ENTERPRISE Transportation Pooled Fund Study TPF-5 (231)

ENTERPRISE

Photo: MnDOT

Automated/Assisted Classification of Winter Road Conditions (Phase 1)

PROJECT SUMMARY REPORT

Prepared by

Athey Creek CONSULTANTS

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Acknowledgements

This document was prepared for the ENTERPRISE Transportation Pooled Fund TPF-5(231) program (http://enterprise.prog.org/). The primary purpose of ENTERPRISE is to use the pooled resources of its North America agency members and the United States federal government to develop, evaluate, and deploy intelligent transportation systems (ITS).

Project Champion and Team

Sinclair Stolle, Iowa DOT, was the ENTERPRISE Project Champion for this effort and served as the overall lead for the project. Tina Greenfield, Iowa DOT; Pat Knight, Pennsylvania DOT; and, Melissa Longworth, Michigan DOT also served as the Project Team.

Members

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

- Federal Highway Administration
- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Michigan Department of Transportation
- Ministry of Transportation Ontario
- Minnesota Department of Transportation
- Pennsylvania Department of Transportation
- Texas Department of Transportation
- Transport Canada

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1.0 Introduction

Winter road conditions are one of the most often requested information types by those using traveler information services provided by departments of transportation (DOT). Results of a 2013 ENTERPRISE project titled, "Use and Impacts of Camera Images and Other Displays of Traveler Information," surveyed travelers and DOT representatives to understand the extent to which camera displays are as valuable to travelers as DOT-generated road conditions. The results found that road condition reports and camera images were almost equally valuable, with many users expressing the greatest value in the combination of camera images and road condition reports created by DOT staff.

One of the most significant challenges with providing travelers reports on winter road conditions is the collection of information for such reports. Classifying winter road conditions for operations and traveler information has primarily been a manual process based on staff observations while performing maintenance activities. It is a resource intensive action, often required during the busiest times of winter storm response. Because reports are based on staff observations, they can also be very subjective. This leads to inconsistent and outdated reports that are of less value to travelers.

The introduction of road weather information systems (RWIS) at fixed locations along the road, mobile sensors and cameras on fleet vehicles, and advanced weather reporting have increased the availability of data for DOT staff to better understand road conditions in addition to staff observations. As the automobile industry prepares for wider deployment of Connected and Automated Vehicles (CAV), the transportation industry anticipates the opportunity to gather even more mobile data about road conditions from private vehicles.

For these reasons, ENTERPRISE commissioned this project to **research the state of practice on automating or assisting staff with the classification of winter road conditions for traveler information**. The objectives for the project were to assemble a Project Team to guide research and support contact with related efforts; and, research current approaches for automating or assisting winter road condition classification.

1.1 Approach

ENTERPRISE recognized that this project would benefit from the participation of individuals who are more directly involved with road weather management activities in their member agencies. A Project Team was established with DOT employees who have maintenance and traveler information expertise. The Project Team consisted of representatives selected by the ENTERPRISE board members and included:

- Sinclair Stolle, Iowa DOT and Project Champion
- Tina Greenfield, Iowa DOT
- Pat Knight, Pennsylvania DOT
- Melissa Longworth, Michigan DOT

If additional work in this area is pursued by ENTERPRISE, additional people may be added to the Project Team. In particular, ENTERPRISE may seek additional representatives from the Aurora and Clear Roads pooled fund programs. These programs are focused on road weather management and more aware of advances that support maintenance staff with winter road condition reporting for operations. Those same advances could also be leveraged for automating or assisting reports for traveler information.

The role of the Project Team during this project was to:

- Review the research focus to guide contacts and initial research
- Receive and comment on interim research findings
- Receive and comment on the project report
- Provide input on the necessity and direction of additional work in this area for ENTERPRISE consideration
- Participate in the final presentation and recommendation, if applicable, on a second phase

Once the Project Team was established, the following central terms and definitions were identified to promote understanding of and maintain consistency with the information desired for this project. This was considered important as terms can often be confused when discussing road weather management strategies as they relate to maintenance operations vs. traveler information. It was also important to establish a common understanding of what the terms automated, assisted and manual meant within the context of this research.

- **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 pre-defined categories (e.g. snow covered, icy, wet)
- **Automated**: Systems with capabilities to interpret data from stationary (e.g. RWIS, NWS) and mobile (e.g. plow sensors, cameras) devices and other systems to classify winter road conditions
- **Assisted**: Systems with semi-automated capabilities (e.g. iPads with preset condition categories and automated location information) used to support operators with classifying winter road conditions
- **Manual**: Operator observations often reported by radio to a central location where information is manually entered into a system for reporting or operations

These terms and definitions were used as the research was conducted. The research itself consisted of a reviewing published reports and conducting interviews. A summary of the targeted contacts and reports was developed with input from the Project Team to ensure a broad and applicable base of known work was covered during the research.

