Automated Classification of Winter Road Conditions – Phase 2

FINAL REPORT

September 25, 2020

ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(359)

Prepared by:
Athey Creek Consultants

ENTERPRISE

Technical Report Documentation Page

1. Report No. ENT-2020-5	2. Government Accession No.	3. Recipients Catalog No.
4. Title and Subtitle Automated Classification of Winter Road Conditions – Phase 2		5. Report Date September 25, 2020 6. Performing Organization Code
7. Author(s) Ginny Crowson		8. Performing Organization Report No.
9. Performing Organization Name and Address Athey Creek Consultants 2610 Lexington Terrace West Linn, OR 97068		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. 2019-0045
12. Sponsoring Organization Name and Address ENTERPRISE Pooled Fund Study TPF-5 (359) Michigan DOT (Administering State) PO Box 30050 Lansing, MI 48909		13. Type of Report and Period Covered Project Report, October 2019 to September 2020 14. Sponsoring Agency Code

15. Supplementary Notes

Final Report available at: enterprise.prog.org

16. Abstract

The process of gathering information about road conditions during a winter storm typically involves plow operators, enforcement or other traffic operations staff reporting on conditions that they observe while on the road. ENTERPRISE sponsored this effort to research what transportation agencies are doing to leverage technology and automate or assist with winter road condition reporting. Phase 1 of the effort focused on gathering information about how agencies were approaching automated and assisted classification of road conditions. This report concludes Phase 2 which has explored specific attributes of data that can be used to automate road condition reporting with the intent of increasing agencies' understanding and evaluation of this data. This was achieved by establishing a list of available data sources, providing an overview of the types of data available from each source, describing common characteristics for various types of data, and gathering information about agency experiences with data to automate the reporting of winter road conditions.

17. Key Words ENTERPRISE, winter road conditions, traveler information, automation		18. Distribution Statement No restrictions	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 27	22. Price

Acknowledgements

This Automated Classification of Winter Road Conditions – Phase 2 report was prepared for the ENTERPRISE Transportation Pooled Fund TPF-5(359) program (enterprise.prog.org). The purpose of ENTERPRISE is to use the pooled resources of its North American members and the United States federal government to develop, evaluate, and deploy Intelligent Transportation Systems (ITS).

Project Champion

Sinclair Stolle, Iowa Department of Transportation, was the ENTERPRISE Project Champion for this effort. The Project Champion serves as the overall lead for the project.

ENTERPRISE Members

The ENTERPRISE Board consists of a representative from each of the following member entities of the program.

- Illinois Department of Transportation (IDOT)
- Iowa Department of Transportation (Iowa DOT)
- Kansas Department of Transportation (KDOT)
- Michigan Department of Transportation (MDOT)
- Minnesota Department of Transportation (MnDOT)
- Ontario Ministry of Transportation (MTO)
- Pennsylvania Department of Transportation (PennDOT)
- Texas Department of Transportation (TxDOT)
- Wisconsin Department of Transportation (WisDOT)

Project Participants

ENTERPRISE would like to acknowledge and thank the following individuals who served on the project team to support and enhance this project:

- Sinclair Stolle, Tina Greenfield, and Kevin Greene – Iowa DOT
- Justin Junttila – Michigan DOT
- Kelly Braunig and Garrett Schreiner – Minnesota DOT
- Mike Adams – Wisconsin DOT

Table of Contents

1.0 Introduction

Several member agencies of the ENTERPRISE Pooled Fund Program experience seasonal winter road conditions that challenge their operational response, especially as it relates to providing current, actionable information for the public to make travel decisions. The process of gathering information about road conditions during a winter storm typically involves plow operators, enforcement or other traffic operations staff reporting on conditions that they observe while on the road. This manual process is rife with challenges. These staff perform several critical functions during road weather events and reporting road conditions for traveler information is often less critical than other functions. Reporting can also be inconsistent in terms of timeliness and accuracy as staff often cover large areas and reports about conditions are subjective.

ENTERPRISE sponsored this effort to research what transportation agencies are doing to leverage technology and automate or assist with winter road condition reporting. Phase 1 of the effort focused on gathering information about how agencies were approaching automated and assisted classification of road conditions. This report concludes Phase 2 which has explored specific aspects of data that can be used to automate road condition reporting with the intent of increasing agencies' understanding of this data.

Project Focus

To better understand data that can be used to automate road condition reporting.

A Project Team was established with maintenance operations and traveler information staff from selected member agencies. The team reviewed a high-level operational concept and considered the data and data sources their agencies are currently using to classify winter road conditions. Using the operational concept and current agency practices, the Project Team then identified the following data attributes to explore and increase their understanding of data that can be used to automate road condition reporting.

- Establish a list of available **data sources**.
- Provide an overview of the **types of data** that can be obtained from each data source.
- Describe common **characteristics** for various types of data.
- Gather and summarize information about agency **experiences** with automating the classification of winter road conditions using various data.

This report provides additional detail on the operational concept and each of the data attributes noted above. Of the first two attributes, data sources and the types of data from those sources were identified based on which would be most applicable to the operational concept for generating an automated road condition report. Though additional data is available from many sources identified, this project focused only on the most relevant types of data.

Information about the common characteristics of relevant data types was gathered but deemed by the Project Team to be less useful than anticipated for helping an agency understand and assess data. A revised approach for gathering additional information about characteristics was identified and focused on developing a series of key questions that agencies should consider when evaluating data to support automated winter road condition reporting.

Information about data experiences from other agencies was the final attribute desired for this project. Projects that were featured in Phase 1 were revisited, including projects in Minnesota, Idaho, and

Pennsylvania, to learn more about their experiences with data. Additional information was also gathered from projects in Iowa, Ontario, and with the University of Alberta.

This report represents the final product of the automated classification of winter road conditions effort and contains the following sections:

2.0 Operational Concept: Use of winter road condition reports and the traditionally manual processes for generating them, as well as a vision for automated reports.

3.0 Data Attributes: Available sources of data, types of data from various sources, defining a use case, and common questions to ask about data characteristics.

4.0 Experiences: Summaries including brief descriptions of the automation approach, data sources and types of data used, and lessons learned.

5.0 Conclusion: Key takeaways for an agency to consider as they evaluate what data could be used to automate winter road condition reporting.

2.0 Operational Concept for Winter Road Condition Reporting

When referring to the operational concept for automated classification of road conditions, the following definitions were used in Phase 1 and during this project.

Road Condition

- State of the road surface in relation to atmospheric weather conditions

Classification

- Identifying what the road condition is and consistently classifying it into predefined categories (e.g. snow covered, icy, wet)

Manual (Reporting)

- Staff observations often reported by radio to a central location where information is manually entered into a system for reporting or operations

Automated (Reporting)

- Systems with capabilities to interpret data from stationary (e.g. RWIS) and mobile (e.g. plow sensors) devices and other systems to classify winter road conditions

Most agencies provide winter road conditions to travelers using a manual reporting process that involves staff observing, classifying, and reporting conditions from the field while performing other operations. Such reports are typically received by a dispatcher or supervisor in the office and then entered in a reporting system that disseminates the information via traveler information services (e.g. phone, website, social media). There are several common challenges with the manual reporting process including:

- Demand for the most current information from staff in the field is highest during winter storms when the demand to perform other operations is also highest.
- Human error and inconsistency are inherent with people making observations and judgements about conditions.
- Reports become outdated and inaccurate because conditions often change before the next observation can be made.
- Time from observation to reporting to dissemination can be long and may contribute to reports being outdated and untimely.
- Reporting coverage can be limited, providing inadequate traveler information.

Automating the process of generating winter road condition reports is intended to address many of these challenges. Automated reporting refers to the use of systems with capabilities to interpret data from stationary (e.g. roadside sensors) and mobile (e.g. vehicle sensors, cameras) sources and other systems to classify winter road conditions that can then be reported to travelers. Figure 1 illustrates that the operational concept for automated reporting of road conditions begins with conditions on the road and ends with reports that are shared with travelers via agency traveler information services (e.g. 511) and other traveler information services outside the agency. Ultimately, this is all done so travelers know what is happening on the roads during a weather event and can make informed decisions about their travels.

