the focal point, populated by manual and automated data and information feeds, supplying information to various information dissemination mechanisms. While the potential benefits of an RCRS are obvious, there are also costs associated with the development, management and support of the software system as well as costs associated with the operator time to perform entry. The benefits and costs are impacted by many institutional and technical issues that operations managers must face. This report presents a synthesis of current industry practices regarding the design, development, operation, maintenance and use of RCRSs. This report compiles information received through a survey and interviews with transportation agencies throughout North America to understand the uses of RCRSs and to identify industry practices that have delivered benefits to the agencies operating RCRSs. A total of 49 Current RCRS Industry Practices, 7 Best Practices and 3 Emerging Best Practices are described in this report.

Best Practices for Road Weather Management, Version 3.0, Ray Murphy, Ryan Swick and Gabe Guevara, Federal Highway Administration, June 2012.
Publication available at https://rosap.ntl.bts.gov/view/dot/26035
From the abstract:

> This report contains 27 case studies of systems in 22 states that improve roadway operations under inclement weather conditions. Each case study has six sections including a general description of the system, system components, operational procedures, resulting transportation outcomes, implementation issues, as well as contact information and references. Appendix A is an acronym list.

See page 41 of the report (page 47 of the PDF) for *Kansas DOT Road Weather Information for Travelers System.*

3.2 Mobile and Field-Based Data Collection

Mobile and field-based data collection approaches are used by state DOTs to supplement traditional reporting workflows and improve the timeliness and spatial coverage of road condition information. These approaches include technologies deployed on maintenance vehicles, such as snowplow-mounted cameras and sensors, as well as systems that collect and transmit real-time observations from the field. By capturing conditions directly from the roadway, these tools help bridge gaps between fixed infrastructure, such as RWIS and manual reporting processes. The following examples illustrate how mobile and field-based data collection approaches are being used to support winter road condition monitoring and reporting.

Integrating Mobile Observations (IMO) Overview, Office of Operations, Federal Highway Administration, 2018.
https://ops.fhwa.dot.gov/publications/fhwahop18041/fhwahop18041.pdf
From the website: Through round 4 of Every Day Counts (EDC-4), the Federal Highway Administration's (FHWA) Weather-Savvy Roads effort promotes two distinct road weather management solutions that allow State and local agencies to proactively manage the surface transportation system ahead of and during adverse weather events: Pathfinder and IMO.

IMO builds on vehicle-based technologies like automatic vehicle location and real-time communication that most states have already implemented in government fleet vehicles. Additional ancillary sensors collect weather and road condition data (such as air pressure, air and surface temperature, spreader rate and materials, windshield wiper status and rate, and relative humidity) and, when available, vehicle systems are accessed to collect and disseminate resident data. The data provides maintenance managers with a detailed view of the weather and road conditions, as well as asset locations along the highway network. This information can support a variety of applications for road weather management maintenance and operations decision making, including road weather forecasts, end of shift reporting, material management, traveler information, performance management, road weather conditions and maintenance decision support.

Installing Snowplow Cameras and Integrating Images into MnDOT's Traveler Information System, Brian Hirt and Scott Petersen, Minnesota Department of Transportation, October 2017.
https://mdl.mndot.gov/_flysystem/fedora/2023-01/201741.pdf
From the executive summary: The Minnesota Department of Transportation (MnDOT) sought to bridge the information gap between MnDOT staff in the field and the traveling public with respect to adverse road conditions. This project aimed to augment existing weather advisories with images of road conditions taken from MnDOT snowplows in the field. MnDOT planned to use its existing 511 travel

information system — namely, the travel information website and 511 mobile app — to share this information with the public.

3.3 Automation and System Integration

RWIS and MDSS are not fully automated systems, but they form the foundation of many automated and semi-automated workflows. RWIS provides continuous, real-time environmental data, while MDSS integrates these data with weather forecasts and operational rules to generate treatment recommendations and support decision-making. When integrated with traveler information systems and TMC platforms, these tools can enable more automated processes for generating and disseminating road condition information. These resources illustrate how automation in winter road condition reporting is enabled by the integration and standardization of data across multiple systems.

Maintenance Decision Support System (MDSS), Research Applications Laboratory, University Corporation for Atmospheric Research, National Science Foundation, 2026.
https://ral.ucar.edu/solutions/products/maintenance-decision-support-system-mdss
From the website:

> **MDSS Prototype Technical Overview**
> The MDSS ingests weather forecast data at locations important to the user's operations. These forecast locations are typically at surface observation stations such as RWIS and METAR sites, though they need not be. The weather forecasts at each forecast location serve as input to the pavement heat balance model (e.g., METRo) that predicts the road surface and subsurface temperatures and the snow depth at each forecast lead-time. These forecast road conditions are used to generate treatment plans at each site based on Rules of Practice guidelines. The prototype MDSS® also includes a graphical user interface display designed for easy interpretation by road maintenance managers. This display application is designed to allow the maintenance manager to generate "what-if" scenarios by setting up customized treatment plans and seeing the resulting predicted road conditions.

