SPR, Part B
MD-24-SHA/UM/6-12

MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

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RESEARCH REPORT

INTEGRATING ROAD WEATHER TECHNOLOGY DATA IN HIGHWAY OPERATIONS

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University of Maryland – Center for Advanced Transportation Technology Laboratory (CATT Lab)

FINAL REPORT

March 2024

This material is based upon work supported by the Federal Highway Administration under the State Planning and Research program. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the Federal Highway Administration or the Maryland Department of Transportation. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT DOCUMENTATION PAGE

<table>
<tr><td colspan="2">1. Report No.
MD-24-SHA/UMD/6-12</td><td colspan="2">2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="4" rowspan="2">4. Title and Subtitle
Integrating Road Weather Technology Data in Highway Operations</td><td colspan="2">5. Report Date
March 29, 2024</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="4">7. Author(s)
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Sara Zahedian, Ph.D. https://orcid.org/0000-0002-6927-1189</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="4" rowspan="2">9. Performing Organization Name and Address
University of Maryland – College Park
Center for Advanced Transportation Technology Laboratory (CATT Lab)
Technology Ventures Building
5000 College Ave, Suite 2206
College Park, MD 20742</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
SHA/UMD/6-12</td></tr>
<tr><td colspan="4" rowspan="2">12. Sponsoring Agency Name and Address
Maryland Department of Transportation (SPR)
State Highway Administration
Office of Policy & Research
707 North Calvert Street
Baltimore MD 21202</td><td colspan="2">13. Type of Report and Period Covered
SPR-B Final Report
April 2022 – March 2024</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
(7120) STMD - MDOT/SHA</td></tr>
<tr><td colspan="6">15. Supplementary Notes</td></tr>
<tr><td colspan="6">16. Abstract
Inclement weather can significantly impact the performance of any transportation system, including roadways. Effective roadway operations and maintenance requires quality weather data to estimate real-time and near-future road conditions. While there are several sources of such data such as radar, Road Weather Information Systems (RWIS), and Mobile RWIS (MARWIS), these data sources are often siloed. Thus, few studies have been conducted to assess the enhanced situational knowledge that can be learned from fusing radar, RWIS, and MARWIS weather data. This project aimed to break down weather data silos to design a comprehensive weather operations decision support platform.</td></tr>
<tr><td colspan="3">17. Key Words
Road weather information systems, RWIS, MARWIS, weather conditions, data fusion, data visualization,
.</td><td colspan="3">18. Distribution Statement
This document is available from the Research Division upon request.</td></tr>
<tr><td colspan="2">19. Security Classif. (of this report)
None</td><td colspan="2">20. Security Classif. (of this page)
None</td><td>21. No. of Pages
50</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

Table of Contents

Acknowledgements

The CATT Lab Team would like to thank Carole Delion, Raqib Mohammed, Warren Henry, Raj Sharma, and Saskia Herrera-Riggs from SHA for their invaluable comments, suggestions, and assistance in managing this project. We would also like to thank Tina Greenfield Huitt (IowaDOT), Travis Lutman (NDDOT), Gene Donaldson, Jeffery VanHorn, Deidre Gleason, and Joseph Spadaro (DelDOT), and Salvatore Cowan and Bonnie Green (NJDOT) for their time in effort in filling out the online survey and participating in the agency interviews. Lastly, we would like to thank Jason Norville (Pennsylvania Department of Transportation), Colby Fortier-Brown (Maine Department of Transportation), Jeff Williams (Utah Department of Transportation), Laura Shanley (Illinois Department of Transportation), Jim Lambert (West Virginia Department of Transportation), Steve Spoor (Idaho Transportation Department), Kevin Duby (Arizona Department of Transportation), Alan Stevenson (Oklahoma Department of Transportation), David Gray (New Hampshire Department of Transportation), Laura Fay (Western Transportation Institute - Montana State University), Jeremy McGuffey (Indiana Department of Transportation), Jeffery Jansen (Minnesota Department of Transportation), and Elizabeth Habic (Federal Highway Administration) for participating in the online survey.

Executive Summary

Inclement weather can significantly impact the performance of any transportation system, including roadways. Effective roadway operations and maintenance requires quality weather data to estimate real-time and near-future road conditions. While there are several sources of such data such as radar, Road Weather Information Systems (RWIS), and Mobile RWIS (MARWIS), these data sources are often siloed. Thus, few studies have been conducted to assess the enhanced situational knowledge that can be learned from fusing radar, RWIS, and MARWIS weather data.

This project aimed to break down weather data silos to design a comprehensive weather operations decision support platform. To do so, this project was guided by the following objectives:

1. **Conduct a more comprehensive literature review** to determine the current state of the practice in how MARWIS data and other innovative weather data are being used in traffic management centers and emergency operations across the nation, particularly if (and how) MARWIS data is integrated into advanced traffic management systems (ATMS) and fused with additional weather data assets (RWIS, NWS radar and forecast data, conflated road weather data, and/or other commercial or publicly available data products). This included surveys and follow-up interviews with agencies to collect information traditional literature reviews could miss.
2. **Identify near-term and long-term areas of emerging technology** that could improve the ability to integrate MARWIS and other weather data into ATMS and Emergency Operations Reporting System (EORS)—specifically how to blend weather data products if appropriate.
3. **Develop mockups and use case scenarios** to illustrate how SHA can visualize and broadly disseminate MARWIS and related weather information through ATMS, EORS, and other decision-support systems. Our objective was to develop innovative, but practical, scenarios grounded in best practices and weather management needs uncovered during the literature review.
4. **Deliver a final report** which contains a synthesis of our literature review, surveys, interviews, and a comprehensive package of the use case and visualization mockups developed for this research project, with accompanying recommendations.

As illustrated in this report, the achievement of these objectives resulted in the following contributions to the field of winter weather roadway operations and maintenance:

1. **Documented state-of-practice** in winter weather data analysis by conducting an in-depth literature review. The literature review provided insights on the impact of winter weather of traffic flow and safety. In addition, the literature documented the data sources commonly used for winter weather impact studies. The three primary weather data sources were RWIS, MARWIS, and weather radar.
2. **Discovered applications, challenges, and benefits of integrating MARWIS data** into a winter weather operations and maintenance decision process. These insights were obtained through a nationally distributed online survey of agency highway operations and operations professionals. Most agencies using MARWIS were in a pilot phase.

3. **Established baseline for MARWIS data interfaces** to support winter weather operations and maintenance decisions. This baseline was discovered during the one-on-one agency interviews that included a demo of each agency's software package(s) used to analyze various weather data. Most agencies, including SHA, rely on out-of-the-box software to view MARWIS data in a stand-alone application that is not fused with other data sources such as RWIS and radar data.
4. **Designed a comprehensive winter weather decision support platform** that integrates MARWIS, RWIS, real-time and predictive radar into a single application. The platform designs allow a user to view state-wide performance, discover district(s) of interest, identify roads of concern, zoom into specific segments on the target road, and view data from specific sensors/data sources on the target segment.

Introduction

A key element of traffic operations is the knowledge of current and predicted surface weather conditions on the road surface. Weather can quickly and dramatically impact safety and mobility on roads. Weather can impact visibility and high winds can blow trucks off roads and bridges. Icy roads can significantly impact vehicle performance.

The Maryland Department of Transportation State Highway Administration (SHA) Office of Transportation Mobility and Operations (OTMO) has access to many radar data products, but these do not always accurately represent conditions on the roadway itself. OTMO has deployed a handful of Road Weather Information System (RWIS) stations around the state. However, RWIS sites can only convey weather information about the immediate area surrounding the station, and many do not have all of the sensors required for winter weather operations. In addition to RWIS, Maryland SHA also has the potential to access up to 108 MARWIS sensors that are installed on state fleet vehicles. MARWIS data has the advantage of allowing OTMO to observe road weather conditions anywhere the MARWIS-equipped vehicles travel. Since these vehicles are often in the middle of the action when it comes to incidents and winter weather, OTMO has the opportunity to receive valuable weather data where they need it most.

OTMO is at the point of having many disparate weather systems all collecting various flavors of weather measurements at different time intervals and varying spatial resolutions. No one is consolidating these weather data products and presenting a common operating picture that can be used by a diverse set of users to make real-time operational decisions, plan for incoming events, and communicate with the traveling public.

The purpose of this project was to support OTMO in understanding how best to leverage existing and yet untapped weather data sources more effectively throughout the entire agency—particularly in real-time applications through intuitive data visualization and notifications. To do so, this project was guided by the following objectives:

1. **Conduct a more comprehensive literature review** to determine the current state of the practice in how MARWIS data and other innovative weather data are being used in traffic management centers and emergency operations across the nation, particularly if (and how) MARWIS data is integrated into advanced traffic management systems (ATMS) and fused with additional weather data assets (RWIS, NWS radar and forecast data, conflated road weather data, and/or other commercial or publicly available data products). This included surveys and follow-up interviews with agencies to collect information traditional literature reviews could miss.
2. **Identify near-term and long-term areas of emerging technology** that could improve the ability to integrate MARWIS and other weather data into ATMS and Emergency Operations Reporting System (EORS)—specifically how to blend weather data products, if appropriate.
3. **Develop mockups and use case scenario**s to illustrate how SHA can visualize and broadly disseminate MARWIS and related weather information through ATMS, EORS, and other decision-support systems. Our objective was to develop innovative, but practical, scenarios grounded in best practices and weather management needs that were uncovered during the literature review.

4. **Deliver a final report** that contains a synthesis of our literature review, surveys, interviews, and a comprehensive package of the use case and visualization mockups developed for this research project, with accompanying recommendations.

Literature Review

Weather Impacts on Safety

Several studies have been conducted to assess the impacts of inclement weather on roadway safety. The work by Fior and Cagliero (2021) developed weather crash risk models for the regions of the United States. Several regional segregation methods were assessed, including elevation-based regions, census divisions, meteorological regions, and urbanization levels. The study found that the Midwest region has the highest risk level and that non-urban areas are more at risk of crashes under inclement weather. Maze et al. (2006) analyzed the impacts of weather on crashes in Iowa. The study found crash rates increased by 13 times the normal crash rate under snow conditions. During snow, low visibility, and high wind speeds, the crash rate increased by 25 times the normal crash rate. However, the study found that winter weather had minimal impacts of crash severity. Similar results on minimal impacts on crash severity were also discovered by Brow and Baass (1997). These results conflict with other studies by Perry and Symons (1991) and Scharsching (1996) that discovered increases in injury rates under snow conditions. Several studies have noted that snow conditions and/or low visibility conditions increase the likelihood of chain-reaction pileup crashes [Burrow and Atkinson, (2019), Call et. al (2018)]. Though rare, such events tend to receive more media attention, such as the 80-car pile-up on Interstate-81 in Pennsylvania in March of 2022 (Medina, 2022).

The work of Tobin et al. (2019) investigated fatal crashes in the United States that occurred during precipitation events, as recorded in the crash reports from the Fatal Analysis Reporting System (FARS). During the years 2013–2017, 8.6% of fatal US crashes occurred during precipitation events. Of these crashes, 81% occurred in rain, 14% in snow, and 5% in sleet, freezing rain and mixed precipitation. Figure 1 shows the monthly percentage of all fatalities and precipitation-related fatalities from 2013 to 2017. Note the increase in the percentage of fatalities related to precipitation in the winter months.