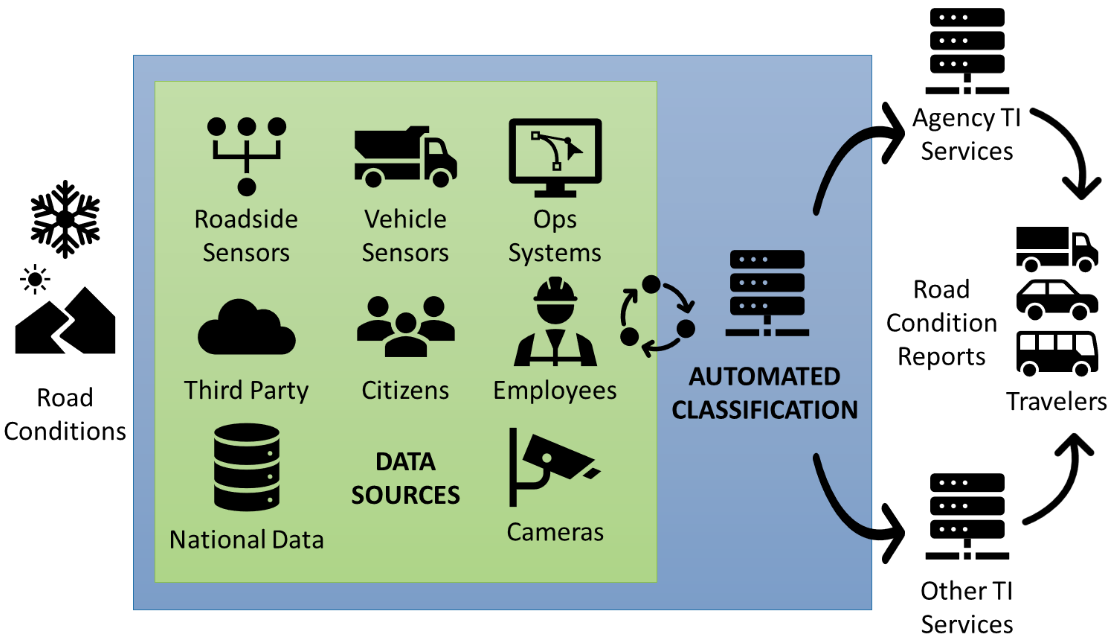


Figure 1: Operational Concept for Automated Classification of Road Conditions

Using this operational concept, data sources were identified with the Project Team to reflect those currently used to generate road condition reports. There are many data sources that then can provide information about conditions on the road. Roadside sensors provide data about pavement temperature and atmospheric conditions. Similar sensors are often on vehicle and can also provide data about friction and material usage. Although, such data is primarily available from agency fleet vehicles today, it is envisioned that data will also be available from private vehicles with connected and automated vehicle features in the future. Operational systems, like the Maintenance Decision Support System (MDSS), are another source of data about road conditions and resources being used to maintain roads. Third party sources can provide information about travel speeds and weather. Citizens can report their own observations about conditions through third party sources or agency-provided options. The most traditional source of data has been employees who are actively maintaining or patrolling roads during weather events. National data sources typically include common data from individual jurisdictions that is centralized to facilitate access from one point. And finally, camera images can provide visual data about road conditions.

Depending on the nature of the road condition report that is provided, the data needed to generate an automated report will also vary. For example, North Dakota DOT road condition reports focus on describing conditions as “snow covered,” “scattered snow/drifts,” and “wet/slush.” This type of report would likely benefit from camera images, as well as roadside and vehicle sensors. Iowa DOT reports roads as “partially covered,” “completely covered,” or “impassible” which is amenable to data from employees. In contrast, Michigan, Pennsylvania, and Washington DOT road condition reports focus on describing impacts as being “high” or as “lane closures” or “total closures” and speeds as “free flowing,” “moderate traffic,” and “heavy traffic.” This type of road condition reporting would likely benefit from third party data in addition to cameras and roadside sensors. Articulating the nature of what is desired in a road condition report is an important step in understanding and assessing the data available for automating the reporting process. This will be further discussed in the next section under data characteristics.

3.0 Data Attributes for Automated Reporting

The operational concept was used to determine what information was desired about the data available for automated winter road condition reporting. Data attributes were identified by the Project Team based, in part, by their own efforts to automate winter road condition reporting. The attributes included data sources, types of data, data characteristics, and agency experiences with data.

Data Sources

As highlighted in the operational concept and further described below, there are a variety of sources that can provide data about conditions on the road. The following list illustrates the most common sources that an agency could start with in their effort to identify data available for winter road condition reports.

- **Roadside sensors:** Provide data from Road Weather Information System (RWIS) and Automated Weather Observing System (AWOS) about road surface and atmospheric conditions at fixed points.
- **Vehicle sensors:** Provide road surface and atmospheric data similar to roadside sensors, along with data about friction and material usage. Currently, such data is mainly available from agency fleet vehicles, but in the future, it could include private vehicles with connected and automated vehicles (CAV) features.
- **Operational systems:** Contain data about maintenance operations, often gathered from roadside and vehicle sensors. For example, an operational system such as MDSS can provide detail about road conditions and materials being used.
- **National data:** Select data repositories have been established to compile common data from individual jurisdictions to make such data accessible from one point. The Weather Data Environment (WxDE), for example, collects data in real time from both fixed environmental sensor stations and mobile sources in nearly all states.
- **Third party:** These sources can provide information about travel speeds, incidents, and weather. In the future, they may also serve as clearinghouses for data from private vehicle sensors, although those business models are still uncertain.
- **Citizens:** Report their own observations about conditions through third party sources or agency-provided options.
- **Employees:** Employees who are actively maintaining roadways and operational systems during weather events are the most traditional source of observational data about road conditions.
- **Cameras:** Images and video can provide visual data about road conditions. Cameras are often installed at fixed locations with sensors (e.g. RWIS) and are increasingly being installed on fleet vehicles to support mobile data gathering.

The availability of these data sources for a jurisdiction will vary and will need to be assessed. Each of these sources also provides different types of data with varying characteristics associated with accuracy, frequency, geographic spread, or format. These attributes need to be understood and accounted for in an automated process where data is combined and classified into a useful, accurate road condition report.

Types of Data

For each category of data source, the key types of data available were identified and include, for example, temperature, grip/friction, images, qualitative statements (e.g. slippery), and camera images. Table 1 highlights each data source and identifies the types of data that can be obtained from that source and that are most applicable to automated classification of winter road conditions.

Table 1: Data sources and types of data

Data sources	Types of data
Roadside sensors • RWIS • AWOS (typically within an airport)	• Atmospheric - Air temperature - Humidity - Visibility distance - Wind speed and direction - Precipitation type and rate • Pavement - Pavement temperature - Freeze point of chemicals on pavement - Pavement condition (e.g. wet, icy) - Pavement chemical concentration - Subsurface conditions (e.g. soil temperature) - Speed - Friction
Vehicle sensors • Fleet vehicles • Private vehicles	• Location • Air temperature • Pavement temperature • Plow up/down • Plow blade friction • Traction • Chemical application
Operational systems • MDSS	• Road snow depth • Pavement temperature • Road mobility • Chemical present
National data • Meteorological Assimilation Data Ingest System (MADIS)	• Meteorological surface dataset - Air temperature - Relative humidity - Dewpoint - Wind speed/direction - Atmospheric pressure - Precipitation

Data sources	Types of data
	- Solar radiation - Soil temperature - Soil moisture • RWIS • Snow - Depth - New snowfall - Water equivalent
National data • Weather Data Environment (WxDE)	• Fixed stations • Mobile stations
Third party • Google • Waze • INRIX • HERE • Private weather service providers	• Speed, real-time • Speed, historical • Incidents • Weather forecasts
Citizens • Waze • Agency-provided tools	• Human observations
Employees • Maintenance staff	• Human observations
Cameras • RWIS • Traffic management • Fleet vehicles (e.g. plow cameras)	• Snapshot images • Streaming video

As types of data in Table 1 were compiled, the characteristics of data available from MADIS were summarized for the Project Team as an example of the detail that could be gathered. Operated by the National Weather Service National Centers for Environmental Prediction, MADIS includes historical data from 2001 forward, as well as real-time data from National Oceanic and Atmospheric Administration data sources and a variety of other providers – including RWIS data from 29 departments of transportation. MADIS has detailed metadata available on their site for most of the large datasets that they offer. As noted in Table 1, three types of data from MADIS were identified as most relevant for generating automated road conditions reports – meteorological surface dataset, RWIS and snow. Metadata for the meteorological surface dataset, for example, includes high level information about geographic coverage, frequency, accuracy (which can be inferred from the MADIS quality check process) and integration options. It does not, however, provide similar information for the individual data elements like air temp. For the RWIS data within MADIS, information about data characteristics is again available but at a composite level from 29 states feeding RWIS data into MADIS. Finally, there is little to no information about reliability in terms of understanding how often the data might not be available.