This report presents the culmination of the research that was conducted, featuring several practices being explored by the transportation industry to automate or assist with the classification of winter road conditions. The report includes the following sections that document the information gathered to meet the project objectives.

- 2.0 Classifying Winter Road Conditions – Summaries of individual approaches to automating or assisting the classification of winter road conditions identified through research.
- 3.0 Conclusion – Key findings identified from research and observations about promising approaches to follow as work continues to evolve in this area.

2.0 Classifying Winter Road Conditions

The emphasis of this report is on winter road condition reporting for traveler information; however, the gathering of road condition information is rooted in maintenance operations. Clearly, DOT staff need to understand road and weather conditions to determine how best to respond to snow and ice during winter storms. Leveraging that information for travelers was perhaps a secondary service when DOTs first began offering it many years ago, but the proliferation of agency and private sector reporting services has elevated road condition reports to a primary and vital service provided by DOTs.

Over the past two decades, agencies have installed extensive RWIS networks on many state-maintained roads to remotely gather localized information about road conditions. In more recent years, agencies have begun to equip fleet vehicles with mobile sensing and observation technologies that can supplement fixed-location RWIS networks. Mobile equipment may be placed on fleet vehicles such as snow plows to measure roadway friction, temperature, and other parameters that can help staff further understand the condition of the road. Vehicles may also be equipped with automatic vehicle location (AVL) and control technologies that can report location and the current operations being performed (e.g. if the plow blade is up or down, if chemicals are being applied). Cameras are also being installed in snow plows to provide remote views of road conditions for management staff to modify activities during snow and ice operations. Data and information from these technologies are sometimes integrated with decision support systems and other systems or they are used more individually to support remote observations.

In addition to technology that can provide additional and more frequent data about road conditions, agencies also continue to rely on staff reports of road conditions based on their observations while in the field. There are tools being developed to assist staff with this more traditional reporting process. Such reporting may allow staff to enter road condition reports using mobile devices and specialized applications. These can streamline the reporting structure, automatically attach location information to a report based on known GPS coordinates at the time of reporting) or other supporting tools. An example is the use of in-vehicle devices (e.g. iPads) to enable operators to select road conditions to be combined with the GPS of the device to create a winter driving report with minimal driver interaction.

Many of the tools developed predominantly for maintenance operations could also be modified and used to support some degree of automated or assisted road condition reporting for traveler information.

2.1 Automated/Assisted Approaches Identified through Research

The remainder of this section features specific applications of the approaches described above as they have been explored for automating or assisting winter road condition reports for traveler information. Each approach includes a title reference, details for further information, indication of its degree of automation/assistance, and a description of the approach. It is important to note that many of these approaches are not exclusively automated or assisted in nature. As illustrated in Figure 1, there may be degrees of automation, assistance or both on the spectrum of approaches to reporting winter road conditions. This figure is also used later in this section to indicate the degree of automation/assistance for each featured approach.

Figure 1 Degrees of Automation and Assistance

When available, the descriptions also capture information about the following characteristics.

- Communications approaches for relaying data and information to a central location
- Requirements for in-vehicle equipment (e.g. sensor data, camera resolution)
- Equipment reliability, maintenance and protection in a mobile work environment
- Staff response to using new approaches
- Performance experiences with various products or technical approaches

Minnesota Department of Transportation (MnDOT) Use of Maintenance Decision Support System (MDSS) for Automated Traveler Information Road Condition Reports