Standardized Framework for Winter Weather Road Condition Indices, Aurora Program Transportation Pooled Fund, Tech Transfer Summary, February 2026.
https://www.aurora-program.org/wp-content/uploads/2026/03/standardized_framework_road_condition_indices_t2.pdf
From the problem statement: In the absence of a standardized national framework, substantial variation among WWRCIs [winter weather road condition indices] has arisen in how road conditions are defined, assessed and communicated. These inconsistencies can create confusion for travelers and limit the ability of transportation agencies to compare performance, share best practices and benchmark winter operations effectively. A standardized national WWRCI framework offers an opportunity to establish a consistent, reliable and transparent approach for assessing and communicating winter road conditions.

Frequently Asked Questions, Road Weather Management Program, Federal Highway Administration, last updated September 2024.
https://ops.fhwa.dot.gov/weather/faq.htm
From the website:

> **What Is a Road Weather Information System (RWIS)?**
> A Road Weather Information System (RWIS) is comprised of Environmental Sensor Stations (ESS) in the field, a communication system for data transfer and central systems to collect field data from numerous ESS. These stations measure atmospheric, pavement and/or water level conditions.

Central RWIS hardware and software are used to process observations from ESS to develop nowcasts or forecasts, and display or disseminate road weather information in a format that can be easily interpreted by a manager. RWIS data are used by road operators and maintainers to support decision making.

What Types and Sources of Road Weather Information are Available?
There are three types of road weather information: atmospheric data, pavement data and water level data. Atmospheric data include air temperature and humidity, visibility distance, wind speed and direction, precipitation type and rate, cloud cover, tornado or waterspout occurrence, lightning, storm cell location and track, as well as air quality. Pavement data include pavement temperature, pavement freezing point, pavement condition (e.g., wet, icy, flooded), pavement chemical concentration and subsurface conditions (e.g., soil temperature). Water level data include stream, river and lake levels near roads, as well as tide levels (i.e., hurricane storm surge).

Transportation managers obtain road weather information from many sources including Road Weather Information Systems (RWIS), general weather observations and forecasts, and private sector vendors. General road weather observations are obtained from national surveillance systems to produce weather watches and warning for public safety. The National Weather Service (NWS) deploys sensor stations, balloon-borne sensors, Doppler radars and other technologies to generate national, regional and county forecasts. Surface weather observing systems are also deployed by the Federal Aviation Administration, the U.S. Geological Survey, the Department of Agriculture, the Forest Service and the Environmental Protection Agency. General road weather data are also available from the National Centers for Environmental Prediction, the National Hurricane Center, local Weather Forecast Offices and River Forecast Centers. Environmental data can also be collected from vehicle-based sensors. Some DOT's have deployed air and pavement temperature sensors on snow plows. Observation data from passenger vehicle sensors will be available in the future through the Vehicle Infrastructure Integration (VII) Initiative, which aims to deploy advanced vehicle-vehicle and vehicle-infrastructure communications.

Private vendors provide high-resolution, route-specific road weather information tailored for particular operational applications. These vendors — also known as Value Added Meteorological Services (VAMS) — add value to general road weather products by customizing forecasts specifically for transportation managers. Precipitation start and stop times are examples of tailored road weather forecasts.

Transportation managers utilize roadway warning systems, interactive telephone systems (e.g., 511) and web sites to disseminate road weather information to travelers in order to influence their decisions. This information allows travelers to make choices about travel mode, departure time, route selection, vehicle type and equipment, and driving behavior.

Integration of Connected Vehicle and RWIS Technologies, Inya Nlenanya, Adnan Inusah and Shauna Hallmark, White Paper, Aurora Program Transportation Pooled Fund, June 2024.
https://www.aurora-program.org/wp-content/uploads/2024/06/integration_of_CV_and_RWIS_technology_w_cvr.pdf
From the abstract: Connected vehicles (CVs) are equipped with advanced technologies that allow them to communicate with infrastructure, other vehicles and external systems. Meanwhile, transportation agencies maintain networks of road weather information systems (RWIS) that monitor weather and pavement surface conditions and communicate these conditions to agency personnel in order to facilitate maintenance operations and decision-making. Integrating CV technology into RWIS

infrastructure has the potential to significantly improve road safety by providing real-time weather information to drivers. This white paper presents the findings to date of the Integration of Connected Vehicle (CV) and Road Weather Information System (RWIS) Technologies project. The project reviewed the literature related to CV-RWIS integration, analyzed ongoing projects carried out by departments of transportation (DOTs) on CVs and RWIS, surveyed state and local transportation agencies regarding their investments in RWIS technologies to facilitate integration with CVs, conducted follow-up interviews with selected agencies, and prepared a summary of current challenges to CV-RWIS integration and recommendations for future research.

3.4 Artificial Intelligence and Predictive Modeling

AI and predictive modeling are increasingly being explored to support winter road condition monitoring and decision-making. These approaches use data from cameras, sensors and forecasts to identify current conditions and predict future roadway states. While many applications remain in development or early deployment, they demonstrate potential to enhance situational awareness and support more proactive operations. A growing body of research focuses on using traffic camera imagery and machine learning techniques to automatically detect road surface conditions.