The original intent was to gather characteristics such as this for each data source and present them in a referenceable manner that could offer agencies insight on how such data might be used for generating winter road condition reports. However, it was challenging to gather detailed information about data characteristics in this manner as most characteristics are defined by how the data will be used. These challenges also raised questions of how valuable a list of characteristics would be for agency operations staff vs. software programmers and how understandable this information would be without the context of an agency's road condition reporting practice. The second question became even more relevant when referring to the operational concept which illustrates the need for starting with a clear understanding of the use case for a winter road condition report. Once a use case is established, potential data sources and types can be identified, and data characteristics can be evaluated within that context.

Data Characteristics and Use Cases

Rather than gathering static information about data characteristics, the Project Team requested guidance on defining a use case and a set of common questions that staff could then ask about various data in order to evaluate its potential within the context of the use case. Both are presented in this section as an approach for evaluating data for use in automating winter road condition reporting.

A use case should describe what a winter road condition report consists of, how reports are currently generated, who is involved with the process of generating and using the reports, and how the reports are used to achieve the safety and reliability goals associated with providing traveler information. The description should explain characteristics of the information (data) that is used to generate current reports, presumably in a manual fashion from maintenance staff observations. Such characteristics should include the following and should also note where there are strengths and weaknesses with the current process.

- **Coverage/Range**: Physical range covered by information/data in terms of road type (e.g. interstates, all state roadways), distance (e.g. length of road in miles), and geography (e.g. urban only, statewide).
- **Frequency (Timeliness)**: How frequently information/data is updated (e.g. every four hours, as conditions change). It should also be noted if data is historic vs. real-time. Historic data may be used, for example, to train models or assumptions for classifying conditions.
- **Reliability (Availability)**: When and how available is information/data (e.g. business hours Monday – Friday, 24/7/365) or when might the data be available.
- **Accuracy**: Frequency and type of errors that can be expected (e.g. inaccurate reports as they become stale).
- **Integration (Format)**: How information/data is gathered (e.g. staff radio information into dispatch for further entry) and potentially available for use in traveler information applications.

The use case does not need to be elaborate or lengthy; a simple table can be used to document these characteristics. The use case is important, however, as it will serve as a framework for gathering and as a baseline for evaluating similar characteristics of data available for generating automated reports. Once the use case is developed, an agency can begin to evaluate the characteristics of available data sources and types, many of which were identified in the previous sections.

To support agencies with gathering data characteristics for evaluation, the questions presented in Table 2 are offered along with supporting detail to explain why the question is important. It is important to note that the supporting detail does not suggest criteria for acceptable answers to the questions because acceptability will vary depending on the use case. Instead, the supporting detail is intended to help agencies understand the purpose for the question and to help them think critically about the answers they receive.

Table 2: Questions corresponding to data characteristics with supporting detail

Characteristic/Question	Supporting Detail
1. Coverage/Range	
a. What geography and road types are covered by the data?	• Helps identify how much more or less roadway could be covered with the data source/data type. • Coverage may sometimes be less but more consistent and reliable; conversely coverage may be broader but less detailed (or accurate).
b. What distance does one data point cover?	• Helps identify how distance covered by one data point relates to the overall range that must be covered in a report, and how data points may be matched or combined from one data source/data type or with another. • Range from a sensor, for example, may be less than a manual observation of a roadway segment. Agencies need to understand if multiple data points may be required to comparatively cover a roadway segment that would have been manually reported. It is also valuable to know if a sensor location represents a unique trouble spot.
Frequency (Timeliness) ****These characteristics should also note if data is historic or real-time.***	
a. How frequently is data updated?	• Helps determine if the frequency of data is adequate for the targeted frequency of providing reports to travelers. • For instances involving the use of multiple data types, this characteristic helps identify when data may be matched or combined.
b. What constraints are there on the frequency with which data is updated?	• Helps identify if data source/type has constraints on its capability to gather (e.g. hardware/software) or transmit (e.g. communication) data.

Characteristic/Question	Supporting Detail
	• Understanding where constraints are will identify how frequently data may be updated and if there are alternatives to adjust for the constraint.
2. Reliability (Availability)	
a. How available is data (e.g. 24/7/365, live only during high volumes)?	• Helps identify instances when data may not be available due to operational limits, malfunctions, etc. • Both snapshot and streaming video from fixed and mobile cameras is increasingly available as a potential data source; however, there can be operational limits associated with unclear nighttime images, spotty communication to transfer images, and images only when and where a plow is operating.
b. How is unavailability of data managed?	• Helps with understanding when real-time data is unavailable if it is substituted with historical data. Also helps identify if and how unavailable data is flagged in some way. • Third-party data providers often rely on anonymous data from mobile devices and at times when adequate real-time data is not available, it is not uncommon for historical data to be substituted.
3. Accuracy	
a. How is accuracy determined and how accurate is data?	• Helps identify the frequency and type of potential errors in data. • This is especially important when using manual reports as a baseline to train models that may use data to generate automated reports. Manual reports tend to have inherent inaccuracy caused by subjectivity and timeliness of observations made by staff.

Characteristic/Question	Supporting Detail
b. How are inaccuracies managed?	• Helps identify if and how inaccurate data is discarded or flagged in any way as part of a quality control process. • Creates awareness of quality control processes and insight on how inaccurate data can be anticipated and accounted for when used to generate automated reports.
4. Integration (Format)	
a. What format is data available in?	• Helps determine how data can be consumed in the process that will generate automated reports. • Data is often shared via a webservice using an application programming interface (API) which allows interaction between two applications. APIs come in a variety of formats including SOAP, XML, JSON, and REST and knowing this will determine how data can be consumed.
b. What constraints are there on using data and further distributing it?	• Helps identify potential limitations with using data to generate a road condition report that will be further distributed to travelers. • Such constraints are more likely among data from third-party providers. Understanding limitations around use of the data will determine if and how it can be used for automated reports.

Answering these questions will help an agency begin to evaluate the characteristics of various data sources and data types for use in generating automated reports. As the characteristics of prospective data are compared to those from the use case, the agency should note where and how characteristics are both similar and different. The agency should then discuss what tradeoffs might exist within the similarities and differences identified. In simple terms, tradeoffs involve giving up something in return for something else. For example, a tradeoff might exist in a data source providing greater geographic coverage but not providing as much or the same level of detail (accuracy).

To help with assessing tradeoffs and evaluating data characteristics in general, agencies should also consider the requirements established by 23 CFR 511 Real-Time System Management Information Program for roadway weather observations. These requirements address most of the characteristics discussed. The minimum requirements for roadway weather observations are described under the provisions for traffic and travel conditions reporting, stating, "The timeliness for the availability of information about hazardous driving conditions and roadway or lane closures or blockages because of adverse weather conditions will be 20 minutes or less from the time the hazardous conditions, blockage, or closure is observed." Regarding information accuracy and availability, the requirements further state, "The designed accuracy for a real-time information program shall be 85 percent accurate at a minimum or have a maximum error rate of 15 percent... The designed availability for a real-time information program shall be 90 percent available at a minimum." Minimum coverage requirements are limited to interstates and routes of significance as identified by the states.