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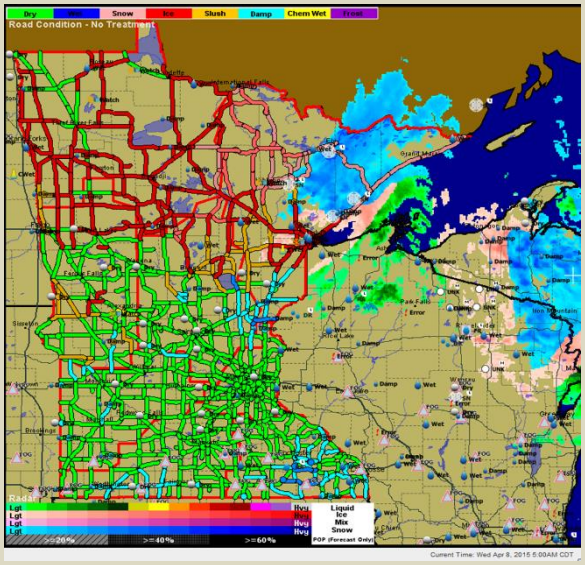
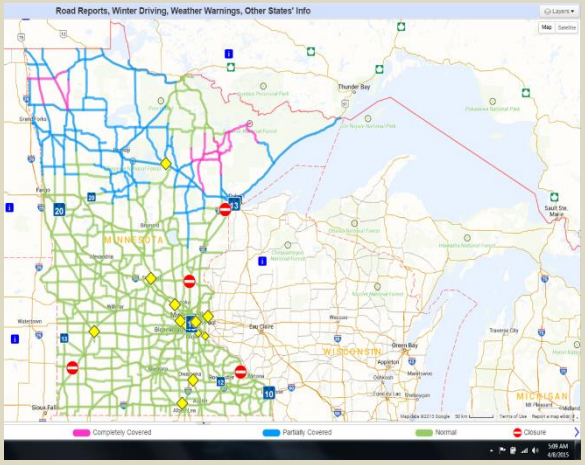
Automated

Issue: MnDOT is challenged with maintaining accurate and timely winter road condition reports using the traditionally manual process of staff observation and entry into their Condition Acquisition and Reporting Systems (CARS) to feed their traveler information services.

Approach: During the 2016-17 winter, staff compared screen shots, as illustrated in these figures, of winter road condition reports from MDSS and 511mn.org to determine if there was a close enough match between the MDSS reports and the manual reports to pursue further development. The staff also felt confident that MDSS entries were more frequent and more consistent than the manually-entered traveler information reports, primarily due to the other demands on plow operators during winter storm events. MnDOT has contracted with their traveler information vendor, Castle Rock, to modify CARS so that it can ingest winter road condition reports from MDSS. The initial CARS modification will be available on a development site during the 2017-18 winter, allowing MnDOT staff to further evaluate the MDSS-generated reports against those that are manually entered.





Results: Following the evaluation, MnDOT will determine whether the automated approach to winter road condition reporting using MDSS can fully replace the manual process that has traditionally been used.

Pennsylvania Department of Transportation (PennDOT) and Carnegie Mellon University (CMU) Image Processing for Road Condition Reports

Christoph Mertz, cmertz@andrew.cmu.edu

Issue: Like other states, PennDOT was interested in exploring methods to automate road condition reporting.

Approach: Previous research at CMU had developed a system to detect pavement cracks, potholes, and other surface textures using camera images taken from vehicles driving the highway and performing image processing. CMU explored opportunities to expand the texture detection system to process images from vehicles and classify the road conditions in an attempt to describe road conditions as accurate as field staff observing the conditions are able to. During this initial research, images were captured from cameras mounted inside snow plows looking out in the front direction and capturing images of the road, and downloaded periodically. Using the image processing system, each image was analyzed and a road condition classification assigned. The initial textures that the system was trained to classify include: snow, slush, and wet roads. However, the system can be trained for additional textures that humans can see and detect. The images captured used in the research were captured either as still photographs or video (individual frames were extracted for analysis). The typical resolution of the cameras capturing the images is 1000X2000. CMU indicated that it is possible to train and classify the conditions with a resolution of 640X480, however the increased resolution results in better performance. A good rule of thumb is that if the resolution is so low that humans looking at the image cannot classify the condition, it is likely that image processing is also not going to be able to classify the condition.

Results: Comparing the image processing results against human reports of the road conditions confirmed that the performance of the image processing system matched that of manual reports. The next step identified was to proceed to testing of the system with real-time download of images and real-time processing to determine if the system could deliver the road condition reports needed to disseminate in traveler information systems. The project is currently on pause, with no immediate plans to move forward. The previous research conducted by CMU to detect cracks and potholes has led to the creation of a private company called RoadBotics, which would be a possible path to commercializing the road condition classification functionality.

Idaho Transportation Department (ITD), Idaho National Labs (INL), IBM Proof of Concept on a High Resolution Forecasting Tool

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Issue: Growing data and images regarding road conditions create unique challenges for interpreting data from multiple sources and turning it into useful information for both maintenance operation and traveler information.