"Machine Learning Detection of Road Surface Conditions: A Generalizable Model Using Traffic Cameras and Weather Data," Carly Sutter, Kara J. Sulia, Nick P. Bassill, Christopher D. Wirz, Christopher D. Thorncroft, Jay C. Rothenberger, Vanessa Przybylo, Mariana G. Caines, Jacob Radford and David Aaron Evans, accepted for publication in the *International Journal of Transportation Science and Technology*, 2026.
https://arxiv.org/pdf/2510.06440
From the abstract: Transportation agencies make critical operational decisions during hazardous weather events, including assessment of road conditions and resource allocation. In this study, machine learning models are developed to provide additional support for the New York State Department of Transportation (NYSDOT) by automatically classifying current road conditions across the state. Convolutional neural networks and random forests are trained on NYSDOT roadside camera images and weather data to predict road surface conditions. This task draws critically on a robust hand-labeled dataset of ∼ 22,000 camera images containing six road surface conditions: severe snow, snow, wet, dry, poor visibility or obstructed. Model generalizability is prioritized to meet the operational needs of the NYSDOT decision makers, including integration of operational datasets and use of representative and realistic images. The weather-related road surface condition model in this study achieves an accuracy of 81.5% on completely unseen cameras. With operational deployment, this model has the potential to improve spatial and temporal awareness of road surface conditions, which can strengthen decision-making for operations, roadway maintenance and traveler safety, particularly during winter weather events.

An Intelligent Human-Centric Communication System for Adverse Weather and Road Conditions, Ibrahim Demir, Yusuf Sermet, Moaiz Abrar and Gabriel Vald, Aurora Program Transportation Pooled Fund, September 2025.
https://www.aurora-program.org/wp-content/uploads/2025/09/CARWIS_w_cvr.pdf
From the abstract: Adverse weather conditions present significant risks to motorists, making safe navigation challenging. Artificial intelligence (AI) advancements have facilitated the development of intelligent systems to address these concerns. This project introduces Conversational AI for Road Weather Information Systems (CARWIS), an AI-powered solution that provides real-time data on road conditions during severe weather. CARWIS gathers data from various sources, including weather forecasts and traffic cameras, and employs natural language processing to generate timely and accurate

insights into road conditions. CARWIS can detect hazardous conditions, such as icy roads or low visibility due to fog or precipitation, and refine its predictions over time, enabling drivers to make informed decisions about their travel plans, potentially reducing accidents and enhancing safety. Additionally, CARWIS can assist transportation professionals in planning for and responding to severe weather events by providing detailed information on road conditions. This enables officials to prioritize resources and make well-informed decisions regarding road closures and safety measures. This innovative solution harnesses the power of AI to improve road safety and reduce incidents during adverse weather conditions. As AI technology continues to progress, it is anticipated that more advanced systems will be developed to assist in navigating and managing severe weather events on roadways.

"Improving Generalizability of Road Condition Classification Models for Department of Transportation Camera Images," Carly Sutter, Kara J. Sulia, Nick P. Bassill, Christopher D. Thorncroft, Vanessa Przybylo, Christopher D. Wirz, Mariana Goodall Cains, Jacob T. Radford and David Aaron Evans, *American Meteorological Society 104th Annual Meeting*, 2024.
Citation at https://ams.confex.com/ams/104ANNUAL/meetingapp.cgi/Paper/438154
From the abstract: The New York State Department of Transportation (NYSDOT) has a large network of publicly available roadside cameras (511ny.org) that are used by both the public and NYSDOT to monitor road conditions, especially during winter storms. In an effort to automate the manual task of monitoring cameras, convolutional neural networks are trained to classify images into one of six road surface categories: severe snow, snow, wet, dry, poor visibility or obstructed. These road-surface models are successful at identifying the road conditions on unseen images (the validation dataset) when all cameras and dates are represented in model development (the training dataset), achieving validation accuracy of ~90%. However, validation accuracy drops to ~60% when evaluated on new dates or cameras, indicating the need to explore additional methods to achieve model generalizability. Improving model generalizability is crucial in developing a tool that can be used in future winters to inform resource allocation and driving safety across the state of New York on thousands of new cameras in different and changing environments.

"Overview of NYSDOT and SUNY Albany Project: Automated Detection of Road Conditions From DOT Cameras With AI," Carly Sutter, Nick Bassill, Kara Sulia and Chris Thorncroft, New York State Department of Transportation, *WINTRE_MIX Workshop*, May 2023.
https://www.eol.ucar.edu/sites/default/files/2023-08/07%20-%20Sulia_WINTRE-MIX_2023-RestrictedFontsRemoved.pdf
This workshop presentation describes research by NYSDOT and partners to improve the generalizability of machine learning models used to classify road surface conditions from traffic camera imagery. The work examines how training data, labeling and model design influence performance when applied to new cameras and conditions, highlighting challenges in deploying these models reliably across different environments.