Defining a use case, evaluating data characteristics, and identifying tradeoffs will help an agency determine if automating road condition reports is feasible and manage expectations for how such reports will differ from those generated manually.

4.0 Experiences with Data for Automated Reporting

Phase 1 of this effort identified several projects exploring the automation of winter road condition reporting. Those projects were revisited in this phase, along with several new projects, to provide additional insight on how different approaches and various data are being used to automate the reporting process. Each project summarized in this section includes a brief description of their approach to automation, list of data sources and types of data used, and lessons learned.

Pennsylvania DOT: Video Via Smartphone Contact: Doug Tomlinson, dtomlinson@pa.gov	
Automation Approach In a research project conducted for Pennsylvania DOT (PennDOT), Carnegie Mellon University (CMU) tested and confirmed the feasibility of using Android smartphones to collect live video from snowplows. Software was developed to ingest the video footage, along with GPS and time of day from the plow automatic vehicle location (AVL) system, to generate a report for the department's Road Condition Reporting Systems (RCRS) road condition logs. Data was labeled against parameters for various snow conditions to develop an algorithm that would interpret snow conditions from the video footage. Two algorithms were developed and evaluated – one mimicked human interpretation and classification of a road weather condition and another using objective parameters to determine a percentage of clear road based on the video footage. The second approach was implemented for testing. It included a series of steps that sift through images for difficult locations (e.g. T-intersections) and artifacts (e.g. windshield wiper). Images are then categorized by time of day and further sorted according to special elements (e.g. streetlights) in their content. Clean images are then analyzed to determine percentage of surface coverage and categorized into one of four classes: road, slush, snow, or unknown. Conditions are grouped into road segments using location data and a road condition report is generated. An illustration of this video analysis process is included in Appendix A.	
Data Sources / Types of Data Used	• Video from Android smartphones mounted in plows • Location and time data from GPS via the plow AVL system for higher degree of accuracy than location data available from smartphone
Lessons Learned	• Video images can vary significantly from day to night and by lighting conditions, creating challenges with consistently categorizing road conditions • Location and timing data were more accurate from the agency AVL system than the smartphone • Selecting an algorithm for categorizing road conditions based on objective parameters was selected over one that would mimic human judgement • Humans were still effectively used during development of the algorithm to establish parameters for categorizing video images • More efficient platforms than smartphones could be used to capture and transmit video images • Additional data (e.g. air and road surface temperature) from plow AVL systems could be used to further support categorization of video images

Minnesota DOT: MDSS and CARS-SnowReports Contact: Garrett Schreiner, garrett.schreiner@state.mn.us	
Automation Approach Minnesota DOT (MnDOT) originally planned to take pavement condition reports generated by Maintenance Decision Support System (MDSS) models that are used to create the colored maps in the system user interface. Instead, select data from MDSS was identified and a module for the department's Condition Acquisition and Reporting System (CARS), called CARS-SnowReports, was developed to translate the data distribute it via traveler information platforms including a website, mobile app, social media, and phone service. Although the data mapping originally focused on pavement condition data types, MnDOT added visibility (e.g. fog) elements from atmospheric condition data because those conditions also impact driving. Data is exchanged between MDSS and CARS-SnowReports every five minutes, with conditions updated as they change or at least every 30 minutes. Validation of the approach was done with visual comparisons between the maps produced in MDSS and maps produced in CARS with traditional manual reporting. See Appendix B for an example of these comparisons. In March 2020, MnDOT moved from manual classification and reporting of winter road conditions to automated reporting using MDSS data.	
Data Sources / Types of Data Used	• MDSS pavement conditions (e.g. Dry, Damp Near Freezing, Snow) were mapped to CARS descriptors and map elements for translation into both visual and narrative winter road condition reports; see Appendix B for full list of translations
Lessons Learned	• It was useful to operate both manual and automated approaches simultaneously to allow for evaluation and to build confidence in the automated approach. • Atmospheric condition data for visibility was a valuable addition for more complete road weather conditions. • Involving maintenance staff in the process for developing the automation approach was essential for buy-in and understanding nuances with MDSS data. • Fixed location and mobile plow camera images are provided, in addition to automated reports, for added traveler information. • Reports are updated as conditions change and consistently every 30 minutes with the automated process, improving timeliness and accuracy. • Further changes are anticipated to better address unique road weather conditions such as fast-moving storms and blow ice, which is a condition that commonly forms on clear, cold days as winds blow snow across roads where it sticks, melts and refreezes.

Idaho National Labs: Artificial Intelligence and Modeling Contact: Scott Wold, scott.wold@inl.gov	
Automation Approach Idaho National Labs (INL) has been working with IBM since 2017 to create a customized operations dashboard for the INL Operations Team to view current and predicted road conditions for over 300 miles of road throughout their facility. INL shuttles about half of their staff around the facility while others drive on their own. The longest route is 90 miles each way. Historically, INL has looked at weather information to determine whether buses should run. They decide whether to operate buses between 4:00-5:00 a.m. Leveraging the IBM Watson artificial intelligence platform, INL has been working to enhance current and forecasted road condition information for operations and make it available to their employees directly. INL uses data and camera images from Idaho Transportation Department (ITD) RWIS, weather data from The Weather Channel, and data from telematics on INL buses. Each bus is equipped with AVL that provides speed, location, acceleration, and deceleration data. INL buses and road scout vehicles also have cameras installed. Video is used to understand road conditions in specific areas. INL's challenges with broader use of video data revolve around transmitting video at a quality high enough to accurately interpret conditions. Camera images within the dashboard are primarily used by operators for visual confirmation. Sensor-based data has been more reliable for building an accurate model for conditions. The model was trained, validated, and continues to learn using historic data that has been accumulated over the past several years. Machine learning is also used to continuously refine the model following each storm. Road condition reports are developed at the mile marker level. The dashboard displays current conditions and allows forward play to depict future conditions. The platform is operational and enhancing awareness of daily forecasts to help manage bus service and staffing.	
Data Sources / Types of Data Used	• Weather data from The Weather Channel • ITD RWIS and INL-installed ESS for atmospheric and road surface temperature • Speed, location, acceleration, and deceleration data from AVL system on bus and scout vehicles • Camera images from RWIS and bus and scout vehicles
Lessons Learned	• Camera image quality is negatively impacted by options for transmission and lighting conditions • Availability of historical data was valuable for training model used to identify both current and future road conditions • Machine learning allows model to be continuously refined, especially after individual storms

The next three experiences are from Iowa DOT, where a variety of approaches are being explored to automate winter road condition reporting for use in maintenance operations and traveler information. Based on their experience to-date, Iowa DOT plans to share a preliminary approach with the public during winter 2020-21. The approach will consist of ingesting Pikalert data and displaying it on an Esri map. This will be compared to manually entered road condition reports, tagged with forecasted weather from the National Digital Forecast Database, in Iowa DOT's traveler information system. Iowa DOT will use this approach to evaluate and gather public feedback on the level of detail and format best suited to traveler information. The feedback will then be used to develop requirements that will be included in a future request for proposals to automate winter road condition reporting.