Approach: ITD, INL and IBM are working together to combine weather data with transportation data and, using sophisticated analytics, provide information that can optimize maintenance operations. The team developed an analytics platform using IBM Watson tool to interpret data from multiple sources, including video and data from 12 ITD RWIS sites. One ITD camera was also used in the platform to detect snow, dry pavement, etc. using the Watson video API. The tool can be trained to recognize any kind of condition and could be deployed across all ITD cameras. The proof of concept platform is being operated at the INL facility in Idaho Falls, ID to generate detailed forecasts for 300 miles of road with weather data forecasted down to 500m. Tailored to winter driving for buses around the INL site, it utilizes three categories of information: predictive (to forecast conditions), current (to minimize vehicle scouting), and historical (to help identify trouble spots). INL is exploring how best to deliver information to specific bus drivers within specific areas. Natural language features are built into the platform and would allow information to be verbalized through an earpiece. INL is also considering if information could be visually shared with bus drivers via tablets on the bus without driver distraction issues.

Results: The proof of concept met all dashboard performance indicators. ITD sees the potential for the platform to be expanded statewide to support automated road condition reporting. They also see value in the platform on the predictive side for maintenance operations. The next phase of work in this area would likely include enhancements that allow the platform to recognize road conditions from all ITD cameras and expanded alert sharing.

ITD Friction Sensor Data for Localized Road Condition Reports

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Issue: ITD has used friction sensor data from RWIS sites for winter maintenance operations and performance measures for many years. The data is very detailed for winter maintenance operations but ITD recognized potential for generalizing the information for travelers as a supplement to their traditional road condition reporting based on staff observations.

Approach: ITD worked with their traveler information vendor, Castle Rock, to develop a way to generalize and transfer RWIS data to travelers as supplemental road condition information. Data is interpreted and categorized into three types: clear, slick, or very slick. The thresholds between these values correspond with those used by maintenance operations as follows:

- .8 and higher is the threshold for clear
- .6 to .4 is the threshold for slick
- Anything less than .4 is very slick

To establish extents for the generalized reports, ITD asked operators to provide an indication of how extensive each RWIS site might reflect conditions based on geography (e.g. plains vs. mountains) and their experience. The extents are typically just a few miles in either direction so that limits the ability for this type of reporting to fully replace manual reports in areas where RWIS sites are deployed further apart. In contrast, I-84 from Caldwell to Boise has overlapping RWIS sensors offering greater opportunity for automated reporting in small urban areas. Information is displayed on 511.idaho.gov as a layer that can be toggled on an off. When users mouse over icons in this layer they see an indication for how far the conditions are expected to extend. When slick conditions are detected, icons appear as a red triangle with a thermometer and the icon appears even if the RWIS layer is not turned on. If a user clicks on the icon, the RWIS display opens and the display changes to draw more attention to the report.

Results: This feature was first released during the 2014-15 winter. ITD has not received significant feedback from the public on the feature but maintenance staff really like the feature and reference the alerts in their road condition reports. In addition to data from fixed RWIS sties, mobile sensors on fleet vehicles could further extend network coverage and improve the potential for automated reporting. In the future, data will likely be collected from even broader sources creating a need for large amounts of dissimilar data to be intelligently analyzed and produce useful information for winter maintenance operations and traveler information.

Wyoming Department of Transportation (WYDOT) Road Condition Reporting Application for Weather Responsive Traffic Management (WRTM)

https://ntl.bts.gov/lib/56000/56800/56890/FHWA-JPO-16-266_v2.pdf

Assisted with Limited Automation

Issue: WYDOT's radio system serves five maintenance districts but only allows one person to speak at a time. This led to radio traffic conflicts during storms that made it difficult for field staff to report road conditions in a timely manner to traffic management center (TMC) operators who would then enter the reports into WYDOT's road condition reporting system, Wyoming Travel Information (WTI).

Approach: WYDOT created a custom application, as illustrated in this figure, to run on tablets in plows. The app was designed to help operators enter road condition reports and perform several other functions including incident reporting, and variable speed limit (VSL) and dynamic message sign (DMS) change requests. Information is sent from the app to the TMC Transportation Reports and Action Console (TRAC) and WTI. Information is relayed using the statewide radio network, WyoLink, along with 13 Wi-Fi hotspots at key locations (e.g. sand piles, fuel sites) to facilitate data exchange, preventing WYDOT from incurring additional cellular service costs. Since the app uses a combination of Wi-Fi and radio, with a data "store and forward" function, radio traffic can also be better managed.

Results: During the 2014-15 winter, WYDOT placed tablets in 20 plows on I-80/I-25 and deployed over 100 additional tablets during the 2015-16 season. They aim to deploy tablets in their entire fleet of roughly 400 plows. They also plan to further enhance their app to add additional functions such as pre-trip inspections. After the initial evaluation period, the following key results were identified.