"Classifying Road Surface Conditions With Self-Trained Artificial Intelligence," Vincent A. Ferrera, Jay Calder Rothenberger, Melissa Wilson Reyes, Carly Sutter, Andrew H. Fagg and Dimitrios Diochnos, *American Meteorological Society 103rd Annual Meeting*, 2023.
Citation at https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/411860
From the abstract: Determining precipitation cover on roads is vital knowledge for transportation planning and safety. The New York State Department of Transportation (NYSDOT) has thousands of camera locations (sites), each of which provide visuals of a stretch of road. In these camera images, it is possible to determine the road surface condition present, or, in other words, whether the road is dry, snow-covered or wet. However, manually evaluating this proves to be both difficult and expensive; thus, we choose to employ machine learning to create a model to automatically provide such classifications. … Nonetheless, in order to perform the popular and versatile methods of "supervised learning" for AI

models, the data must be accompanied by ground-truth labels. Trained professionals have provided labels for several subsets of NYSDOT images. These labeled images can then be fed into supervised machine learning pipelines, allowing us to train a model to classify observed road surface conditions for future images.

Winter Road Weather: Decision Making, NSF AI2ES, National Science Foundation, undated.
https://www.ai2es.org/winter-weather/#road
From the website: Severe winter weather poses significant challenges for roadway safety, increasing the risk of accidents and disrupting transportation systems. To address this, our winter weather team has developed an AI model that provides real-time, automated identification and prediction of road weather conditions for the New York Department of Transportation (NYSDOT). This model leverages a comprehensive dataset created in collaboration with NYSDOT, which includes archived images from 2,400 live 511NY traffic cameras. Our solution will deliver real-time decision-support tools to help NYSDOT rapidly assess and respond to hazardous winter road conditions. By enhancing situational awareness and enabling faster, data-driven decisions, this project aims to improve public safety, reduce weather-related delays and optimize road maintenance operations across New York State.

Automated Extraction of Weather Variables From Imagery, Gerry Wiener, William Petzke, Tom Brummet and Curtis Walker, Aurora Program Transportation Pooled Fund, February 2023.
https://www.aurora-program.org/wp-content/uploads/2023/02/automated_extraction_of_weather_variables_w_cvr.pdf
From the abstract: Department of transportation (DOT) maintenance supervisors utilize a variety of tools including maintenance decision support systems (MDSS) to gain a better understanding of current and future road surface conditions (RSC) during winter weather. MDSS automatically attempt to deduce current RSC based on road weather information system (RWIS) and other data to a greater or lesser degree of accuracy. Although current MDSS implementations present highway camera imagery, they typically do not incorporate automated camera image recognition in order to improve the MDSS assessment of winter RSC. Thus, there can be discrepancies between the road weather conditions in camera images and MDSS RSC assessments. For example, an MDSS assessment may determine that a highway is clear whereas associated camera images show snow or vice versa. Such discrepancies can lead to a loss of confidence, system criticism and noncompliance with MDSS recommendations. From that point of view, the integration of automated RSC camera image recognition into MDSS implementations can have a number of benefits:

- Better RSC assessment performance
- Better road treatment recommendations owing to better RSC identification
- Improved MDSS use and compliance with system recommendations owing to user confidence

Recent research in RSC identification has applied convolutional neural networks (CNN) and related techniques to the winter RSC identification problem. The National Center for Atmospheric Research (NCAR) is interested in transitioning these automated RSC identification techniques from the research community to the DOT community. Since NCAR has significant experience in the research-to-operations arena, the NCAR team worked with Aurora Program members to develop a set of recommendations for transitioning the relevant technology to MDSS applications. Even though recent research efforts seem quite successful, the NCAR team was also interested in the potential to improve the initial CNN RSC identification by incorporating additional relevant data such as the following:

- RWIS precipitation/temperature data
- Vehicle speed/volume data.

Some research efforts are moving beyond individual models toward integrated systems that combine multiple data sources and analytical methods.

Identifying Real-World Transportation Applications Using Artificial Intelligence (AI): Real-World AI Scenarios in Transportation for Possible Deployment, Meenakshy Vasudevan, Haley Townsend and Edward Schweikert, Karl Wunderlich, Carolina Burnier, Britton Hammit, Doug Gettman and Kaan Ozbay, Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation, July 2020. Publication available at https://rosap.ntl.bts.gov/view/dot/50752
From page 20 of the report, page 30 of the PDF:

> **Digital Assistants**
> For many years, 511 systems have used natural language processing (NLP) to understand a user's requested route. These systems historically have been limited in both their technical capability (e.g., understanding user phrases with background noise while driving) and the phraseology expected from the user (e.g., bus stop identification numbers, freeway names and sections). Significant enhancements of NLP capabilities in digital assistants should be available in coming years. Metropolitan Transportation Commission (MTC) Bay Area 511 now has an Alexa skill to pass through requests for 511 information for the same phraseology that works with their interactive voice response (IVR) module (Amazon, 2020). Alexa skills are becoming popular with cities as part of 311 and community service information systems, one of many examples in John's Creek, GA, a suburb of Atlanta (Hutmacher, 2018).
>
> Recently, the Virginia Department of Transportation (VDOT) held a "hackathon" with more than 50 volunteer developers to leverage the VDOT open data application programming interfaces (API) for a variety of quick demonstration projects. One of the winners ("Talk DOT") was an Alexa skill to allow users to ask questions of the VDOT database as if they were manipulating the VDOT Web interface (Chandran & Kumar, 2018). Additional functions of AI-based assistants, such as smart home technology can easily be extended to TMC operations, such as voice-activated video wall configuration and other enhancements to traditional operations.