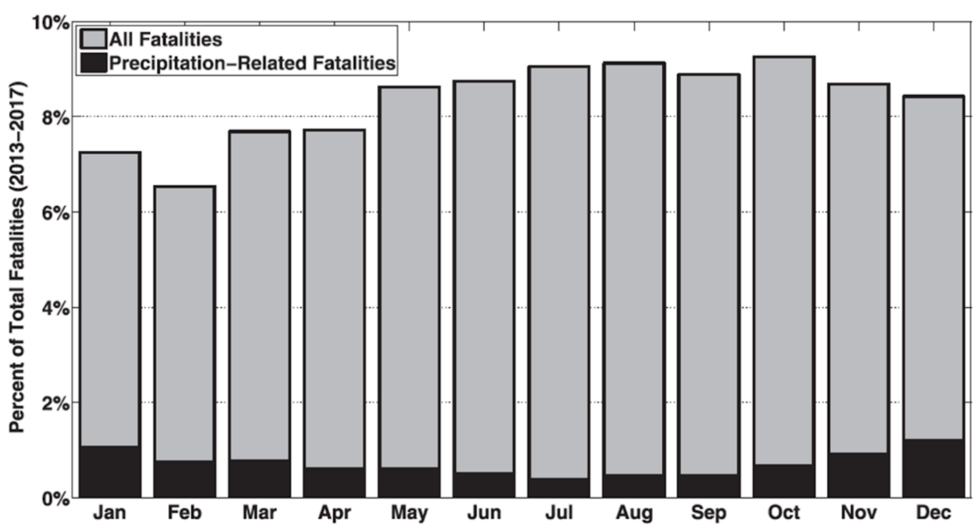


Figure 1: 2013-2017 Percent Monthly Fatalities, All and Precipitation Related (Tobin et al., 2019, data source FARS)

Weather Impacts on Traffic Flow

Speed and Travel Time Impacts

Many studies have been conducted to evaluate the impact of inclement weather on speeds and corridor travel times. A study on the impact of rain on traffic flow and speeds in the Hampton Roads region of Virginia found that increasing rain intensity resulted in decreases in freeway capacity. The study also found that speeds decreased 5%–6.5% in rainy conditions. (Smith et al., 2004). The research by Kurte et al. (2019) evaluated the impact of weather on hourly vehicle probe speeds in Chicago. The study used self-organizing maps to categorize the impacts of weather in urban/non-urban areas as well as residential/non-residential areas. Rain and low visibility were found to significantly reduce hourly speeds, in some cases speed reductions of up to 40 mph were observed. A study of intersection approaches by Lu et al. (2019) discovered that speeds were reduced by 16.9% on slushy surfaces and by 23.3% on snow covered surfaces. Studies in Minneapolis-St. Paul, Baltimore, and Seattle discovered neither rain nor snow impacted jam density, but both impacted free-flow speeds and the speed at capacity was dependent on the precipitation intensity. Maximum reductions of 6%–9% and 8%–14% were observed under rain conditions for free-flow speeds and speeds at capacity. Snow produced larger maximum reductions of 5%–19% (Hranac et al., 2006). Next, a study on the impact of rain in Belgrade, Serbia found free-flow speed reductions of 4.5% to 11.6% depending on rainfall rates and lane. The study also observed lane capacity reductions of 2.5% to 13.0% (Abohassan et al., 2021). A similar study conducted by Barjenbruch et al. (2016) evaluated the impact of two major winter weather events in Salt Lake City, Utah. As illustrated in Figure 2, vehicle speeds were reduced by a freezing rain event (shown with the green bar on the x-axis) relative to a normal, non-event control date. Similar results were observed during a snow event.

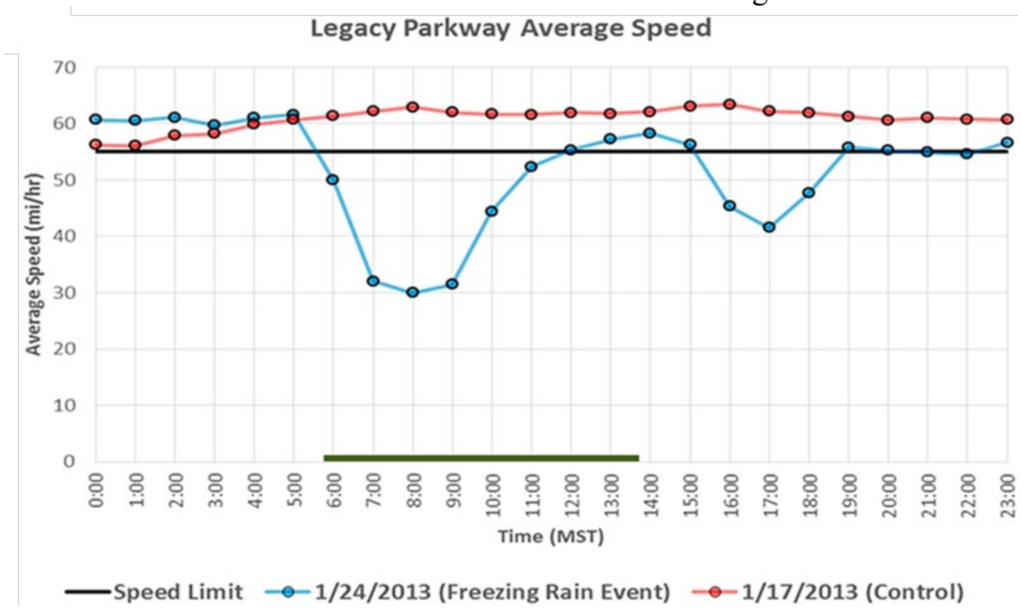


Figure 2: Impact of Freezing Rain on Speeds (Barjenbruch et al, 2016, data source PeMS)

Several studies have assessed the impact of weather via changes in travel times. In London, light snow increased travel times by 5.5%–7.6% while heavy snow increased travel times by 7.4%–11.4% (Tsapakis et al., 2013). The study by Stern et al. (2003) evaluated travel times on a mix of freeways and major arterials in DC. The researchers discovered that peak-period travel time increased between 11% and 25% when precipitation was present. Next, a study in Northern Kentucky evaluated non-holiday and non-event impacted weekday speeds to estimate the impact on travel time and reliability. Several modeling techniques were employed to discover that snow had a more severe impact than rain on travel times and that reliability was more impacted than travel times (Zhang and Chen, 2018).

Volume and Demand Impacts

Recognizing the potential influence of inclement weather on traveler behavior, several studies have assessed the changes in observed volumes. A study in Belgium found that traffic volumes significantly decreased under rain, snow, and windy conditions (Cools et al., 2010). An analysis in Atlanta, Georgia evaluated the impacts of precipitation, temperature, visibility, and wind speed on hourly weekday traffic flow. As shown in Table 1, the study applied machine learning techniques to determine the hours of day most likely to experience volume reductions from precipitation, visibility, and temperature (below 32 degrees Fahrenheit). Precipitation, visibility, and temperature caused statistically significant reductions in volume (Sathiaraj et al. 2018).

Table 1: Percent Reduction in Traffic Volume Under Inclement Weather (Sathiaraj et al., 2018)

Hour	Precipitation	Temperature	Wind	Visibility
0	7.69	14.86	4.74	31.87
1	5.13	16.89	7.01	34.39
2	1.85	24.51	2.78	35.78
3	7.89	31.08	6.58	30.26
4	1.22	10.26	3.61	28.92
5	2.5	13.57	6.67	27.8
6	7.4	12.38	6.52	13.66
7	8.14	10.55	7.08	12.99
8	3.07	8.97	4.46	7.35
9	3.57	7.02	8.46	6.66
10	2.74	6.54	5.46	10.99
11	2.86	5.54	2.9	5.85
12	4.88	5.83	2.32	7.53
13	5.07	4.01	1.39	4.96
14	5.24	3.76	0.58	3.46
15	6.49	9.34	1.19	3.79
16	8.7	9.41	0.45	5.89
17	9.16	17.56	1.02	7.27
18	4.69	22.46	−0.59	12.68
19	6.48	21.91	1.71	14.65
20	7.66	22.95	2.74	15.92
21	7.69	43.65	2.69	19.68
22	12.33	43.56	3.23	19.42
23	8.45	46.68	5.96	16.82

Next, a study using winter storm data from Illinois, Minnesota, New York, and Wisconsin used automatic traffic recorder (ATR) station data to assess changes in hourly traffic volumes under winter storm conditions. The results showed that volume reductions were correlated with snowfall amounts and temporal considerations such as hours of day and weekday versus weekends (Hanbali and Kuemmel, 1993). Similar findings were found by Maze et al. (2006), Burrow and Atkinson (2019), Tsapakis et al. (2013), where volume changes were dependent on precipitation amount and time of day. Burrow and Atkinson (2019) and Cools et al. (2010) noted that non-mandatory trips are generally more prevalent on weekends and such trips may be shifted to different times or canceled. Interestingly, Maze et al. (2006) and Call (2011) found that commercial vehicle volumes were less impacted by snow events which resulted in increased percentages of commercial vehicles during snowstorms. Lastly, a study of the impact of weather at signalized intersections by Lu et al. (2019) discovered that the saturation flow rate was reduced by 17% on slushy road surfaces and by 25% on snow covered road surfaces.

Other Impacts

More recent studies are leveraging data from new technologies to investigate the impacts of inclement weather on driver/traveler behavior. In an assessment of connected vehicle data, driver behavior in deteriorated road conditions (caused by weather) was evaluated by Li et al. (2020). The study found that braking pressure decreased up to 60% of the median intensity and the variation in braking pressure has significantly greater variance in deteriorating conditions. These results suggest that speed data alone may not be sufficient to identify changing road surface conditions on arterials. Next, the novel study by Lepage and Morency (2021) investigated the impact of weather on mode shift between bike-sharing, taxis, subway, and bus. A generalized additive model was applied to discover that rain decreases bike sharing, subway, and bus demand while increasing taxi demand.

Weather Data Sources

This section reviews the road weather data resources available to the transportation agencies for traffic management and operations.

Fixed Road Weather Information System (RWIS) Stations

Fixed RWIS stations are the most common resource traditionally used by state DOTs to obtain road weather information. The main components of an RWIS are Environmental Sensor Stations (ESS) (Interactive Environmental Sensor Station Page - FHWA Road Weather Management (dot.gov)), a data transfer communication system, and a central system to collect data from various stations (https://ops.fhwa.dot.gov/weather/faq.htm). There are more than 2,000 ESS nationwide used specifically for state transportation agencies RWIS (Surveillance, Monitoring, and Prediction - FHWA Road Weather Management (dot.gov)).