- ***Improved the efficiency of road condition reporting*** by maintenance employees and TMC operators. Road condition reports doubled and VSL change requests tripled. The app proved to be useful in operations and the agency believes they are better off with the app.
- ***Improved traffic management during weather events***. WYDOT found that the app was easier to get information from than the radio, they could make more DMS change requests, and VSL and DMS changes were more accurate as a result.
- ***Improved timeliness of reporting to public.*** Maintenance operators could make twice as many reports because less time was needed for reporting.
- ***Improved situational awareness.*** With the app, maintenance staff felt more informed about road conditions in their area.

Furthermore, WYDOT identified that an added benefit to using tablets in the plows was that maintenance employees could also receive information such as weather information, asset locations and messages shared with the public. The tablets also allow employees to send and receive email messages and offer integration with other maintenance activities, providing additional benefits beyond the standalone device used only for road condition reporting.

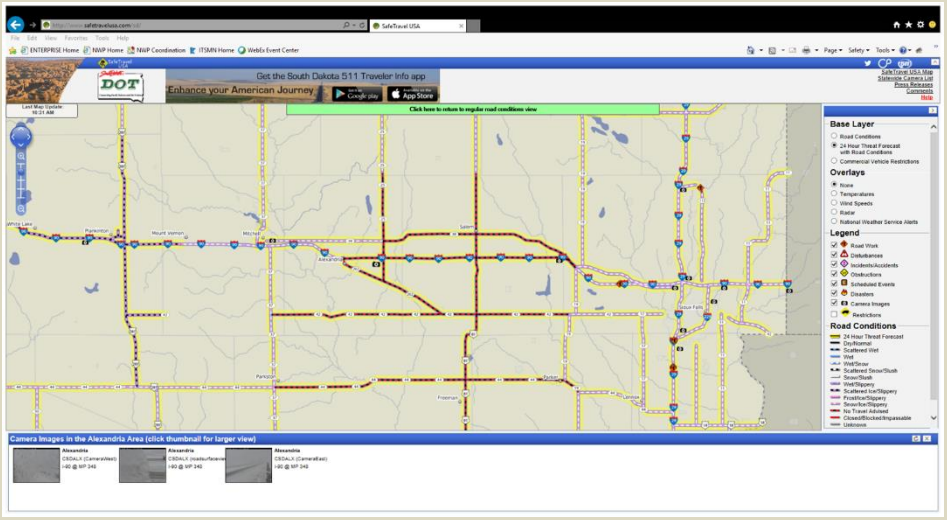
South Dakota Department of Transportation (SDDOT) Regional Traveler Information System (RTIS) for Weather Responsive Traffic Management (WRTM)

https://ntl.bts.gov/lib/56000/56900/56952/FHWA-JPO-16-269_V1.pdf

Assisted with Limited Automation

Issue: Like many transportation agencies, SDDOT relies on plow operator observation and reports of winter road conditions for both maintenance operations and traveler information. However, SDDOT does not have a TMC and they do not operate 24/7. This resulted in less frequent, less timely and less accurate winter road condition reports for their traveler information services.

Approach: Traditionally, plow operators would use the radio to report road conditions to a supervisor. Then the supervisor would enter reports into the Integrated Roadway Information System (IRIS) for dissemination via SDDOT traveler information services. With this project, SDDOT wanted to make road condition reporting more efficient for plow operators and find a way to warn travelers of potential threats when staff-generated road condition reports were unavailable. SDDOT first installed mobile data collectors (MDCs) in their plows to assist operators with entering current road conditions directly into IRIS. The application and MDC interface for entering road conditions are similar to what the plow operators were already using to enter weather and road condition information into MDSS. To warn travelers of potential threats during off-hours, SDDOT also integrated MDSS with their traveler information services to extract and summarize data to identify worst-case status for roadways over a 24-hour forecast period. Depending on the status identified, SDDOT traveler information services will report forecasted threats, as illustrated in this figure, separately from current road conditions.



Results: Twenty-three (23) maintenance staff tested a simulated application for road condition entry, and all reported it was easy to use. They further reported that the MDCs and application would support more frequent, timely and accurate road condition reporting that would ultimately keep travelers better informed. SDDOT planned to deploy the app on all plows for statewide road condition reporting during the 2015-16 season. SDDOT also conducted traveler surveys regarding threat forecasts. Of those responding to the survey, 80-87% found the forecasted information to be “quite useful” or “very useful” and survey responders agreed that information helped manage their travel plans by changing timing and route, and by feeling more prepared.