3.5 Connected Vehicle and Emerging Data Sources

These resources illustrate the expanding role of CV technologies and vehicle-based data in enhancing road weather monitoring and traveler information systems. Connected vehicle technologies are expanding the range of data available to support winter road condition monitoring and reporting. By leveraging vehicle-based sensors and integrated communication networks, these approaches provide more continuous and geographically distributed coverage than traditional fixed infrastructure. While many applications are still emerging, they offer potential to enhance situational awareness and support more automated traveler information systems.

Related approaches include the use of probe and third-party data to estimate roadway conditions. These data sources often overlap with CV applications, as vehicle-based observations may be aggregated and distributed through external platforms. Further discussion of crowdsourced and third-party data applications is provided in Section 3.6.

Piloting Connected Vehicle Technology on Interstate 80 in Wyoming, Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation, March 2025.
https://www.itskrs.its.dot.gov/sites/default/files/2025-03/case-study/WYDOT_CV_Pilot_Case_Study_FINAL_508c_V5.pdf
From the case study: In this case study you will learn:

- How the Wyoming Department of Transportation (WYDOT) built a connected vehicle (CV) network to address weather-related incidents and reduce costly road closures
- How WYDOT was able to expand the benefits of CV messaging outside of the original deployment area
- How data from the WYDOT CV Pilot was leveraged to enable hands-free traveler information updates

Road Weather Management Using Connected Vehicle Technology, WSP USA, Aurora Program Transportation Pooled Fund, September 2024.
https://www.intrans.iastate.edu/wp-content/uploads/2024/09/road_weather_management_using_CV_technology_w_cvr.pdf
From the abstract: Road weather systems collect, analyze and share weather information to help mitigate the disruptive impact of weather events on the nation's surface transportation system. Much research and development has been undertaken to advance road weather management practice. Meanwhile, many state and local efforts have aimed to deploy connected vehicle (CV) equipment on the roadside and in vehicles. CV message exchanges present an opportunity to provide vehicle-produced, standardized road weather data to transportation infrastructure owners and operators while standardizing the dissemination of weather-related information to travelers. In particular, road weather systems have the potential to benefit from the data that vehicles may produce and to provide critical information to drivers of those vehicles. It has been several years since any significant research, development and deployment of weather-related connected vehicle applications have been undertaken. Many weather-related CV standards (such as SAE J2945/3) have been released recently but have not yet had much opportunity to be used in practice. The goal of this project was to determine how the data in CV messages could be utilized to enhance existing use cases or potentially enable new use cases for road weather information. Section 2 of this report outlines the results of initial research, including an overview of CV technology and use cases for CV message data. Section 3 presents a Concept of Operations focusing on message exchanges that will enhance the quality of the weather data used in road weather and traffic management activities.

"The Use of Vehicle-Based Observations in Weather Prediction and Decision Support," Amanda R. Siems-Anderson, *Meteorological Applications*, Vol. 31, Issue 4, July/August 2024.
https://rmets.onlinelibrary.wiley.com/doi/10.1002/met.2225
From the abstract: Vehicle-based mobile observations are taken across the world every day by operational and research meteorological organizations, public transportation agencies, and private car manufacturers. Whether directly weather-related (e.g., air temperature) or not (e.g., wiper speed), the coverage and frequency of these observations holds the promise of filling in gaps between fixed observing stations and greatly improving situational awareness and weather forecasting, from road surface condition-specific applications and winter road maintenance to urban and street-level numerical weather prediction and beyond. However, in order to take advantage of these observations, the weather, water and climate enterprise must work together with the transportation enterprise across academic, public and private sectors to provide a mechanism for obtaining these data, so that the benefits of using these unconventional observations may be realized.

Considerations of Current and Emerging Transportation Management Center Data, Michael L. Pack, Nikola Ivanov, Jocelyn K. Bauer and Elizabeth Birriel, Federal Highway Administration, July 2019.
https://ops.fhwa.dot.gov/publications/fhwahop18084/fhwahop18084.pdf
From Chapter 2, Emerging Data Sources (page 5 of the report, page 21 of the PDF): The private sector is constantly evolving and innovating — trying to create the next data product or service that will give businesses a competitive advantage. While it is difficult to predict the future, this section includes data

that is becoming available now or will likely become available in the next several years. Not every private sector provider wants to reveal its anticipated products or schedules, but table 1 provides a list of newer and emerging data sources that not all agencies have used yet.

3.6 Crowdsourced and Third-Party Data

Crowdsourced and third-party data sources are increasingly being used by transportation agencies to supplement traditional and agency-collected data for winter road condition monitoring. These approaches rely on information generated outside of DOT operations, including data from the traveling public and private-sector platforms. By leveraging widely distributed data sources, these approaches can improve spatial coverage and provide more timely insights into roadway conditions, particularly in areas where fixed infrastructure is limited. The following resources highlight current approaches to using crowdsourced data for road weather information.