Iowa DOT: Model with SAS Contact: Sinclair Stolle, sinclair.stolle@iowdot.us	
Automation Approach Iowa DOT is working with SAS, a data analytics company, to develop a model that generates both current and forecasted winter road conditions. The model was initially developed and trained using data primarily from RWIS and manually generated winter road condition reports. After comparing outputs from the model to the manually generated reports during a live snowstorm, problems were discovered with inconsistent timestamping and fusing of the data that was used to initially develop and train the model. For example, data updating frequencies for RWIS and manual reports were not understood and appropriately addressed. Historic data was stored in units different than real-time (e.g. Celsius vs. Fahrenheit) and anomalies in sensor data were also discovered (e.g. checkpoint sensor from Hawaii was showing up in a real-time data feed at 80 degrees). SAS made revisions and moved into the next phase of work. Weather forecasts from the National Weather Service and vehicle speed data from INRIX have been added to further enhance the model. Outputs from the model have been archived by Iowa DOT GIS staff and further evaluation of the data has not yet been completed. This pilot project is scheduled to end at the end of 2020.	
Data Sources / Types of Data Used	• RWIS and AWOS sensors for barometric pressure, dew point, humidity, precipitation rate, surface temperature and wind direction • Plow automatic vehicle location data • Hourly weather forecasts from weather data provider • Manually generated winter road condition reports (to train model)
Lessons Learned	• Knowing the characteristics (e.g. unit labels, quality controls, update frequency) of data being used is especially critical when building parameters for modeling based on the data and when fusing data with other sources • Historical data can be effectively used to train models if data characteristics are clearly understood in relation to real-time data that may be used • Comparing reports generated automatically by the model to those that were manually generated by staff was a useful approach for evaluating the model; however, be aware that models trained with this approach can produce technically correct results but or human inaccuracies

Iowa DOT: Esri Model with Camera Images Contact: Sinclair Stolle, sinclair.stolle@iowdot.us	
Automation Approach Iowa DOT has an enterprise license agreement with Esri that has allowed them to explore how to classify images from mobile cameras with a machine learning model that relates classified images to road segments and generates winter road condition reports. Approximately 10,000 camera images were classified with one or a combination of five labels – wet, dry, partially snow covered, completely snow covered, and unsure/bad image – describing the road weather conditions observed in the image. Some images were given multiple labels when more than one condition was observed or when it was difficult to differentiate between classes. Images were also labeled by more than one person and as such were sometimes labeled differently. Esri used images that had a single label to establish a convolutional neural network that facilitates the comparison of the human labeled (learned) images with new images to classify them. The result was an F1 reliability score of 0.8 for the model with accuracy derived from the sum of true positives and true negatives divided by the total number of observations. In addition to challenges with consistently assigning labels to the initial images used in training the model, it was observed that using a graphics processing unit (GPU) would likely improve the model's ability to rapidly process images during storms with rapidly changing conditions or a high volume of images being generated. Iowa DOT is working with Esri on a second phase of this project that will operationalize the model for testing and validation during the 2020-2021 winter season. In this second phase, the system will automatically classify every image captured, and then aggregate the classified images into pre-defined road segments to generate automated road condition reports. Since Iowa will be using the same segments that are in the production traveler information system, it will allow comparisons to validate reliability and accuracy. Iowa DOT is also working on a feedback loop that will allow staff to review images and help continuously improve the model.	
Data Sources / Types of Data Used	• Camera images – stationary and mobile • Trained set of labeled camera images
Lessons Learned	• System will be limited by the availability of mobile camera images at places and times where stationary cameras are not available • Expect to combine dry/wet conditions into one category because it has been especially challenging at night to distinguish between wet vs. dry pavement • Once segmented road condition reports (aligning with pre-defined segments used by maintenance) have been added and confirmed, dynamic segments will be considered • Model could make predictions on 5,400 images in less than four minutes; using a GPU would optimize this processing speed which could be critical when visibility is especially poor, conditions rapidly change, or when cameras generate higher volumes of images • Using samples (e.g. every tenth image from a camera) when labeling images helps ensure a good variety of road type, lighting, and conditions • Classified images with a high F1 score can be passed into maintenance decision support systems that use sensor data for ground truth validation

Iowa DOT: Pikalert and CAV Data Contact: Tina Greenfield, tina.greenfield@iowdot.us	
Automation Approach Iowa DOT is working with InTrans at Iowa State University to implement Pikalert and evaluate its potential for maintenance operations. As identified in Phase 1 of this ENTERPRISE effort, Pikalert is an open-source tool designed to assess current road weather conditions and develop forecasts out to 72 hours. Pikalert can ingest data from multiple sources including vehicle sensors, RWIS, weather models, and radar to provide current and forecasted road weather conditions. It was specifically designed to leverage the anticipated increase in vehicle sensor data from connected and automated vehicle developments. The vehicle sensor data being ingested in Iowa is limited to agency fleet vehicles. Additionally, Pikalert is using data from the Iowa DOT RWIS, linear referencing system, and plow camera video. The initial instance of Pikalert was implemented in the winter of 2019-20 and Iowa DOT sees potential for its ability to enhance winter road condition reports for traveler information. Pikalert will be modified in Iowa for further evaluation of its potential for Iowa DOT maintenance operations during the winter of 2020-21.	
Data Sources / Types of Data Used	• Fleet vehicle sensor data • RWIS sensors via USDOT Weather Data Environment (WxDE) • Plow camera video
Lessons Learned	• Vehicle sensor data is currently limited to Iowa DOT fleet vehicles, further limiting the breadth and depth of information Pikalert can output • Initial deployment has shown value for enhancing traveler information • Additional modifications could provide further value as a source of road weather forecasts and treatment recommendations for maintenance operations

Aurora: Model with RWIS Contact: Tae Kwon, tjkwon@ualberta.ca	

Automation Approach

The Aurora pooled fund program sponsored work by the University of Alberta to develop guidance that could support agencies with locating fixed RWIS sites to maximize coverage. A second phase of this work focused on determining the density of RWIS sites required to maximize information availability based on topography and winter severity (Kwon, T., 2016, 2020).

The University's current work is looking at a more microscopic view of the space in-between fixed RWIS sites to develop a model that will allow the construct of assumptions about the road weather conditions in that space. Road surface temperature (RST) and road surface index (RSI) data are being used as benchmark data points. That data is being supplemented with topographic and geographic information, and image data from both stationary and mobile cameras. The data is combined in the model to predict road surface conditions between fixed RWIS sites. The resulting model is expected to be replicable across RWIS deployments and vendors. Theoretically, the framework could also be expanded to ingest additional data from personal connected vehicles.

An image-based road condition monitoring solution has been developed on the basis of a deep learning artificial intelligence (AI) technique; however there are challenges with combining and characterizing road surface conditions as the solution needs to be customized for a new study area and further tuned using new location specific data. Viability of this solution will be dependent upon how the model is being trained including human factors such as the interpretation and categorization of camera images within a predetermined series of condition categories. Real world testing is not included in the scope of this effort. Work on this project is scheduled to continue through spring/summer 2021 and has potential benefits for both maintenance decision support and traveler information use cases.

Data Sources / Types of Data Used	• RWIS – road surface temperature, road surface index • Topographic and geographic information • Camera images – stationary and mobile
Lessons Learned	• RST and RSI data are consistently available and extracted from RWIS sites and as such are being used as dependent variables in the model • RSI data extracted from camera images need additional testing for real-world implementation • Accurate recognition and categorization of camera images is initially done by humans and further refined by AI techniques; however, as with all models, some data is misclassified and needs to be further trained and evaluated • Availability of mobile camera images and vehicle sensor data is limited by availability at points in between fixed RWIS sites, so the model treats such data a supplemental at this time • Placement strategies for stationary RWIS should consider spatial dependence under different weather condition to provide data that best serves roadway maintenance and traveler information

Ministry of Transportation Ontario: Forecasted Conditions Contact: Steve Birmingham, steve.birmingham@ontario.ca	

Automation Approach

The Ministry of Transportation Ontario (MTO) worked with their weather vendor, Wood, to develop an information layer for their traveler information website that would forecast winter driving (road) conditions on an automated basis. Using data from RWIS and weather forecasts, the layer provides a basic indication of forecasted driving conditions by coloring and labeling over 500 route segments on a map as red (poor), orange (caution), yellow (fair) and green (good). Threshold criteria was established for these categories using wind speed, precipitation, and visibility. When data is unavailable route segments are colored gray (no data). Forecasted conditions are further presented over four ranges of time: current (0-3 hours), short-term (3-6 hours), medium- term (6-9 hours), and long-term (9-12 hours).