While fixed RWIS has proven to be an effective tool supporting the decision making of road operations, the high cost of installing RWIS stations signifies the importance of a strategic plan for the statewide deployment of such a system. The few available RWIS location guidelines only provide general recommendations, such as the availability of power and communication utilities (Garrett et al., 2008). A handful of studies introduced frameworks to optimize the spatial location of RWIS stations. Kwon et al. (2017) formulated the RWIS location-allocation problem as a mathematical model that maximizes the coverage over the accident-prone areas considering the underlying spatial structure of RWIS measurements. Biswas and Kwon (2022) considered both spatial and temporal attributes of various road weather attributes such as air temperature, road surface temperature, and dew point temperature to optimize the location of RWIS stations over a network.

Mobile RWIS

There can be wide geospatial gaps in traditional fixed RWIS data as it is limited to the locations where ESS sensors are deployed. Mobile RWIS technologies are relatively recent solutions to fill this gap and supplement the fixed RWIS networks. Figure 3 shows a map of the states currently using mobile RWIS.

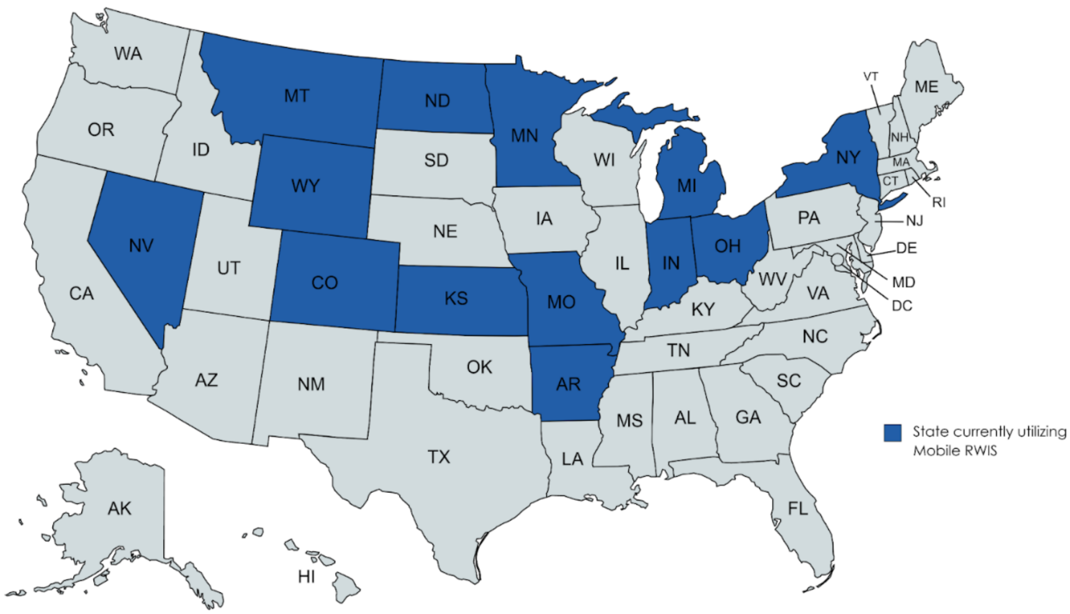


Figure 3: Map of States Utilizing Mobile RWIS (Recreated from El-Rayes & Ignacio, 2022)

In 2019, Clear Road published a comprehensive report (Minge et al., 2019) analyzing the four commercially available mobile RWIS sensors, namely Lufft's MARWIS, Teconer's RCM411, High Sierra's Mobile IceSight, and Vaisala's DSP310. The report compares the accuracy of the sensors based on various parameters, including air temperature, surface temperature, relative humidity, surface conditions, and water film thickness. Table 2 represents the rank of sensors based on the percentage error of each parameter when compared to a baseline. Here, the rank of one indicates the smallest percent error. However, the report mentions that the difference in values used to rank the sensors are often very small and depends on the installation. Therefore, other factors such as purchase, and installation costs might be more significant for agencies when deciding what sensor to buy. The report (Minge et al., 2019) also compares the sensors based on some qualitative parameters summarized in Table 3:

Table 2: Rank of Sensors Based on Percent Error (Minge et al., 2019)

	Air Temperature	Surface Temperature	Relative Humidity	Surface State	Water Film Height
Vaisala	3	2	3	1	1
High Sierra	2	4	2	3	N/A*
Teconer	4	3	N/A*	2	3
Lufft	1	1	1	4	2

Parameter not measured by sensor for this evaluation

Table 3: Qualitative Parameters of Sensors (Minge et al., 2019)

	Mounting	Connection and communication	User Interface	Maintenance
Vaisala	Roof of the vehicle	Phone's cellular network	Mobile phone applications	• Periodic sensor inspection • Checking mounting, cables, screws, etc. regularly • Yearly filter change in the humidity probe
High Sierra	Driver side rear window	RS-232, RS-485, and/or Wi-Fi	Laptop computer	• Periodic sensor inspection • Yearly calibration check • Annual service plan option for an additional cost
Teconer	Trailer hitch	Bluetooth unit and then cellular	Mobile phone applications	• Periodic sensor inspection
Lufft	Roof of the vehicle	RS-485 or Bluetooth.	Mobile phone applications	• Periodic sensor inspection • Checking mounting cables, screws, etc. regularly

More recently, the Illinois Center for Transportation, in collaboration with the Illinois Department of Transportation; and the Federal Highway Administration (El-Rayes and Ignacio, 2022), published a comprehensive report evaluating the benefits of implementing Mobile RWIS. This report conducted a literature review to investigate the mobile RWIS-related federal guidelines and programs and utilization of mobile RWIS and maintenance decision support systems (MDSS) by seven selected state DOTs (MI, MN, IN, OH, CO, NV, CA). Additionally, this report discussed the cost performance, additional benefits, and challenges of mobile RWIS reported by the state DOTs. Table 4 summarizes commercially available mobile RWIS included in the study.

Table 4: Data Types Provided by Mobile RWIS Technologies (El-Rayes and Ignacio, 2022)

Parameters	Lufft MARWIS	Teconer RCM411	Vaisala MD30	Vaisala DSP310	High Sierra Elec. IceSight	PreCise ARC System	RoadWatch	High Sierra Elec. Surface Sentinel
Road Conditions (dry, moist, wet, ice, snow, slush, chemically wet)	✓ All six conditions	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet	✓ Five conditions No chemically wet			
Road Surface Temperature	✓	✓	✓	✓	✓	✓	✓	✓
Water Film Height	✓ Up to 6mm	✓ Up to 3mm	✓ Up to 5mm	✓ Up to 2mm				
Ice Percentage	✓							
Friction	✓ Calculated	✓	✓	✓	✓ Calculated			
Ambient Air Temperature	✓	✓	✓	✓	✓	✓	✓	✓
Dew Point Temperature	✓	✓	✓	✓				
Relative Humidity	✓	✓	✓	✓	✓	✓		
Current Use by DOTs	ARDOT, MNDOT, MODOT, INDOT, NDDOT, NDOT, ODOT, CDOT, and NYCDOT	MNDOT	MDOT, MNDOT and ODOT	Not Reported	MNDOT and NYSDOT	AKDOT, ADOT, CTDOT, IDOT, IADOT, MnDOT, MDDOT, NDOT, NYSThruway, NDDOT, ODOT, SDDOT, TDOT, WSDOT, and WYDOT	CALTRANS and NDOT	Not Reported
Hardware Cost	$10,700	$9,000	N/A	Unavailable	$ 6,680 Software $360/yr Cell Data $220/yr	$918	$600	$ 1,260 Software $360/yr Cell Data $220/yr

Furthermore, El-Rayes and Ignacio (2022) conducted interviews with four state DOTs (MI, MN, IN, CO) to gather feedback on several aspects of Mobile RWIS and MDSS, including distribution of sensors within the DOT fleets, how units were mounted to vehicles, and travel routes.

Radar (real-time and predictive)

Radar data is another resource used by state DOTs to get weather forecasts and online weather road conditions. The National Weather Service (NWS) operates a network of 160 high-resolution doppler weather radars called NEXRAD. The radars collect precipitation and wind data. The data is available to the public in several forms, including graphics on the NWS website. According to the Clear Road report (CTC & Associates LLC, 2020), 20 states out of 22 member states use NWS as one of the sources of their weather forecast. Researchers at CATT Lab have developed a methodology to conflate radar data to the traffic messaging channel

(TMC)[1] road network. The conflated data is valuable for road weather analysis as it can be combined with other traffic data such as speed, incident, and flow at the segment level (CATT Lab 2020).

Other Weather Data Sources

In addition to RWIS and radar data, other existing data sources, such as reports from plow drivers, video from traffic cameras or snowplow cameras (CTC & Associates LLC, 2020; Jonsson et al., 2014), and crash reports (Tobin et al., 2019) can potentially be used in road weather operations and analysis. Additionally, recent technologies such as connected vehicles communicating high frequency controller area network (CAN bus) data are capable of detecting road weather conditions based on the change in the vehicle and driver behavior (Li et al., 2020). Smartphones can also be leveraged to get information about the road surface using their built-in GPS receiver and accelerometer (Li and Goldberg, 2018).

Operation Decision Support and Response Management

This section reviews the ways in which transportation agencies visualize the road weather data to aid in their decision-making process. A review of the best practices used by transportation agencies to disseminate the information to the public is also presented.

Software and Dashboards for Data Visualization

Transportation agencies have been utilizing weather data to varying extents to support their day-to-day operations. The Clear Road Report (CTC & Associates LLC, 2020) includes a survey of 21 state transportation agencies that aimed to identify what maintenance decision tools and practices were used by each agency. Table 5 contains the results of the survey.

[1] TMC segments are an industry standard way to divide roadways into distinct geographic segments for the purpose of reporting average traffic speeds, average travel times, and other similar metrics.

Table 5: Transportation System Maintenance Decision Tool Survey Results (CTC & Associates LLC, 2020)

State	Decision Tree	MDSS	Field Crew Recommendations	Meteorologist Recommendations	DOT Staff Recommendations
Arizona					
Connecticut					X
Delaware					X
Idaho	X				
Indiana		X	X		X
Kansas	X		X		X
Massachusetts		X	X	X	X
Michigan	X	X	X		
Minnesota		X	X		X
New Hampshire			X		
Nevada			X	X	
Ohio			X		X
Oregon			X	X	X
Pennsylvania			X	X	X
Rhode Island		X	X	X	X
South Dakota		X			
Utah	X		X		
Vermont			X		
West Virginia			X		X
Wisconsin		X	X		
Wyoming		X	X		
Total	**4**	**8**	**16**	**5**	**11**

As shown in Table 5, a majority of the surveyed transportation agencies rely on field crew and DOT staff recommendations, while several state agencies (ID, IN, KS, MA, MI, MN, RI, SD, UT) are also utilizing sophisticated tools such as maintenance decision support systems (MDSS) and decision trees in maintenance operations decisions.

Platforms such as the Regional Integrated Transportation Information System (RITIS) incorporate the Clarus RWIS data into the host of dashboards available and enable the viewing of real-time road weather data by transportation operation specialists, university researchers, and Metropolitan Planning Organizations (MPOs) (CATT Lab, working paper). Figure 4 shows the wide coverage of Clarus RWIS stations in the RITIS platform.