EDC-6: Crowdsourcing for Advancing Operations, Every Day Counts, Federal Highway Administration, last updated March 2025.
https://www.fhwa.dot.gov/innovation/everydaycounts/edc_6/crowdsourcing.cfm
From the website:

> **Crowdsourced data from multiple streams can be integrated and used in real time for improved operations.**
>
> State and local transportation systems management and operations (TSMO) programs strive to optimize the use of existing roadway facilities through traveler information, incident management, road weather management, arterial management and other strategies targeting the causes of congestion. TSMO programs require real-time, high-quality and wide-ranging roadway information. However, gaps in geographic coverage, lags in information timeliness and life-cycle costs for field equipment can limit agencies' ability to operate the system proactively.
>
> Public agencies at all levels are increasing both their situational awareness and the quality and quantity of operations data using crowdsourcing, which enables staff to apply proactive strategies cost effectively and make better decisions that lead to safer and more reliable travel while protecting privacy and security of individual user data.
>
> **Real-Time, Low-Cost, Valuable Data**
> Three common sources of crowdsourced data are social media platforms, third-party data providers, and specially developed mobile apps. These data can be passively or actively transmitted and may be quantitative or qualitative in nature. Included is information related to speed, travel time, incident type, travel behavior, public sentiment, vehicular operation, and more. Some data are free with little to no cost to process, while other data can be purchased at a more effective cost point than traditional traffic monitoring equipment (e.g., roadway sensors and cameras).
>
> Because crowdsourced data are obtained whenever and wherever people travel, agencies can capture in real time what happens between sensors, in rural regions, along arterials, and beyond jurisdictional boundaries. Crowdsourced data can often be accessed by traffic management centers (TMC) with minimal or no time lags and is not subject to local sensor or system outages. Complementing crowdsourced data with data integration tools enables TMC operators to focus more quickly on proactively managing emerging events, rather than reacting to them after congestion forms.

A Comparison of Crowdsourcing Approaches for Road Weather Information, Fact Sheet, Weather-Responsive Management Strategies, Federal Highway Administration, August 2022.
https://rosap.ntl.bts.gov/view/dot/64661
From the report: State and local departments of transportation (DOTs) have started to experiment with and gain trust in crowdsourced data to supplement traditional data sources such as road condition reports from field personnel and road weather information system (RWIS) environmental sensor stations (ESS). Crowdsourcing is defined as the practice of obtaining services or content by soliciting contributions from a large group of people.
….

This factsheet provides an overview of three different approaches to crowdsourcing used by State and local DOTs, specifically for road weather condition monitoring. Because technology is changing rapidly, the information herein is a snapshot of current practices.

Systems for Notifying the Public of Local Road Closures Using Smartphone Map Applications, Transportation Research Synthesis, Local Road Research Board, Minnesota Department of Transportation, April 2020.
https://mdl.mndot.gov/index.php/_flysystem/fedora/2023-01/trs2001.pdf
From the introduction: The Local Road Research Board (LRRB) is interested in developing a central repository of local and state road closure and traveler information that could be used to notify the traveling public about road network closures in real time. Updates to this travel information database will feed Google Maps, potentially through Waze and Apple Maps to provide information about current road closures and road conditions to smartphone users. (Waze is a geographic information system (GIS) based roadway mapping and navigation application that includes crowdsourced and partner-provided data. The application provides driving directions, a live traffic map and road alerts.) Updates may also appear on the state's 511 traveler information database. To inform the development of this database, selected state and local transportation agencies were surveyed about their use of systems for notifying the public of road closures and reopenings through traveler information services. Also surveyed was a representative from University of Maryland's Center for Advanced Transportation Technology Laboratory (CATT Lab), which developed and maintains a web-based system of selected state and local road closure data. Follow-up interviews were conducted with selected survey respondents and with a representative from Florida Department of Transportation (DOT). This Transportation Research Synthesis presents the results from the surveys and interview. Findings from a limited literature search supplement these outreach efforts.

4 Summary and Future Considerations

This synthesis highlights wide variation in how state DOTs update and communicate winter road conditions. While some agencies are beginning to incorporate automated or predictive tools, many continue to rely on manual or hybrid workflows that require significant staff input.

A range of technologies and vendor-supported platforms are available to support winter road condition reporting, but adoption and integration remain uneven. Across agencies, many of the identified challenges relate less to tool availability and more to data integration, workflow implementation, and confidence in automated or predictive outputs.

This limited-scope effort also identified several themes and considerations that may warrant additional exploration through future research, pilot testing, peer exchange or collaborative activities.

4.1 Key Themes and Emerging Challenges

Findings from the survey and review of relevant literature highlight several recurring themes and challenges related to the use of automation and predictive tools for winter road condition reporting. While many agencies are exploring new technologies, implementation remains limited, and several factors continue to affect the reliability, scalability and usability of these tools. Common themes identified through the synthesis are summarized in Table 15.

Table 15. Summary of Key Themes and Challenges

Theme	Description
Data and Coverage	Difficulty capturing localized and rapidly changing conditions.
Validation	Lack of standardized validation methods.
Integration	Challenges connecting tools with existing systems.
Resources	Staffing, funding and technical expertise limitations.
Predictive Use	Limited use of predictive tools in public-facing reporting.

Data and Coverage Gaps

Many agencies reported inconsistent coverage of RWIS and other real-time data sources, particularly across large or rural networks. These gaps limit agencies' ability to provide consistent, systemwide updates. While third-party and crowdsourced data sources are becoming more available, they are not yet widely incorporated into road condition reporting workflows.