The forecasted driving (road) condition reports for the public focus on translating data into meaningful information (e.g. heavy/moderate) rather than specific measurements (e.g. 7”) to minimize confusion. The language used also reflects the winter road condition terminology established by the Transportation Association of Canada (Hodgins, B., 2011). Data is updated and forecasted conditions are published as an XML file on an hourly basis. The XML file is then consumed by and published to the traveler information website in a specially designated layer for forecasted road conditions. Appendix C presents the threshold criteria established by MTO for each condition and illustrates the forecasted driving (road) condition reports presented to travelers.

MTO has a separate layer of information on their website for real-time road conditions, which are still manually generated. The experience with forecasted conditions is being explored as an option for automating their process for reporting real-time road conditions. Similar to the forecasted driving layer, the real-time road conditions layer is presented on the traveler information map as a line-based layer. During the 2019-20 winter season, 20 percent of MTO’s user feedback was complaints about the real-time road condition information not being accurate. Although road condition information is updated five times per day, some patrols have more than 300 miles of highway to patrol making it difficult to provide current observations on consistent intervals. MTO held a workshop in February 2020 to document their use case for automating real-time road condition reporting in terms of what information is collected, who is collecting it and how it is used. MTO plans to test and evaluate automated reporting for real-time road conditions using RWIS data during the winter of 2020-21.

Data Sources / Types of Data Used	• RWIS – wind speed, precipitation, surface temperature • Weather forecasts
Lessons Learned	• Translating reports for public into simple yet meaningful phrases minimizes confusion in contrast to detailed reports with specific measurements • Would like to allow maintenance staff ability to override automated reports to provide more specific detail when necessary • Recognize tradeoff between less granularity in detail vs. greater consistency in accuracy and timeliness when automating reports • Process used to automate forecasted road conditions is expected to be replicable for generating current road condition reports

5.0 Conclusion

Experiences with data for automating winter road condition reporting offered insight on the variety of automation approaches that continue to be explored, the data being used in those approaches, and the lessons that have been learned. Data was further studied in this project using an operational concept that defined the general process of automated reporting, beginning with conditions on the road and ending with reports that are shared with travelers via agency traveler information services (e.g. 511) and other traveler information services outside the agency. The operational concept was used to identify the data attributes that would create an understanding of the data that can be used to automate winter road condition reporting.

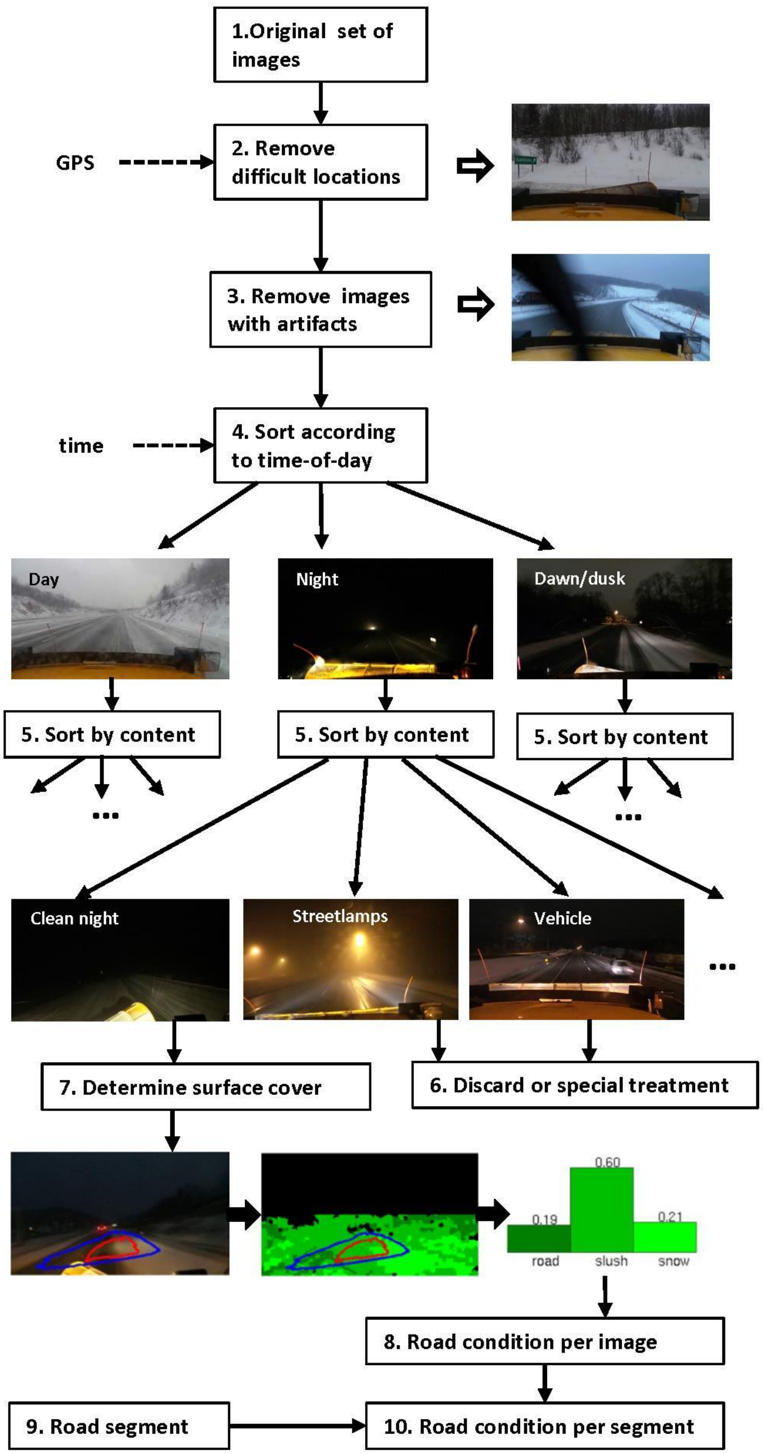
Information about data attributes was gathered and presented, including data sources and the types of data from each source most relevant to winter road condition reporting. Guidance for an agency to define its use case for automated reporting was also presented, along with a set of common questions for agencies to use in identifying and evaluating the characteristics of various data to best meet their defined the use case.

Key takeaways from the information presented in this report include the following.

- Roadside sensors, like RWIS, are the most prominent data source used in the automation approaches summarized in this report.
- The use of vehicle sensors as a data source has potential but is still limited to availability in agency fleet vehicles vs. the broader public vehicle fleet which may be available in the future as connected and automated vehicle technology is introduced.
- Camera images as a data source are becoming more widely available but can be limited in terms of availability when mobile, clarity when visibility is low during blizzard or nighttime lighting conditions, and accurate categorization of a road condition. The processing power necessary for classifying camera images in real-time can also be cost prohibitive.
- Artificial intelligence and machine learning have been used somewhat successfully in some automation approaches to manage the vast amount of data that may be used. It is likely that both will be used with even greater success as more experience is gained with them.
- Defining a use case for automating winter road condition reports is essential for identifying the appropriate data sources and evaluate the characteristics of those sources for their ability to successfully address the use case.
- A defined use case will also help identify similarities and differences that can be anticipated between manual and automated reporting, supporting further consideration of tradeoffs that may exist.
- There is no prominent approach to automation based on the experiences summarized in this report. This is, in part, due to the uniqueness of the use cases driving each experience and the evolving nature of data available – especially mobile data – to support automated reports.
- Finally, although there is a growing variety of data available to support automated winter road condition reporting, understanding the data in relation to a defined use case and its limitations will be the biggest indicators for successfully using the data.