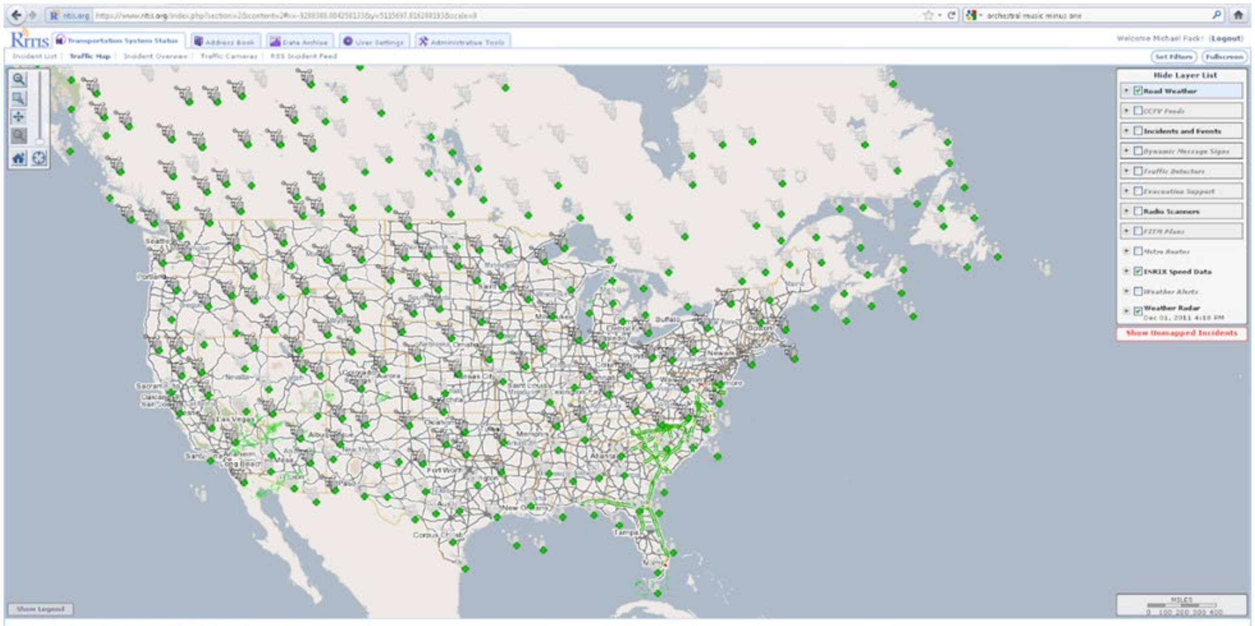


Figure 4: Clarus Data Integration with RITIS

Researchers have been exploring ways of using this weather data to aid with actionable decisions. The work of Sathiaraj et al. (2018) provided a decision tree-based approach to identify hour of day, temperature, and precipitation as key decision rules for managing the impact of extreme weather effects on traffic volumes. The weather data was used from the Integrated Surface Hourly (ISH) dataset of the National Centers of Environmental Information (NCEI). They also provided visualization dashboards to incorporate the weather data with the traffic data for use by transportation planners, centralized traffic control rooms and urban infrastructure decision makers. Figure 5 illustrates the decision support tool.

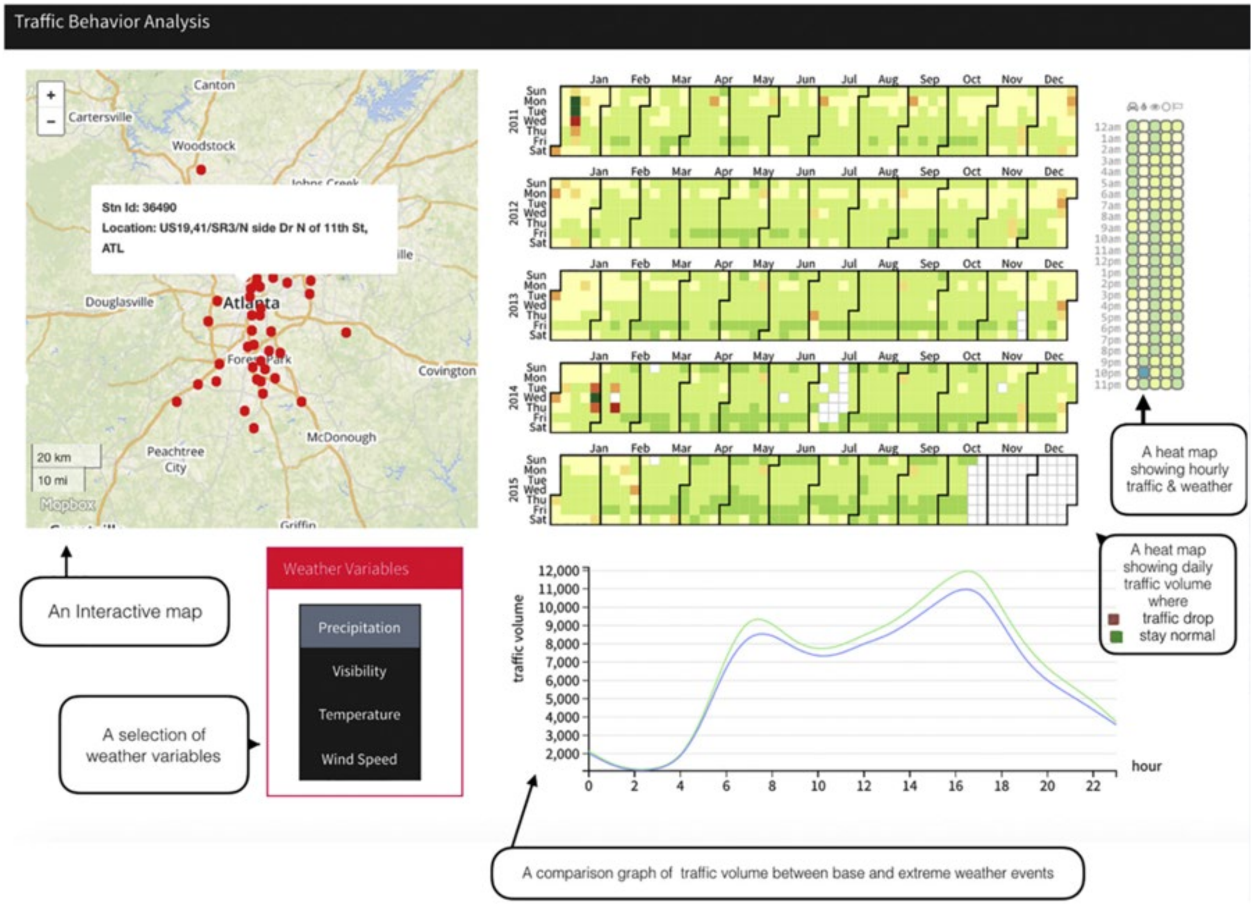


Figure 5: Geo-Visualization Decision Support Tool (Sathiaraj et al., 2018)

Studies have also been conducted to assess the weather impacts at a regional level (Kurte et al., 2019). This study in Chicago incorporated the weather data from the Dark Sky API and land-use data from the Chicago Metropolitan Agency for Planning (CMAP) with the traffic data from National Performance Management Research Data Set (NPMRDS). They used Self-Organizing Maps (SOM) to map the weather patterns to the links, which were classified by their surrounding land-use patterns. The results showed a significant difference in the impacts of weather to various land-use types, allowing agencies to identify key locations to focus their weather maintenance efforts.

Another study done in Canada (Lepage and Morency, 2021) utilized the weather and traffic data for various modes to come up with ways to predict traffic demand for different modes in relation to weather events by utilizing meteorological station data from Environment Canada. Such approaches can be used by agencies to predict changes in traffic demand in response to weather events and formulate their maintenance strategies. This enables the agencies to formulate planned approaches towards dissemination of weather and maintenance information to the public.

Communication of Weather Alerts to the Traveling Public

A public communication plan is important to inform the public of the expected road conditions, speed reductions, and other information on what they may encounter during upcoming weather events. Good communication is valuable for adjusting drivers' expectations for upcoming severe weather events (Clear Roads, 2018). Agencies use various avenues of communication. South Dakota DOT (SDDOT) engages in conference calls with the South

Dakota Highway Patrol and National Weather Service (NWS), to keep all parties up to date with the forecasted extreme events. When necessary SDDOT also coordinates with the Department of Health and National Guard depending on the severity of the incident. The Colorado DOT follows similar practices in collaboration with the NWS. Similar practices are observed by the Pennsylvania Department of Transportation (PennDOT), the New York State Department of Transportation (NYSDOT), and other transportation agencies (Clear Roads, 2018). Variable message signs are generally considered a reliable way of informing the public of relevant weather-related impacts to traffic. PennDOT also uses *511PAConnect* for disseminating extreme-weather related information to the public and its impacts to traffic (Clear Roads, 2018). Michigan DOT's Weather Responsive Traveler Information Project (Wx-TINFO) has been adopting ways to improve agency efficiency and productivity as it pertains to the dissemination of weather-related traffic information to the public (FHWA Report, 2016). One of the key accomplishments has been improving the public information pipeline by incorporating the Dynamic Message Signs (DMSs) within the ATMS so as to process and update the DMS information faster.

Methodology

While the literature review provided solid background on winter weather data, analysis, and impacts, this research team wanted to reach out to winter operations professionals across the country. To do so, online survey was created and distributed to peer traffic operations and maintenance professionals across the U.S. The questions for this survey can be found in Appendix A of this report. The responses to the survey provided valuable insights on which agencies were using MARWIS, the level of experience with MARWIS, how MARIWS was being used to make operational winter weather decisions, best-practices, and challenges of integrating MARWIS data into a decision support system.

The results of the survey generated a short list of agencies to interview. These agencies included the Delaware DOT (DelDOT), Iowa DOT, New Jersey DOT (NJDOT), and the North Dakota DOT (NDDOT). The team also met with MDOT representatives to better understand the state-of-practice in Maryland. The research team met with each of these agencies to discuss the details of their experience with MARWIS technologies and associated data. In each of the meetings, the interviewed agency provided a demo of their MARWIS data visualization platforms that were ultimately used to inform the design of comprehensive weather operations decision platform.

Upon completing the agency interviews, attention was turned to the designs of the comprehensive weather operations decision platform that went through several design iterations to ensure the final designs met the needs of MDOT winter operations decision makers. The designed platform integrated MARWIS with RWIS and radar data to allow users to fuse and compare data from each data source. The designs were then presented to MDOT officials to get their feedback and final sign-off.

Research Findings and Discussion

Online Survey Results

The online survey (provided in Appendix B) was distributed to traffic operations professionals across the county. As shown in Figure 6, 17 state DOTs responded to the survey of which 7 responding agencies were currently using MARWIS, 5 were planning to use MARIWS in the near future, and 5 were not using and do not planning on using MARWIS.