Validation Gaps

Data quality and reliability remain ongoing concerns. Agencies described challenges validating data from multiple sources, particularly when inputs conflict or are incomplete. In many cases, manual review is still required to confirm conditions before updates are shared with the public, which can slow reporting and limit the benefits of automation.

Integration Gaps

Integrating data across systems continues to present challenges for many agencies. RWIS, traffic management systems, 511 platforms and vendor tools are often used in parallel rather than as part of a unified workflow, requiring staff to manually transfer data between systems.

Resources

Staffing constraints and reliance on individual expertise affect how traveler information is updated and maintained. Several agencies noted limited personnel available to manage data, validate conditions and operate multiple systems. These limitations, coupled with a lack of standardized procedures, can create inconsistencies in reporting.

Predictive Use

Although interest in predictive tools is growing, their use remains limited. Agencies expressed uncertainty about the accuracy and reliability of forecasts, particularly at larger scales. In addition, translating predictive outputs into clear, actionable and reliable messaging continues to present challenges.

4.2 Future Considerations

The survey responses and review of relevant literature also highlighted several areas that agencies and research organizations may wish to explore further as automation and predictive tools continue to evolve.

Data Quality and Coverage

Many of the challenges identified by agencies, including difficulty capturing localized conditions and limited accuracy, are related to gaps in data availability. Expanding RWIS networks and incorporating additional data sources, such as vehicle-based sensors and connected vehicle data, may improve the accuracy and geographic coverage of road condition information. Combining multiple data sources can also help reduce uncertainty.

Validation Practices

Agencies currently use a range of approaches to verify conditions, but these efforts are often informal or inconsistent. Additional work related to validation methods, metrics and performance thresholds may help agencies better assess the reliability of automated and predictive tools. Strong validation practices may also support confidence in newer approaches.

System Integration and Interoperability

Integration challenges continue to affect the effectiveness of otherwise promising tools. Improving interoperability among RWIS, decision support tools and traveler information platforms may help reduce manual effort and improve consistency. Standardized data formats and shared platforms may also support more efficient workflows.

Pilot Testing and Evaluation

Several agencies are currently testing automation and predictive tools through pilot efforts. These programs provide opportunities to evaluate performance, identify limitations and refine approaches before broader implementation. Continued pilot testing and documentation of agency experiences and results may help build a stronger understanding of appropriate use cases and operational considerations.

Predictive Tools and Public Reporting

Predictive tools are often used to support internal decision-making, but their use in public-facing road condition reporting remains limited. Additional exploration may help identify effective approaches for translating predictive outputs into clear, reliable and actionable travel information for the public.

Collaboration and Knowledge Sharing

Many agencies are working through similar challenges related to automation and predictive road condition. The survey responses and literature highlighted ongoing interest in peer exchange, shared pilot experiences, and collaborative research related to these tools and approaches.

Appendix A: Survey

The survey below was provided in an online format to Clear Roads members.

Traveler Information System Overview

1. What public traveler information system(s) does your state use to provide winter road condition updates? Please select all that apply.
    - ☐ 511 (mobile app)
    - ☐ 511 (SMS text message alerts)
    - ☐ 511 (telephone)
    - ☐ 511 (website)
    - ☐ Non-511 website, app, text alerts or phone line
    - ☐ Social media
    - ☐ Variable message signs
    - ☐ Other (Please describe.)
2. Please briefly describe the traveler information platform your agency uses to deliver road condition data to the public. Include the product name and vendor if the platform was not developed in-house.
3. What types of road condition information does your agency share with the public during winter weather events? Please select all that apply.
    - ☐ Active snowplow locations
    - ☐ Plow cam photos
    - ☐ Stationary webcams
    - ☐ Road weather information system (RWIS) information
    - ☐ Closures or restricted travel
    - ☐ Forecasted conditions or alerts
    - ☐ Surface condition (e.g., wet, icy, snow-covered)
    - ☐ Travel difficulty/driving advisories
    - ☐ Other (Please describe.)
4. Who is responsible for entering or approving road condition updates in your agency's traveler information system? Please select all that apply.
    - ☐ Centralized transportation management center (TMC) staff
    - ☐ Regional TMC staff
    - ☐ Maintenance supervisors
    - ☐ Snowplow operators
    - ☐ Other (Please describe.)
5. How often are road condition updates typically made during winter weather events?
    - ○ In real time, as conditions change
    - ○ Every hour
    - ○ Every two hours
    - ○ Twice daily
    - ○ Other (Please describe.)
6. Does your state display or have the ability to toggle a layer on or off showing current road conditions in neighboring states?
    - ○ No
    - ○ Yes (Please describe.)