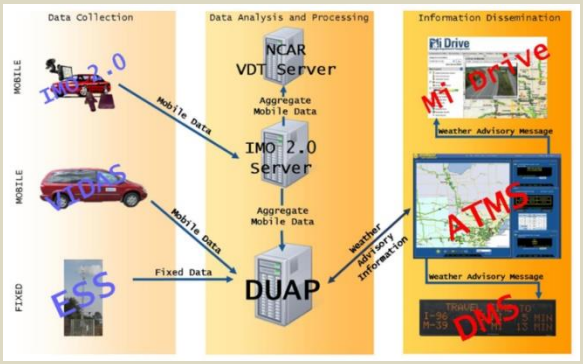
Michigan Department of Transportation (MDOT) Weather Responsive Traveler Information (Wx-TINFO) System Implementation Project

https://ntl.bts.gov/lib/58000/58000/58015/FHWA-JPO-16-323.pdf

Assisted with Limited Automation

Issue: MDOT was challenged with receiving timely weather information that would allow TMC operator to convey messages to travelers via DMS and MiDrive.org. Though this project was more weather than road condition oriented, the tools developed by MDOT could potentially be modified for road condition reporting.

Approach: The Weather Responsive Traveler Information (Wx-TINFO) system was developed to address this challenge. Wx-TINFO integrates near real-time weather information with environmental information using both fixed and mobile data sources. Within Wx-TINFO, the Data Use Analysis and Processing (DUAP) system processes weather data from a variety of sources to provide automated weather alerts and DMS message recommendations to TOC operators. DUAP collects dissimilar data, performs quality control, and parses and stores information in data files that are used by other MDOT apps and systems as illustrated in this figure. The MDOT ATMS is used by TOC operators to manage information on DMS and MiDrive.org. As weather alerts and recommended messages are received from Wx-TINFO, TOC operators have the option to accept or reject them in their traffic management operations.



Results: MDOT traffic operations staff found the Wx-TINFO improved their real-time traffic management capabilities during weather vents, allowing them to post more weather alerts on DMS and MiDrive. MDOT maintenance staff also found the information valuable for future use, with the potential to improve accuracy and detail in road weather reporting.

North Dakota Department of Transportation (NDDOT) iPad Deployment for Winter Road Conditions

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Assisted

Issue: NDDOT has used temporary staff during the winter months to staff a call center where plow operators could report road conditions and reports could be entered in the department's traveler information system. In summer 2016, NDDOT budget reductions prevented them from bringing back temporary staff and maintenance needed to find another way to accomplish road condition reporting.

Approach: Staff developed the idea for plow operators to do road condition reporting from their trucks using iPads. The iPads were loaded with the road condition reporting system (RCRS) application, optimized for mobile use. Servers were also upgraded to accommodate the higher volume of simultaneous entries. Procedures were modified and plow operators were retrained to make their entries using the iPads instead of calling reports in. If plow operators are too busy to update road condition reports, district management staff can do it for them. The optimized mobile application also allowed district managers to make reports after hours if they receive calls from patrol about changing conditions. One iPad is assigned to each maintenance garage and it typically starts with the lead shift person reporting conditions, although some operators have used their smartphones to update road conditions. The iPads also allow plow operators to do anything they would typically do on a desktop computer such as accessing MDSS, timesheets, materials usage, roadside inventory, etc.

Results: Initially the change to using the iPad for road condition reporting presented several challenges. NDDOT maintenance did not have iPads, RCRS was not optimized for mobile use, the server was not equipped to handle multiple entries simultaneously, and cellular communication needed to be supplemented with Wi-Fi. Operators needed to be retrained to do entries instead of calling conditions in and the procedures for reporting had to be modified. Getting iPads in place and completing training before winter was also challenging. Training had to be completed in waves across eight districts. Operators also initially felt they did not have time to make the entries and did not feel technically qualified to enter all the data needed for an entry (e.g. precipitation, wind speed). In time, operators found the benefits outweighed their concerns and realized the reporting was not as labor intensive as they expected. Even though NDDOT was forced into this approach and had to implement it quickly, they have discovered numerous benefits to the new approach and plan to continue it during the 2017-18 winter season.

The next four approaches are applications that have been developed by the Federal Highway Administration (FHWA) for various aspects of road weather management. Although their primary focus is to support maintenance operations, they are referenced here because they could potentially be modified to support automated or assisted winter road condition reporting for traveler information.

Pikalert

https://www.itsforge.net/index.php/community/explore-applications#/41/131

Pikalert provides high-precision road weather forecasts and recommendations for maintenance operations using weather and road condition information from connected vehicles, RWIS, radar and weather models. It can ingest data from multiple sources and perform quality checks that flag potentially erroneous data. Pikalert is available in the following user interfaces:

- Enhanced MDSS (EMDSS) is web-based and intended for maintenance staff. It provides road weather and condition forecasts out to 72 hours.
- Motorist and Advisory Warning (MAW) is available as both a web-based and phone app intended for public use. It also provides road weather and condition forecasts but it is restricted to 24 hours out.