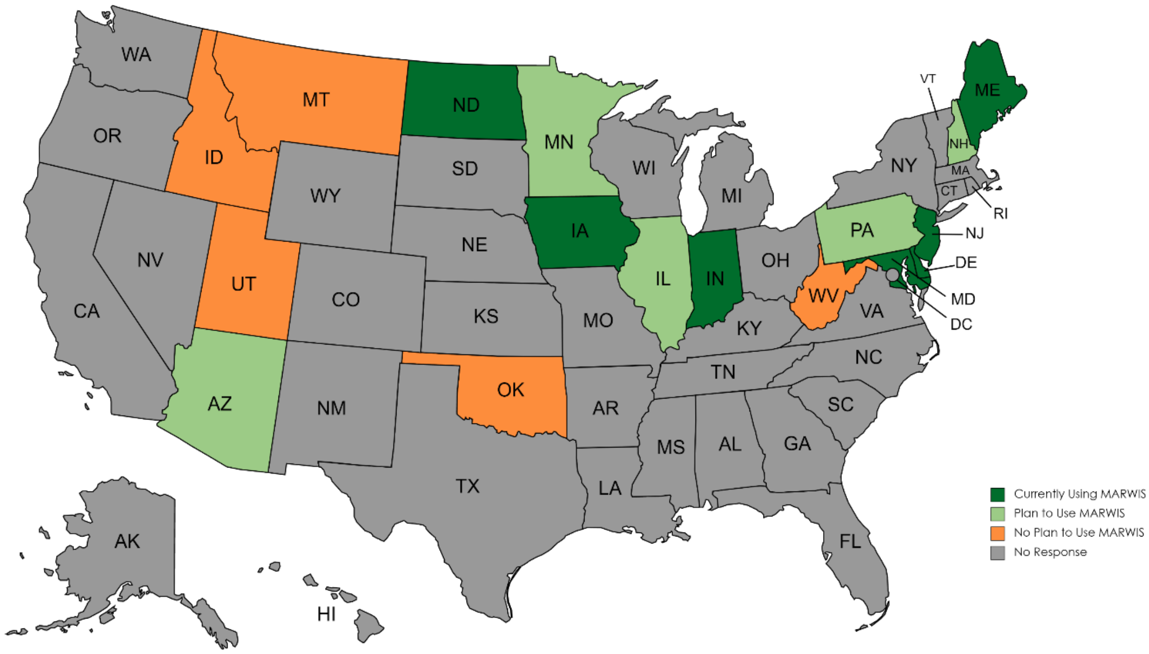
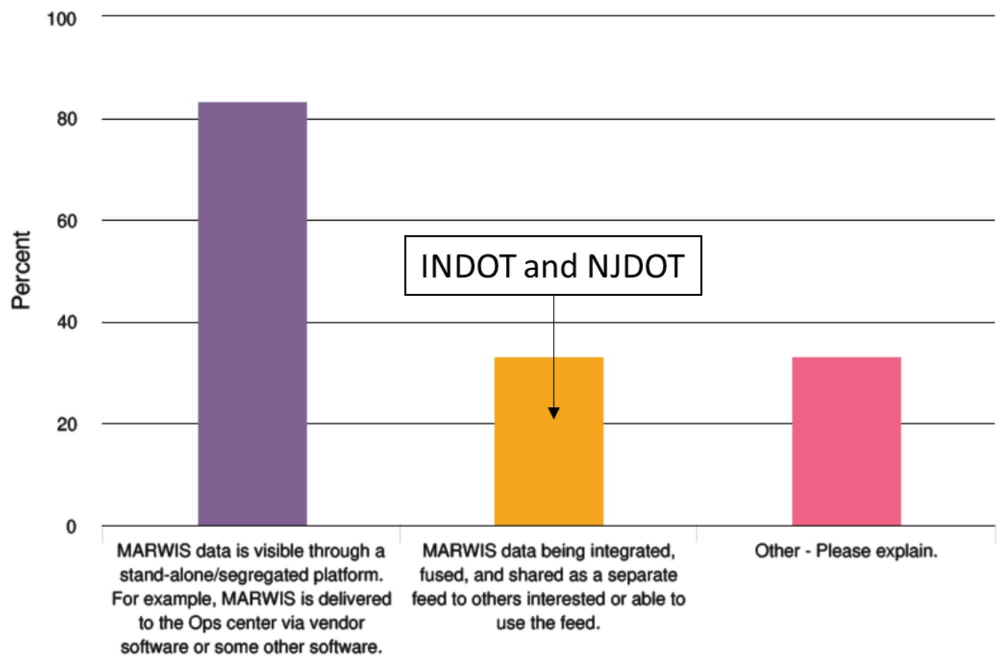


Figure 6: Survey Response Map

The survey next asked respondents to provide insights on how their MARWIS data was integrated into their traffic operations and supporting systems. Figure 7 presents the summary of responses to this question. Five responding agencies indicated MARWIS was only visible through a stand-alone/vendor provided software package. However, INDOT and NJDOT responded as having MARWIS fused with other data to provide a more complete picture of roadway performance.



Value	Percent	Responses
MARWIS data is visible through a stand-alone/segregated platform. For example, MARWIS is delivered to the Ops center via vendor software or some other software.	83.3%	5
MARWIS data being integrated, fused, and shared as a separate feed to others interested or able to use the feed.	33.3%	2
Other - Please explain.	33.3%	2

Figure 7: Survey Responses – How integrated is the MARWIS data into your traffic operations programs and supporting systems?

Table 6 shows the agency responses to the question, "Is there anything within the user interface that is particularly effective in communicating valuable information? If so, please explain." This open response question discovered that color-based road segments and friction readings were especially useful.

Table 6: Survey Responses – Is there anything within the user interface that is particularly effective in communicating valuable information? If so, please explain.

Response
No, info is very basic. Air and Pavement temperature is amongst other spreader data coming from the trucks.
color-based visualization on the road, time scaling, ML-based forecasts
The mobile **friction** data is very useful. We also find great value in the truck camera images from the MARWIS
Our MARWIS devices communicate data in the same manner as our stationary RWIS sites. A single user interface is used to view both data sets.
Live views with **friction** and depth of precipitation readings. A lot of times we will route them over existing road weather sensors and compare the data live.

Table 7 presents the response to the question, "Is there anything within the MARWIS data displays/UI that is ineffective and/or needs improvement to help better convey the information to operations personnel or decision-makers? If so, please explain." While some agencies were satisfied with their MARWIS interfaces, most identified areas for improvement such as integration with other layers/data sources.

Table 7: Survey Responses – Is there anything within the MARWIS data displays/UI that is ineffective and/or needs improvement to help better convey the information to operations personnel or decision-makers? If so, please explain.

Response
For now simple is fine for us.
information about general times for each of the colors. **Integration with other systems**.
Video wall like view helpful...also **multiple layers of additional data (crashes, fixed cameras, fixed RWIS, regional office boundaries, etc),**
Main issue is changing pavement surfaces. The device needs to be recalibrated for each surface.
We have run into an issue on bandwidth or cell coverage during major events. The units seem to go down or the vendor website (viewmondousa.com) wont update/load the info.

Next, Table 8 provides as summary of responses to the question, "How many of your agency's vehicles are equipped with MARWIS technology?" Iowa DOT owned approximately 500 MARWIS sensors while the other respondents were in a pilot phase of MARWIS data integration.

Table 8: Survey Responses – How many of your agency's vehicles are equipped with MARWIS technology?

Response
Approximately 500
1
20
16
26
12 current, with one out for repair

Table 9 provides the response to the question, "How frequently do you route MARWIS-equipped vehicles over a roadway to ensure the data collected are still useful for decision-making?" Here, most responding agencies are not making winter maintenance schedule adjustments based on MARWIS data, but rather use the MARWIS data to monitor road surface performance under the defined maintenance schedule.

Table 9: Survey Responses – How frequently do you route MARWIS-equipped vehicles over a roadway to ensure the data collected is still useful for decision-making?

Other/depends on the situation: please explain
Currently we have these installed in Maintenance and Traffic Safety vehicles so we monitor more than direct them places.
Depends on situation (see response to next question)
They are on our plow trucks so the operator just runs their normal route as needed.
We do not make special trips just to collect MARWIS data. The data is collected through the course of using the vehicle for other operations (plowing, etc.)
it is on a safety patrol truck and moves according to that schedule

Table 10 shows the response to the question, "Is the number of equipped vehicles enough to give you the coverage needed? For example, are you able to collect data on all of your roadways every X-minutes to ensure the measurements don't become stale and unusable for decision-making? Please explain." With the exception of Iowa DOT, most agencies indicated the need for more MARWIS technologies to be installed on winter maintenance vehicles to acquire the desired coverage.

Table 10: Survey Responses – Is the number of equipped vehicles enough to give you the coverage needed? For example, are you able to collect data on all of your roadways every X-minutes to ensure the measurements don't become stale and unusable for decision-making? Please explain.

Response
Generally, yes.
No, this has just been a test deployment for a larger mobile RWIS project this winter.
Not all roads covered, the funding was for a pilot deployment.
We have 16 as part of a pilot project, the districts really like the data but we haven't been approved to purchase more.
Our MARWIS installations vary from location to location. Some are installed on plow trucks and others are installed on supervisor's vehicles. The freshness of the data may vary as some of these vehicles may cycle routes more often than others.
Currently no, we are just getting our feet wet with the program.

Next, Table 11 provides a summary of the responses to the question, "Which MARWIS type(s)/model(s) are you using? (select all that apply)." Though the sample size was small, Lufft was found to be the most common sensor, followed by Vaisala.

Table 11: Survey Responses – Which MARWIS type(s)/model(s) are you using? (select all that apply)

Value	Percent	Responses
Lufft MARWIS	50.0%	3
Vaisala MD30	33.3%	2
RoadWatch	16.7%	1
High Sierra Elec. Surface Sentinel	16.7%	1
Other - Please Specify	16.7%	1

Table 12 summarizes the responses to the question, "Please select the three most valuable MARWIS data fields in terms of their importance for making operational decisions?" Here, pavement temperature and pavement condition were the leading responses followed by precipitation intensity/depth and friction. It is worth noting that not all MARWIS sensors provide friction readings.

Table 12: Survey Responses – Please select the three most valuable MARWIS data fields in terms of their importance for making operational decisions?

Value	Percent	Responses
Pavement temperature	100.0%	6
Pavement condition	100.0%	6
Precipitation intensity/depth	33.3%	2
Other: please specify	33.3%	2

Other: please specify	Count
Friction	2
Totals	2

Table 13 provides the responses to the question, "Describe how your agency uses MARWIS data. For example, what does MARWIS data uniquely enable your agency to do in the realm of road weather management? Are there any scenarios that particular MARWIS data is especially useful?" Here, road surface temperatures and general road condition monitoring were leading responses.

Table 13: Survey Responses – Describe how your agency uses MARWIS data. For example, what does MARWIS data uniquely enable your agency to do in the realm of road weather management? Are there any scenarios that particular MARWIS data is especially useful?