Appendix A: Pennsylvania DOT Video Analysis Steps

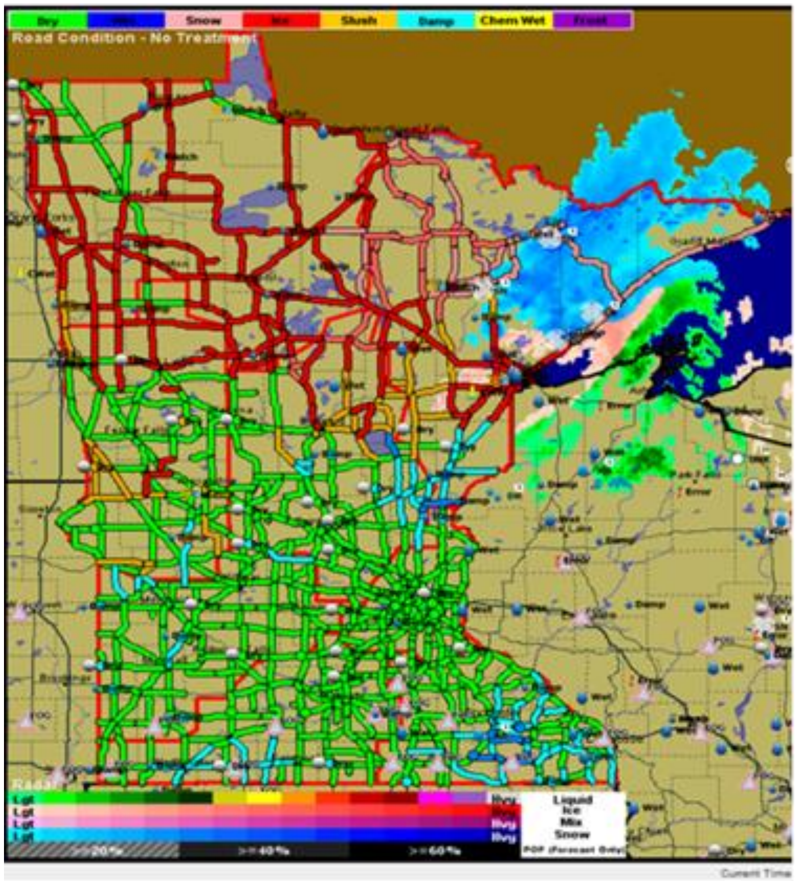
Illustration of steps in video analysis to produce road condition reports in Pennsylvania research effort (Mertz, C., Ehrlichman, C., Kozar, J., Varadharajan, S.).



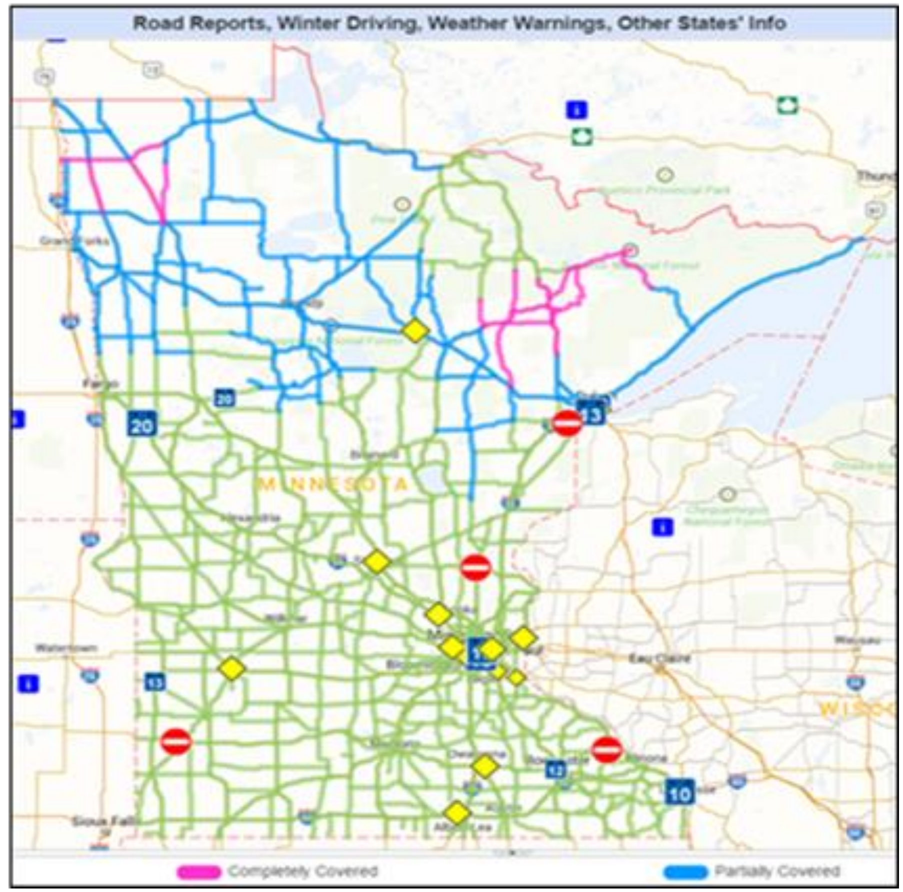
Appendix B: Minnesota DOT CARS-SnowReports Validation and Data Translations

Examples of mapping produced by MDSS and mapping produced by CARS. Visual comparisons between maps were used by MnDOT to validate their approach to automating winter road condition reports for traveler information.

MDSS



CARS/511



Translations between MDSS data and CARS descriptions (narrative) and mapping (visual) elements used to generate automated reports.

MDSS code	MDSS pavement_conditions	CARS Descriptor	Priority	Painted Road Color / TG Web Legend	Full Descriptor
70000	Dry	Dry pavement	6	Green / Normal	The pavement is dry
70100	Damp	Damp pavement	6	Green / Normal	The pavement is damp
70200	Damp Near Freezing	Damp pavement with slick spots	6	Green / Normal	The pavement is damp and may be slick in spots
70300	Lightly Damp	Lightly damp pavement	6	Green / Normal	The pavement is lightly damp
70400	Wet	Wet pavement	6	Green / Normal	The pavement is wet
70500	Wet Near Freezing	Wet pavement with slick spots	6	Green / Normal	The pavement is wet and may be slick in spots
70600	Lightly Wet	Lightly wet pavement	6	Green / Normal	The pavement is lightly wet
70700	Chemically Wet	Wet pavement with icy patches	6	Green / Normal	The pavement is wet and there may be icy patches
70800	Snow	Snow on roadway	3	Pink / Completely Covered	There is snow on the roadway
70900	Dusting of Snow	Dusting of snow on roadway	4	Blue / Partially covered	There is a dusting of snow on the roadway
71000	Compacted Snow	Compacted snow on roadway	3	Pink / Completely Covered	There is compacted snow on the roadway
71100	Very Light Snow	Very light snow on roadway	4	Blue / Partially covered	There is very light snow on the roadway
71200	Light Snow	Light snow on roadway	4	Blue / Partially covered	There is light snow on the roadway
71300	Heavy Snow	Heavy snow on roadway	3	Pink / Completely Covered	There is heavy snow on the roadway
71400	Deep Snow	Deep snow on roadway	3	Pink / Completely Covered	There is deep snow on the roadway
71500	Snowcovered	Snowcovered roadway	3	Pink / Completely Covered	The roadway is snowcovered
71600	Very Lightly Snowcovered	Very lightly snowcovered roadway	4	Blue / Partially covered	The roadway is very lightly snowcovered
71700	Lightly Snowcovered	Lightly snowcovered roadway	4	Blue / Partially covered	The roadway is lightly snowcovered
71800	Heavily Snowcovered	Heavily snowcovered roadway	3	Pink / Completely Covered	The roadway is heavily snowcovered
71900	Deeply Snowcovered	Deeply snowcovered roadway	3	Pink / Completely Covered	The roadway is deeply snowcovered
72000	Slush	Slush on roadway	4	Blue / Partially covered	There is slush on the roadway
72100	Very Light Slush	Very light slush on roadway	4	Blue / Partially covered	There is very light slush on the roadway
72200	Light Slush	Light slush on roadway	4	Blue / Partially covered	There is light slush on the roadway
72300	Heavy Slush	Heavy slush on roadway	3	Pink / Completely Covered	There is heavy slush on the roadway
72400	Deep Slush	Deep slush on roadway	3	Pink / Completely Covered	There is deep slush on the roadway
72500	Slushy	Slushy roadway	4	Blue / Partially covered	The roadway is slushy
72600	Very Lightly Slushy	Very lightly slushy roadway	4	Blue / Partially covered	The roadway is very lightly slushy
72700	Lightly Slushy	Lightly slushy roadway	4	Blue / Partially covered	The roadway is lightly slushy
72800	Heavily Slushy	Heavily slushy roadway	3	Pink / Completely Covered	The roadway is heavily slushy
72900	Deeply Slushy	Deeply slushy roadway	3	Pink / Completely Covered	The roadway is deeply slushy
73000	Frost	Frost on roadway	5	Blue / Partially covered	There is frost on the roadway
73100	Ice	Ice on roadway	2	Pink / Completely Covered	There is ice on the roadway
73200	Very Light Ice	Very light ice on the roadway	4	Blue / Partially covered	There is very light ice on the roadway
73300	Light Ice	Light ice on roadway	3	Blue / Partially covered	There is light ice on the roadway
73400	Heavy Ice	Heavy ice on roadway	2	Pink / Completely Covered	There is heavy ice on the roadway
73500	Deep Ice	Deep ice on roadway	2	Pink / Completely Covered	There is deep ice on the roadway
73600	Icy	Icy roadway	2	Pink / Completely Covered	The roadway is icy
73700	Very Lightly Icy	Very lightly icy roadway	3	Blue / Partially covered	The roadway is very lightly icy
73800	Lightly Icy	Lightly icy roadway	3	Blue / Partially covered	The roadway is lightly icy
73900	Heavily Icy	Heavily icy roadway	2	Pink / Completely Covered	The roadway is heavily icy
74000	Deeply Icy	Deeply icy roadway	2	Pink / Completely Covered	The roadway is deeply icy
74100	Wintry	Wintry conditions	3	Pink / Completely Covered	Expect wintry conditions
74200	Slippery	Slippery conditions	3	Pink / Completely Covered	The roadway is slippery