Pikalert is also available as open source software available through the USDOT-sponsored Open Source Application Development Portal (OSADP). More information about the FHWA/National Center for Atmospheric Research project that developed Pikalert is available in "Results from the Integrated Mobile Observations Study" (May 2013).

Integrated Modeling for Road Condition Prediction (IMRCP)

https://imrcp.data-env.com/

IMRCP is an experimental system designed to combine weather and traffic data into traffic modeling. The primary objective of IMRCP is to demonstrate the integration of traffic, weather, and operational event forecasts to model and predict integrated road conditions. IMRCP uses the TrEPS/DYNASMART model and focuses on the impacts that weather has on traffic.

IMRCP is being demonstrated along the I-435 corridor in the Kansas City metro area. It allows users to view traffic, weather and road conditions and alert by road segments. It also allows users to create reports and subscriptions for notifications based on observation type(s), format and time parameters.

Weather Data Environment (WxDE)	
https://wxde.fhwa.dot.gov	***Automated and Assisted***

WxDE collects and shares transportation-related weather and road condition data from across the US for transportation system management and operations (TSMO) and Connected Vehicle (CV) Applications. Data is gathered from 40 state and local transportation agencies and other contributors. WxDE is available for use with MDSS, fleet management systems, motorist advisory and warning systems for traveler information, and weather responsive traffic management systems. WxDE performs data quality checks similar to Pikalert and the Pikalert VDT forecasting modules have been integrated with WxDE. Data is collected, processed and available using a report/subscription query interface.

Road Weather Performance Management (RW-PM) Tool	
https://ntl.bts.gov/lib/61000/61100/61112/FHWA-JPO-17-486.pdf	***Automated and Assisted***

The RW-PM uses CV and other data sources to provide real-time traffic mobility and road weather conditions for both DOT and CV operators to manage performance. RW-PM is also available as open source software available through the OSADP.

RW-PM completed a pilot project with MnDOT on I-35W from November 2015 to April 2016 on nine light duty vehicles. The project used RWIS and snowplow data from Pikalert and used Pikalert for Road Weather and INFLO apps for weather responsive traffic management speed harmonization. Traffic speed data was obtained from Google maps, MnDOT sensors, and CV performance. The pilot project presented real-time conditions and recommendations on a web page. Motorist and road weather maintenance advisories were made available to CVs using the RW-PM tool mobile app on Android phones with cellular and Bluetooth connectivity.

2.2 Additional Pooled Fund Related Research

In addition to the work conducted by agencies and the vendor products noted, the Aurora and Clear Roads pooled fund program have conducted projects related that could directly or indirectly support the automation and assistance of winter road condition reporting for traveler information. Following is a brief summary of both programs and the relevant projects they have sponsored.

The Aurora pooled fund is an international program of collaborative research, development, and deployment in the field of road weather information systems (RWIS). Its vision is to deploy RWIS to integrate state-of-the-art road and weather forecasting technologies with coordinated, multi-agency weather monitoring infrastructures. It is hoped this will facilitate advanced road condition and weather monitoring and forecasting capabilities for efficient highway maintenance and real-time information to travelers. Although most projects are focused on maintenance operations vs. traveler information there the following have some correlation to the automation and assistance for winter road condition reporting for traveler information.

- Cameras and Operational Impact of Remote Road Condition Monitoring. Focused on evaluating the effectiveness of cameras in snow removal related maintenance operations based on a deployment by Utah DOT. The evaluation found the cameras to be effective at reducing costs associated with maintenance staff making trips to check road conditions. The evaluation did not focus on the use of cameras for traveler information road condition reporting.
- Field Test and Evaluation of a Mobile Automated Winter Road Condition Reporting System. This project evaluated the performance of a smartphone-based, automated road surface condition monitoring tool called AVL-Genius, developed by the iTSS Lab at the University of Waterloo. The system captures images of the road surface and classifies them into pre-defined categories of road surface condition. The evaluation found that the system achieved an average of 73% accuracy in classifying over 16,000 images. The main causes for misclassification were attributed to poor image quality due to dirty windshields, low visibility, glare from sunlight, residual salt on the road surface, and shade from roadside trees.
- Intelligent Image-Based Winter Road Condition Sensor. There were three phases to this work to test the combination of images and other RWIS data to determine road conditions. The final phase of testing in Sweden tested the system's ability to classify up to five road conditions and it was determined that the field image classification system was far too low in accuracy to be acceptable.