Response
Maintenance staff use it to adjust treatment rates and see if the **road temperatures are tracking like expected, and monitor cold spots**
We are currently using it for **road condition monitoring**. Our upcoming project will deploy them onto crew supervisor vehicles to help inform treatment decisions. In-office staff will primarily use them for the value they provide to road forecasting.
Road temp, colored coded crawling ants showing historical weather / pavement conditions
The Marwis data fills in the gaps between our stationary ESS. We are starting to use friction more in our operations so this data is very useful.
Our MARWIS only provides **road information**, not atmospheric conditions. We use the road data to adjust our maintenance forces during a storm.
DelDOT has a wide variety of roadway sensors around the State and at many of our bridge locations. We use the MARWIS data for **spot checks and general roadway monitoring**. It's also a good check to warn our drivers if the conditions are right for black ice or they are encountering low friction areas they may not be aware of.

Table 14 summarizes the responses to the question, "Are there any lessons learned that Maryland should know about before implementing their own MARWIS program? Any mistakes that were made in your implementation or things that you would do differently if you were to start again? Any enhancements that you would like to make to your systems?" Most of the lessons learned were related to sensor maintenance and connectivity.

Table 14: Survey Responses - Are there any lessons learned that Maryland should know about before implementing their own MARWIS program? Any mistakes that were made in your implementation or things that you would do differently if you were to start again? Any enhancements that you would like to make to your systems?

Response
we had bad luck with bluetooth-connected units. There's so much interference on our vehicles we have a hard time keeping them paired. Cabled systems are the only way we buy them now.
We don't have enough experience to make recommendations. We would like to have the information available in an API and able to be incorporated with any other weather data and forecasting.
Keep Vaisala on their toes for managing their equipment. Seems to be a bigger issue than expected with certain versions of their sensors
Calibration for the type of surface you are on is key with the Marwis. Utilize the camera images if possible, a picture is worth as much or more than the data at times.
Only mistakes we've encountered are some mounting locations issues on our trucks. We've mounted them within the arrow board structures which makes them prone to low lying tree branches. We've also mounted 2 to our paratransit buses that drive through a bus wash and we needed to modify the mounting bracket for those as well. Only other issue was the website going down during a major event.

Table 15 shows the breakdown of responses to the question, "Is your agency considering or planning to integrate MARWIS into their road weather data collection plan?" Note that this question was only asked for those who answered no to "Is your agency currently using MARWIS technology?" Here five of the respondents were planning to explore MARWIS, while six agencies have no plans to integrate MARWIS technologies into their winter maintenance operations plan.

Table 15: Survey Responses - Is your agency considering or planning to integrate MARWIS into their road weather data collection plan? (For those who answered no to "Is your agency currently using MARWIS technology?")

Value	Percent	Responses
Yes	45.5%	5
No	54.5%	6
		Totals: 11

Lastly, Table 16 shows the response to the question, "Why is your agency interested in MARWIS technologies? What will MARWIS uniquely enable your agency to do in the realm of road weather management? Are there any scenarios that you anticipate MARWIS data being especially useful? For example, wind speed and direction from MARWIS will be valuable at bridge locations." Note that this question was only asked for those agencies who are planning to integrate MARWIS technologies. Here, most agencies are interested in MARWIS technologies because it has the ability to enhance the capabilities to monitor specific road segments and is often less expensive than RWIS.

Table 16: Survey Responses - Why is your agency interested in MARWIS technologies? What will MARWIS uniquely enable your agency to do in the realm of road weather management? Are there any scenarios that you anticipate MARWIS data being especially useful? For example, wind speed and direction from MARWIS will be valuable at bridge locations. (For those that answered Yes to previous question)

Response
We are planning to do a small pilot to determine the level of interest is using the technology and **its value in operations**.
IDOT just completed a quick study, Evaluating the Benefits of Implementing Mobile Road Weather Information Sensors. The study can be found at : https://apps.ict.illinois.edu/projects/getfile.asp?id=10059. The study consisted of a literature review, phone surveys with 4 other states and recommendations that were used to outline a pilot project follow-up study. The phase 2 study will hold it's kick-off meeting later this month and will end in 2025. This will allow two winters of data collection. MARWIS data will be evaluated in the study for it's **benefits in decision making**. The study will also look at other uses such as product evaluation and road condition metrics. One task of the research is to identify benefits The study will also look at the DTN - MDSS software. Effective implementation of these systems is expected to improve the efficiency of winter maintenance techniques and equipment, provide safer roads and benefit the environment by reducing the use of deicing chemicals.
We will be gathering data during winter storms. The device product has not been decided yet
Cheaper than a RWIS station and it allows us to cover more area.
We plan to put the MARWISs on our plow trucks. This will give the operators **real time information** about road conditions such as: snow, moisture, ice, road temperature and friction. We will also be sending the information to our MDSS provider.

Findings from Agency Interviews

Delaware Department of Transportation (DelDOT)

During the interview, the research team learned that DelDOT currently uses ViewMondo software to visualize MARWIS data. Figure 8 presents the MARWIS sensor status view. DelDOT is in the process of integrating MARWIS API feeds to the DelDOT Data Visualization platform. A screen shot of the DelDOT platform is shown in Figure 9 which shows a timeline of readings from an RWIS station. Once integrated, a similar view will be made available for MARWIS data.

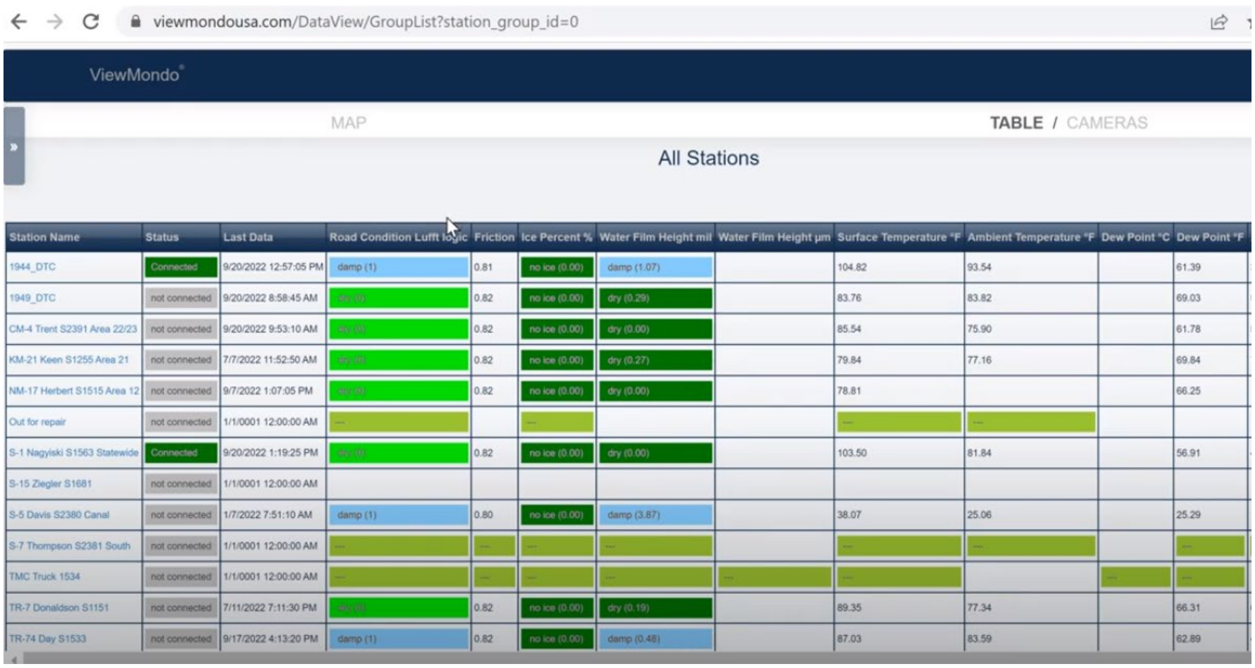


Figure 8: DelDOT ViewMondo Interface – Sensor View

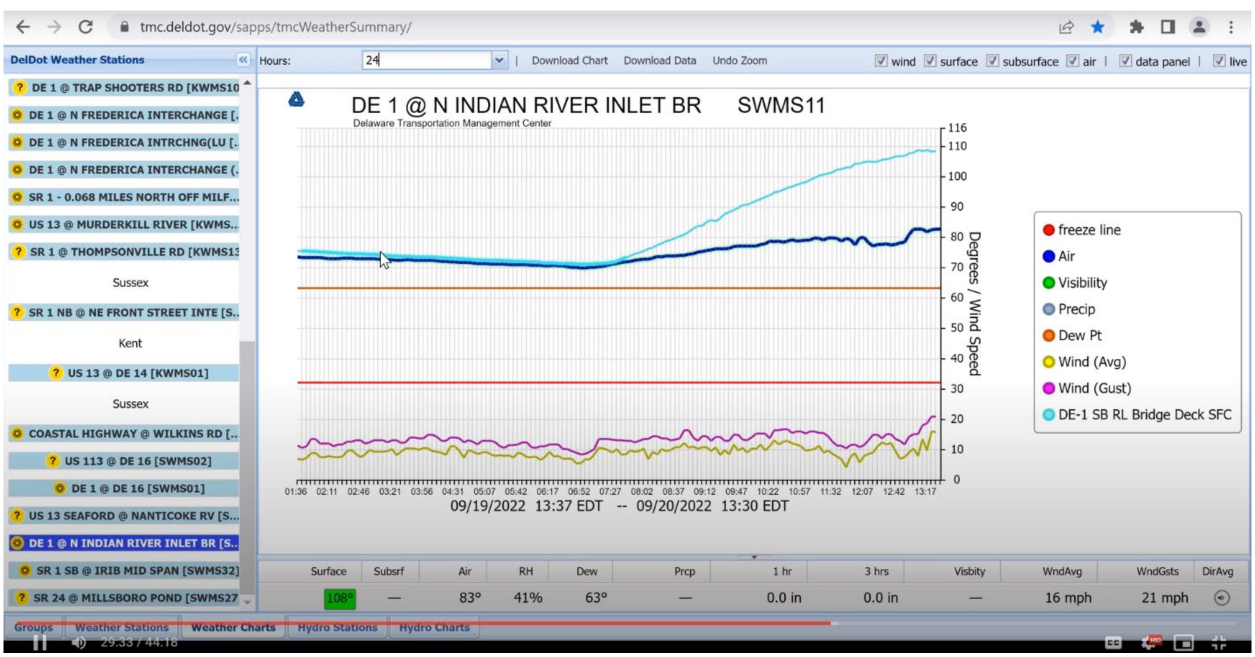


Figure 9: DelDOT RWIS Station Interface

Iowa Department of Transportation (IowaDOT)

Based on the survey responses, Iowa DOT was the clear leader in experience with MARWIS technologies and data. Iowa DOT was the only vendor that was using more than one vendor for MARWIS sensors. In doing so, Iowa DOT was able to provide insights on the pros and cons of these vendors. Regardless of the vendor, MARWIS data is received and archived every 5-10 seconds and is supplemented with automated vehicle location (AVL) data and plow cameras. This data is viewed on the Iowa DOT MARWIS Interface as shown in Figure 10 (Live View) and Figure 11 (Historical View). MARWIS data is also displayed on dashboard displays so drivers can make decisions on whether or not to apply deicing materials. Pavement temperature is what is generally used for these decisions made by vehicle operators. During the interview, the research team learned that current MARWIS technologies do not have the spatial resolution to distinguish lane specific readings. While Iowa DOT archives MARWIS data, they do not have a specific use case.