Appendix C: MTO Forecasted Driving (Road) Conditions

Table describing the hazard parameters and threshold criteria established by MTO for each driving (road) condition reporting to travelers.

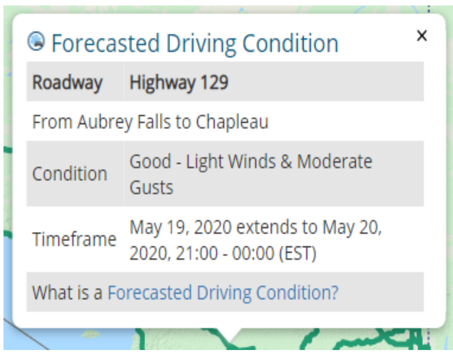
Driving Forecast Categories and the thresholds which trigger them

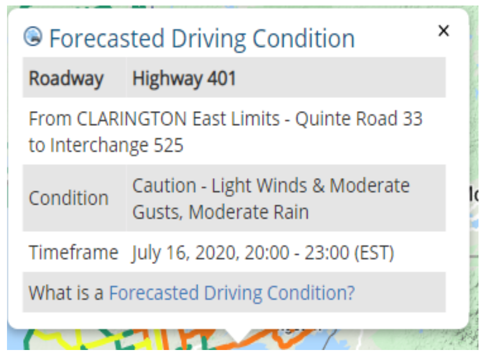
Good
Fair
Caution
Poor

Weather Thresholds and Resulting English and French Phrases

Hazard Parameters	Initial Setting	Updated Thresholds	English Alters	French Alerts	Driving Conditions/Conditions de conduite
Wind_Speed	Same	(if wind<50 km/h)	Light Winds & Moderate Gusts	Vents Légers & Rafales Modérées	Good/Bien
Wind_Speed	Same	(if 50 km/h<=wind<80 km/h)	High Winds & Strong Gusts	Vents Forts & Rafales Violents	Fair/Juste
Wind_Speed	Same	(if wind>=80 km/h)	Very High Winds & Extreme Gusts	Vents Violents & Rafales Extrême	Poor/Mauvaise
No Precipitation	Same	(No Precipitation)	No Precipitation	Aucune Précipitation	Good/Bien
Flurries	Min. threshold identified	Flurries/Light snow (<= 1 cm/3h)	Flurries	Neige Légère	Good/Bien
Light Rain	Min. threshold identified	Light Rain (<= 1 mm/3h)	Showers	Averses	Good/Bien
Snow	New Category - low precip	(if 1 cm/3h<Snow and/orOR Ice Pellets<3 cm/3h)	Light snow	Neige Légère	Fair/Juste
Snow	Previuosly yellow	(if 3 cm/3h<=Snow and/orOR Ice Pellets<=5 cm/3h)	Moderate Snow	Neige Modérées	Caution/Prudence
Snow	Previuosly yellow	(if Snow Or Ice Pellets>5 cm/3h) & PoP<80%	Modrate Snow Possible	Neige Modérées Possible	Caution/Prudence
Snow	same	(if Snow Or Ice Pellets>5 cm/3h) & PoP>=80%	Heavy Snow	Neige Abondante	Poor/Mauvaise
Rain	New Category - Low precip	(if 1 mm/3h<Rain<3 mm/3h)	Light Rain	Pluie Légère	Fair/Juste
Rain	Previuosly yellow	(if 3 mm/3h<=Rain<=6 mm/3h)	Moderate Rain	Pluie Modérées	Caution/Prudence
Rain	Previuosly yellow	(if Rain>6 mm/3h) & PoP<80%	Moderate Rain Possible	Pluie Modérées Possible	Caution/Prudence
Rain	same	(if Rain>6 mm/3h) & PoP>=80%	Heavy Rain	Pluie Forte	Poor/Mauvaise
Freezing Rain	same	(if any Freezing Rain) & PoP<80%	Freezing Rain Possible	Pluie Verglaçante Possible	Fair/Juste
Freezing Rain	same	(if any Freezing Rain) & PoP>=80%	Freezing Rain	Pluie Verglaçante	Poor/Mauvaise
Icing	same	Presence of any precipitation with Pvmnt temp ±2°C from Zero & PoP<80%)	Icy Roads Possible	Chaussée Glacées Possbile	Fair/Juste
Icing	same	Presence of any precipitation with Pvmnt temp ±2°C from	Icy Roads	Chaussée Glacées	Poor/Mauvaise
Frost	same	No precipitation& Pavmt cond. FROST (3 consecutive hours)	Slippery/Icy Roads Possible	Chaussée Glissante/Glacées Possible	Fair/Juste
Black Ice	same	No precipitation& Pavmt cond. Snow/Ice (3 consecutive hours)	Slippery/Icy Roads	Chaussée Glissante/Glacées	Poor/Mauvaise
Visibility	same	(if 250<=Visibility<=500 m)	Low Visibility	Visibilité Réduite	Fair/Juste
Visibility	same	(if Visibility<250 m)	Poor Visibility	Visibilité Mauvaise	Poor/Mauvaise

Examples of how MTO presents forecasted road conditions to travelers using a colored-coded map and informational dialog boxes available after clicking on a road segment.





References

Kwon, T., and Fu, L. *RWIS Network Planning: Optimal Density and Location.* Aurora Pooled Fund Program/Iowa Department of Transportation. Ames, IA, 2016.

Kwon, T., Biswas, S., Xu, S., and Fu, L. *Optimal RWIS Sensor Density and Location – Phase II.* Aurora Pooled Fund Program/Iowa Department of Transportation. Ames, IA, 2020.

Hodgins, B., Dinning, M., and Wismer, D. *Winter Road Condition Terminology User Guide.* Transportation Association of Canada. Ottawa, ON, 2011.

Mertz, C., Ehrlichman, C., Kozar, J., and Varadharajan, S. *Road Condition Reporting*. Pennsylvania Department of Transportation. Harrisburg, PA, 2015.