The Clear Roads pooled fund is a national research consortium focused on rigorous testing of winter maintenance materials, equipment and methods for use by highway maintenance crews. Although its research is predominantly focused on maintenance operations, the following projects are somewhat relevant to the automation and assistance for winter road condition reporting for traveler information.

- Using Friction Measurements to Gauge Winter Maintenance Performance. Summarized research and information regarding the use of friction measurements as winter maintenance performance indicators, with an emphasis on how transportation agencies are using friction measurements to assess road conditions for maintenance operations.

- Standards and Guidance for Using Mobile Sensor Technology to Assess Winter Road Conditions. The standards and guidance being developed through this project are intended to help transportation agencies better understand and make use of data from the variety of vehicle-mounted sensors that are available. *This project is still underway and scheduled for completion in early 2019.*
- Plug and Play Initiative. There were three phases to this work focused on identifying common communication and data exchange protocols among the variety of sensors and other equipment on fleet vehicles. Cellular communication was identified as the most prevalent form of communication with other methods like Wi-Fi used as supplements. A much broader number of data types were identified as important for inclusion in a plug and play protocol. *Further research is possible in this area under the proposed project,* Developing Test Bed Software to Qualify Plug and Play Technology*.*
- Aftermarket Cameras in Winter Maintenance Vehicles. Research conducted for this project will provide guidance to transportation agencies in their use of aftermarket cameras installed on winter maintenance vehicles. However, it is also noted that for the purposes of this research, the public would not be a primary consumer of these images, though Clear Roads recognizes that incorporation of selected images into a public sharing system like 511 will be of interest to some states. *This project will likely be initiated in late 2017.*

3.0 Conclusion

Significant work has been done for both the automated and assisted classification of winter road conditions for both traveler information and maintenance operations. Research has shown encouraging results for both automated and assisted classification of winter road conditions. Assisted classification of road conditions seems prevalent with many agencies using tablets for maintenance reporting in plows and other field vehicles. Automated reporting also appears to be evolving in terms of techniques for gathering data and for analyzing and presenting that data. Based on the findings of the research, the following are suggestions for consideration:

- ***Assisted classification with in-vehicle devices.*** Multiple DOTs have deployed in-vehicle devices and apps to assist plow operators with reporting conditions. These range from specialized apps on tablets designed for road condition reporting exclusively, to a suite of functions that support material management, performance reporting, and roadway monitoring in addition to road condition reporting. In addition to those approaches summarized in this report, Iowa and Washington departments of transportation are also using in-vehicle devices for various aspects of road condition reporting. If ENTERPRISE pursues another phase to this project, one topic of a workshop could be to discuss specific lessons learned with in-vehicle user interfaces. This could benefit states considering in-vehicle assistance, developing new interfaces or updating existing in-vehicle devices. Based on this trend, ENTERPRISE members upgrading or procuring road condition reporting systems or traffic management systems should also consider adding functionality these systems to support the ingest of reports from in-vehicle devices.

- ***Integration of decision support system data***. Integration of road condition reports from decision support systems appears to offer a near-term approach for automated road condition reporting in states already operating such systems. Typically, decision support systems are already utilizing operator input, so there is still human involvement in the overall reporting process. If ENTERPRISE pursues another phase to this project, a potential workshop topic area could be detailed discussions about how MDSS and other decision support systems can be integrated with road condition reporting systems and traveler information services to automate that part of the reporting process.

- ***Image processing.*** A number of approaches for processing images to automatically classify road conditions were identified in the research, and the status is typically 'emerging' but not yet used in production. Efforts initiated in Pennsylvania (CMU) and in Ontario (University of Waterloo) both are focused on classifying road conditions for traveler information using images. Efforts in Utah are primarily focused on the maintenance aspect but has potential to directly support traveler information. It is also likely that other universities may be approaching road condition classification through image processing, or there may be existing systems that process images to identify textures that could be modified to support road condition reporting. Another candidate workshop topic could be sharing of image processing approaches for road condition classification, with the intent of encouraging more research to support DOT needs, and supporting transition from research to everyday use by DOTs.

- ***Emerging vendor products and services.*** A number of vendors indicated that they have emerging solutions for automating road condition reports that are not yet tied to DOT deployments or traveler information. Vendor presentations of these emerging approaches could be conducted, either as part of a workshop or through online webinars to help DOTs understand the future potential of this area of research.

The use of automated or assisted classification of winter road conditions is increasing among DOTs. The ability to deploy equipment sensors, cameras, tablets, cell phones and related apps in vehicles is a catalyst that is encouraging rapid growth in this area of focus. In the next few years, it is expected that there will be several expanded and further developed uses of these approaches.