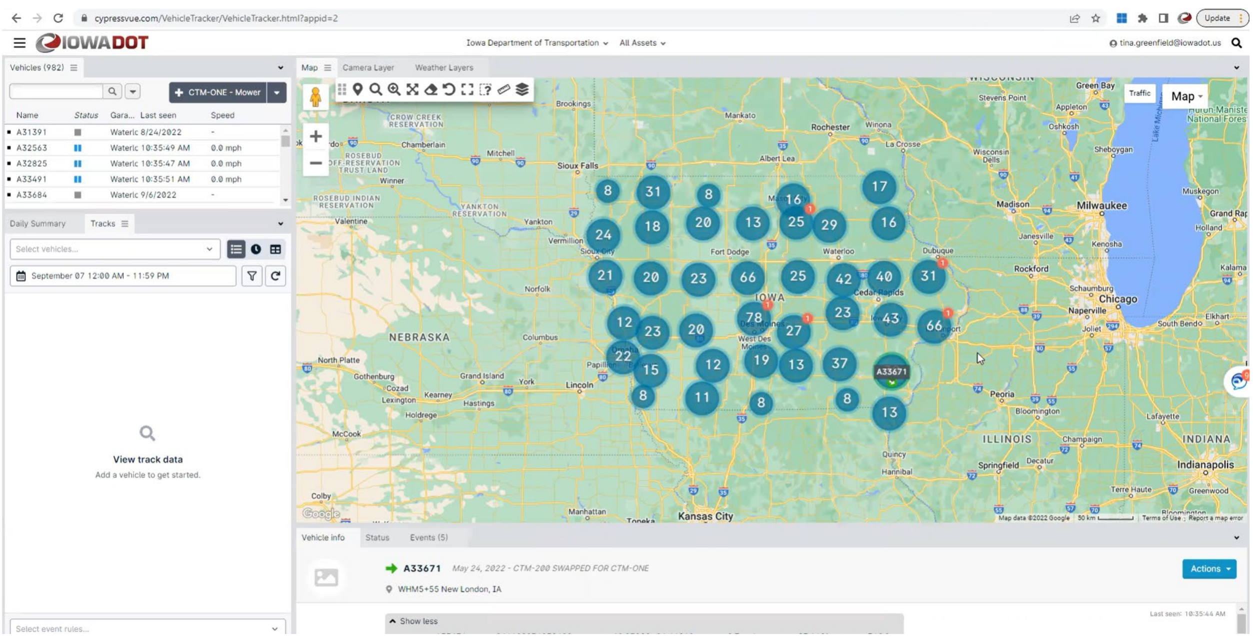


Figure 10: IowaDOT MARWIS Interface – Live View

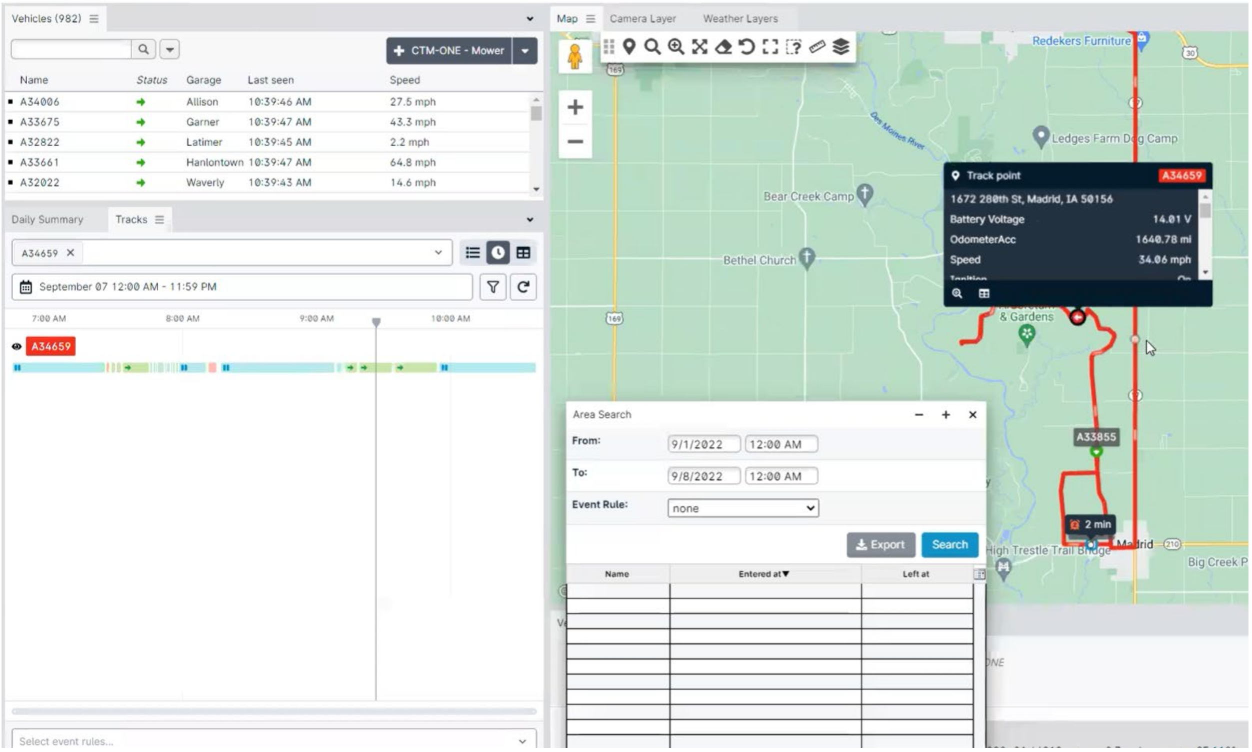


Figure 11: Iowa DOT MARWIS Interface – Historical Vehicle Timeline

New Jersey Department of Transportation (NJDOT)

NJDOT first deployed MARWIS sensors in 2019 and continues to grow the program. NJDOT fleet vehicles are equipped with a MARWIS sensor and streaming video feed that send data to their web-based data management and visualization portal called the Weather Savvy Roads Management System. The system was developed by NJDOT and is currently a stand-alone platform but will be integrated into the NJDOT Advanced Transportation Management System (ATMS) system. The system framework is presented in Figure 12, while Figure 13 shows the Weather Savvy interface. Similar to Iowa DOT, NJDOT MARWIS readings are presented to the vehicle operators that may be used to inform the drivers decision to apply de-icing materials.

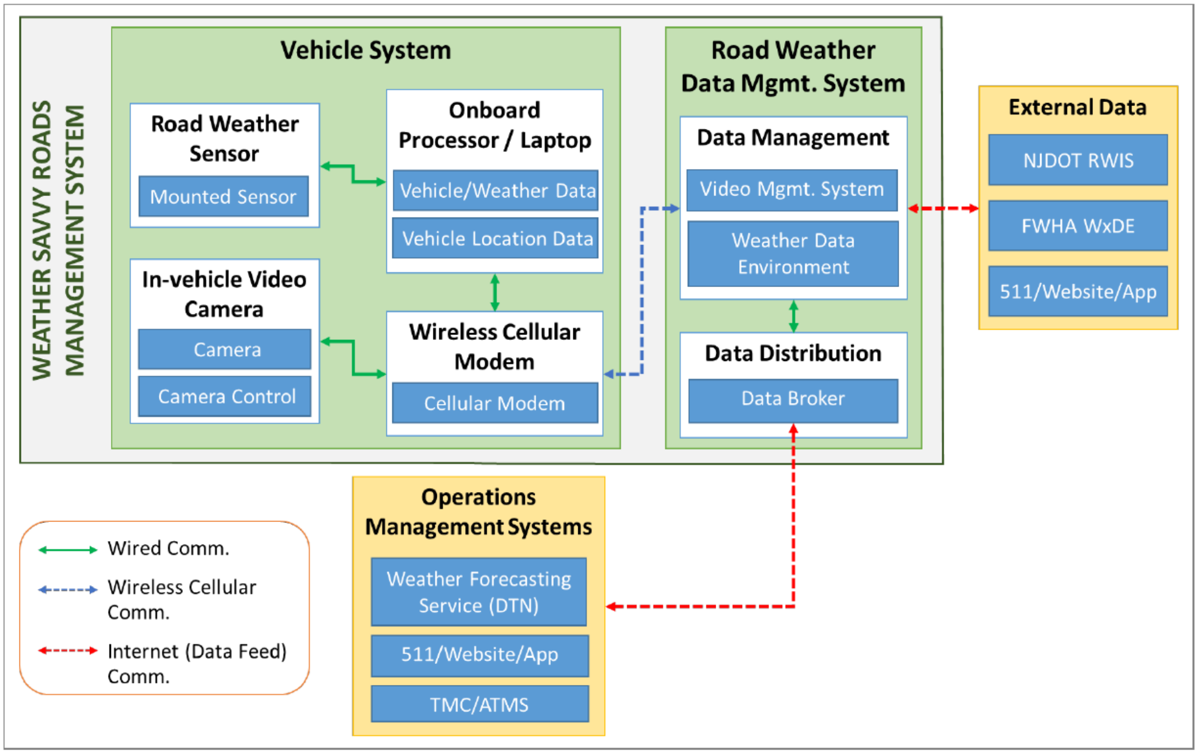


Figure 12: NJDOT Weather Savvy System Framework

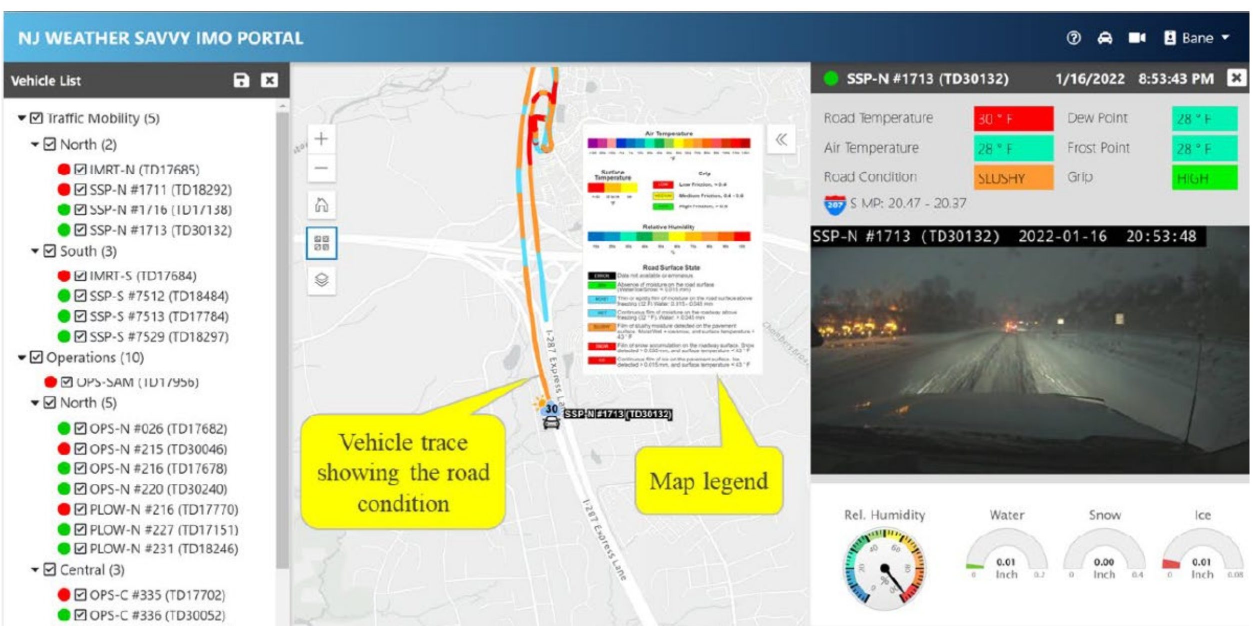


Figure 13: NJDOT Weather Savvy Interface

North Dakota Department of Transportation (NDDOT)