7. (Required) Has your agency implemented or tested any **automation tools or technologies** to generate or assist with winter road condition reporting?
   - Yes. (Directs the respondent to **Automation Tools and Technologies in Use or Being Tested**.)
   - No, but we are considering testing or implementing automation tools. (Directs the respondent to **Considering Testing or Implementing Automation Tools**.)
   - No, and we have no current plans to do so. (Directs the respondent to **Predictive Tools: Sorting Question.**)

Automation Tools and Technologies in Use or Being Tested

1. Please identify the automation tools or technologies your agency using or testing. Select all that apply.
   - ☐ Automated vehicle location (AVL)-integrated snowplows
   - ☐ Another snowplow sensor package
   - ☐ Road weather information system (RWIS) + Maintenance Decision Support System (MDSS) integration
   - ☐ Automated 511 triggers
   - ☐ Internal condition dashboards
   - ☐ Other (Please describe.)
2. Is your agency partnering with a third-party product or platform for automated road condition reporting?
   - No
   - Yes (Please identify the product or platform.)
3. Please describe how the automation process works, including integrations and review methods used.
4. How does your agency validate the accuracy of automated winter road condition reporting tools? Please select all that apply.
   - ☐ Field verification by staff
   - ☐ Plow camera or visual data comparison
   - ☐ Review by TMC or operations staff
   - ☐ Post-event analysis or auditing
   - ☐ No validation
   - ☐ Other (Please describe.)
5. What challenges has your agency encountered with automated reporting?
6. What weather events or road conditions are the most challenging for your agency's automated system to report?
7. Please rate the effectiveness of your agency's automated reporting in supporting winter road condition updates.
   - Extremely effective
   - Very effective
   - Somewhat effective
   - Not so effective
   - Not at all effective
   - Too early to tell
8. Has your agency attempted to formally measure the effectiveness of its automation tools?
   - No
   - Yes (Please describe.)

9. What advice would you give to other agencies interested in testing or implementing automation tools or technologies?
10. Please provide links to documents associated with your agency's automation tools for reporting winter road conditions. Send any files not available online to kristen.bailey@ctcandassociates.com.
11. (Required) Is your agency currently using or testing any **predictive tools** to support winter road condition reporting?
    - Yes (Directs respondent to **Predictive Tools in Use or Being Tested**.)
    - No, but we are considering exploring predictive tools. (Directs respondent to **Exploring Predictive Tools**.)
    - No, and we have no current plans to do so. (Directs respondent to **Wrap-Up**.)

Considering Testing or Implementing Automation Tools

1. What automation tools are being explored or are of interest to your agency?
2. What factors are driving your agency's interest in automated methods for updating winter road condition reports?
3. What are the main barriers you foresee related to testing or implementing automation tools?
4. (Required) Is your agency currently considering testing or implementing any **predictive tools** to support winter road condition reporting?
    - Yes. (Directs respondent to **Predictive Tools in Use or Being Tested**.)
    - No, but we are exploring options (Directs respondent to **Exploring Predictive Tools**.)
    - No, and we have no current plans to do so. (Directs respondent to **Wrap-Up**.)

Predictive Tools: Sorting Question

(Required) Is your agency currently using or testing any **predictive tools** to support winter road condition reporting?

- Yes. (Directs respondent to **Predictive Tools in Use or Being Tested**.)
- No, but we are exploring options. (Directs respondent to **Exploring Predictive Tools**.)
- No, and we have no current plans to do so. (Directs respondent to **Wrap-Up**.)

Predictive Tools in Use or Being Tested

1. What predictive tools or models is your agency using or testing to forecast or anticipate winter road conditions? Please select all that apply.
    - ☐ Forecast-based modeling using machine learning or AI
    - ☐ In-house predictive model or tool
    - ☐ Maintenance Decision Support System (MDSS)
    - ☐ Road weather information system (RWIS)-integrated modeling (e.g., RWIS + forecast + pavement modeling)
    - ☐ Other (Please describe.)
2. What data sources feed into your agency's predictive tools or models? Please select all that apply.
    - ☐ Automated vehicle location (AVL) data
    - ☐ Crowdsourced traffic or condition reports
    - ☐ Plow camera imagery
    - ☐ RWIS
    - ☐ Vehicle-mounted sensors (e.g., road temperature, friction)
    - ☐ Weather forecast data
    - ☐ Other (Please describe.)

3. How does your agency validate the accuracy of predictive condition reporting tools? Please select all that apply.
    - ☐ Field verification by staff
    - ☐ Plow cam or visual data comparison
    - ☐ Review by TMC or operations staff
    - ☐ Post-event analysis or audit
    - ☐ No validation
    - ☐ Other (Please specify.)
4. What challenges has your agency encountered with predictive tools and technologies?
5. What weather events or road conditions are the most challenging for your agency's predictive tools to report?
6. Please rate the effectiveness of your agency's predictive tools in supporting winter road condition updates.
    - o Extremely effective
    - o Very effective
    - o Somewhat effective
    - o Not so effective
    - o Not at all effective
    - o Too early to tell
7. Has your agency attempted to formally measure the effectiveness of your predictive tools?
    - o No
    - o Yes (Please describe.)
8. What advice would you give to other agencies interested in testing or implementing predictive tools or technologies?
9. Please provide links to documents associated with your agency's predictive tools for supporting winter road condition updates. Send any files not available online to kristen.bailey@ctcandassociates.com.

Exploring Predictive Tools

1. What predictive tools are being explored or are of interest to your agency?
2. What factors are driving your agency's interest in predictive methods for updating winter road condition reports?
3. What are the main barriers you foresee related to testing or implementing predictive tools?

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.

CLEAR ROADS

research for winter highway maintenance

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