NDDOT has been using MARWIS technologies for about five years. MARWIS data is viewed in out-of-the-box software ViewMondo (Figures 14 and 15) that is provided by the sensor vendor. NDDOT receives data from MARWIS sensors every 15 minutes. Similar to other agencies, vehicle operators can view MARWIS readings on an iPad dashboard display that is also used to take images of the roadway every minute. Vehicle operators most commonly use pavement temperature and friction to inform de-icing decisions. One challenge that NDDOT faced when integrating MARWIS was the need to calibrate the sensors based on pavement surface. While they have overcome the challenge of calibrating the sensors, the vehicle operators use their knowledge of the local road network to manually adjust to changes in pavement type. NDDOT archives MARWIS data but only used historical data when challenged about treatment activities.

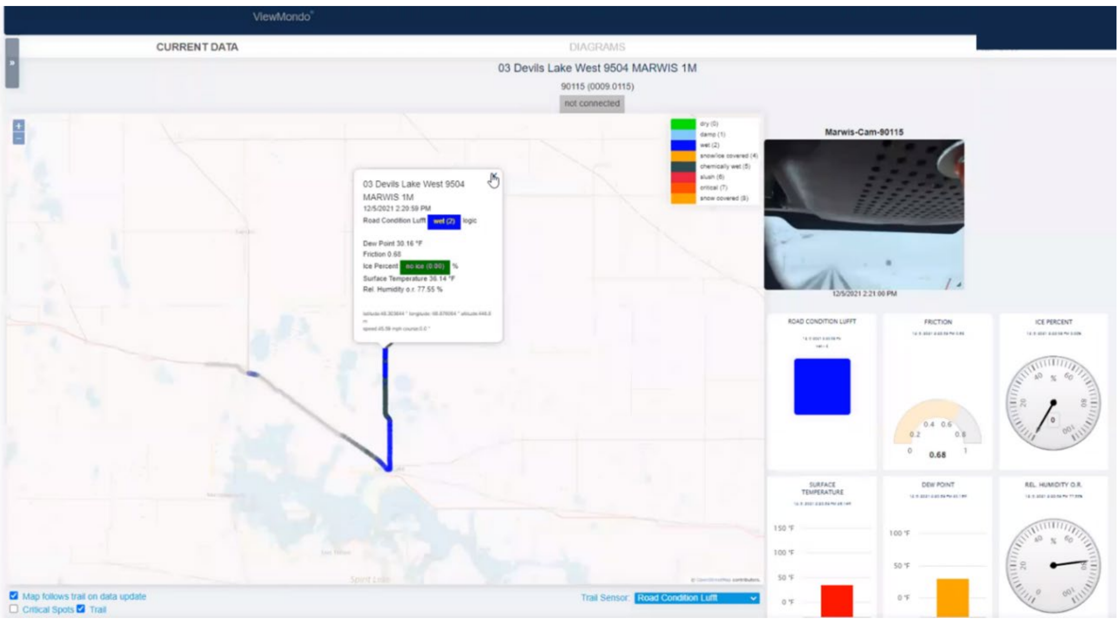


Figure 14: NDDOT ViewMondo Interface – Live Sensor View

Figure 15: NDDOT ViewMondo Interface – Historical Sensor View

Maryland Department of Transportation State Highway Administration

MDOT operations and maintenance professionals rely on two primary software packages to make decisions about winter weather maintenance. The first is the MDOT Emergency Operations Reporting System (EORS) that provides automated data visualizations/dashboards on events (such as crashes and road work) and RWIS measurements. A snapshot of the EORS interface is presented in Figure 16. While EORS provides-ViewMondo software to display real-time and historical MARWIS data (Figure 17).

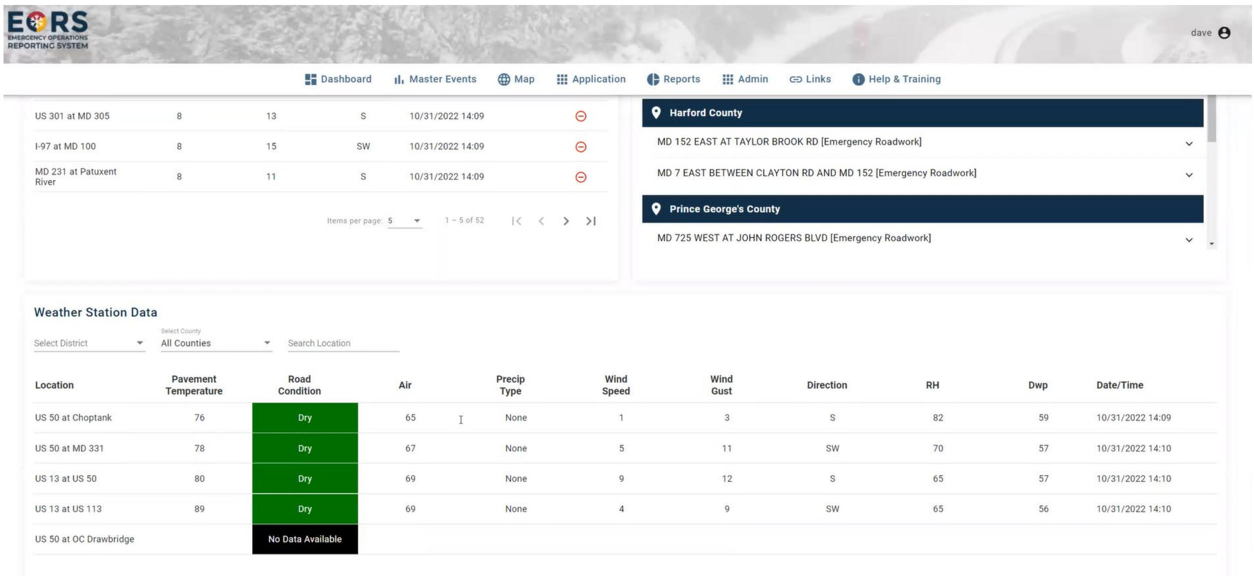


Figure 16: MDOT EORS Interface

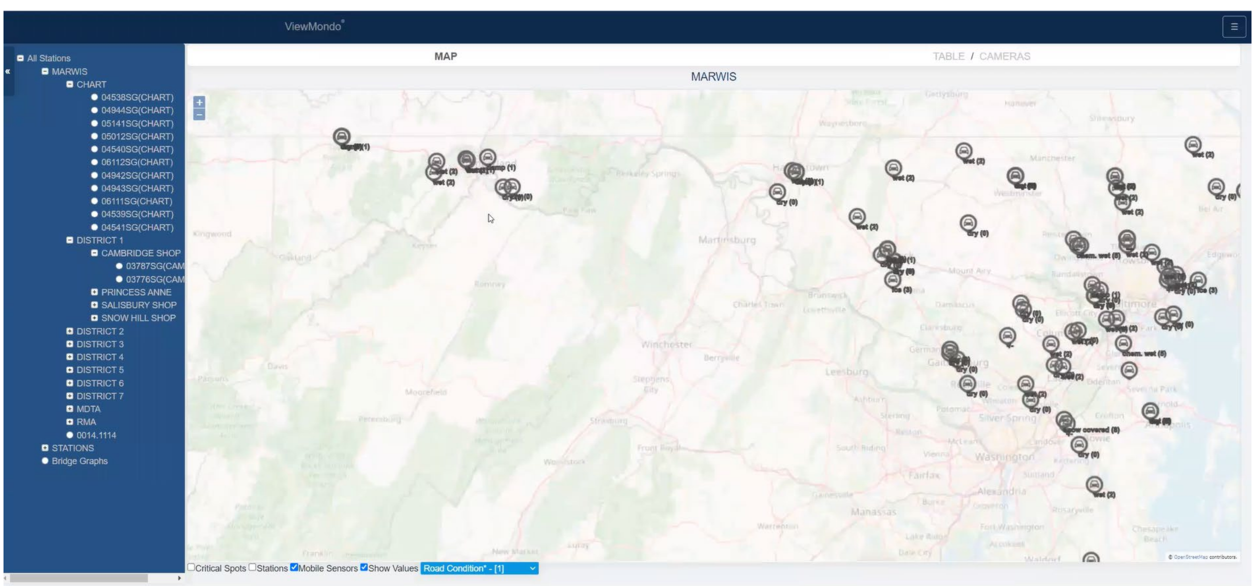


Figure 17: MDOT ViewMondo Interface

Summary of Agency Interview Findings

The agency interviews provided an opportunity to learn about the challenges and benefits of integrating MARWIS data into winter operations and maintenance decision procedures. During these interviews it became clear that MARWIS was most valuable in real-time operations while historical applications of MARWIS data were limited. Every interviewed agency has a means of displaying the real-time MARWIS measurements to vehicle operators. Pavement temperature and friction coefficient are most commonly used to inform decisions on de-icing material applications.

While most agencies utilize out-of-the-box software to view MARWIS data (predominately ViewMondo), NJDOT has MARWIS data integrated into the Weather Savvy platform with plans to integrate the data into an ATMS platform. DelDOT is in the process of integrating data into their weather decision support system. Based on these findings, it is clear that most agencies rely on multiple software packages/data displays to paint a complete picture of winter operations and maintenance performance. This feedback was used to guide the design of a Comprehensive Weather Operations Decision Support Platform for MDOT.

Design of an SHA Comprehensive Weather Operations Decision Support Platform

The information learned from the literature review, online survey, and agency interviews were used to design a first-of-its-kind comprehensive weather operations decision support platform. The platform integrates data from RWIS, MARWIS, and radar to enable users to select the data source(s) of interest. The platform was designed to allow users to start with a state summary view, discover districts of interest, investigate roads of interest in that district, and zoom to specific road segments and sensors. The platform was designed to be intuitive and interactive so that users can easily navigate to the data of interest. Figure 18 presents the state summary view of the platform that includes a weather map, pavement temperature summary, precipitation summary, vehicle activity summary, and a district summary.

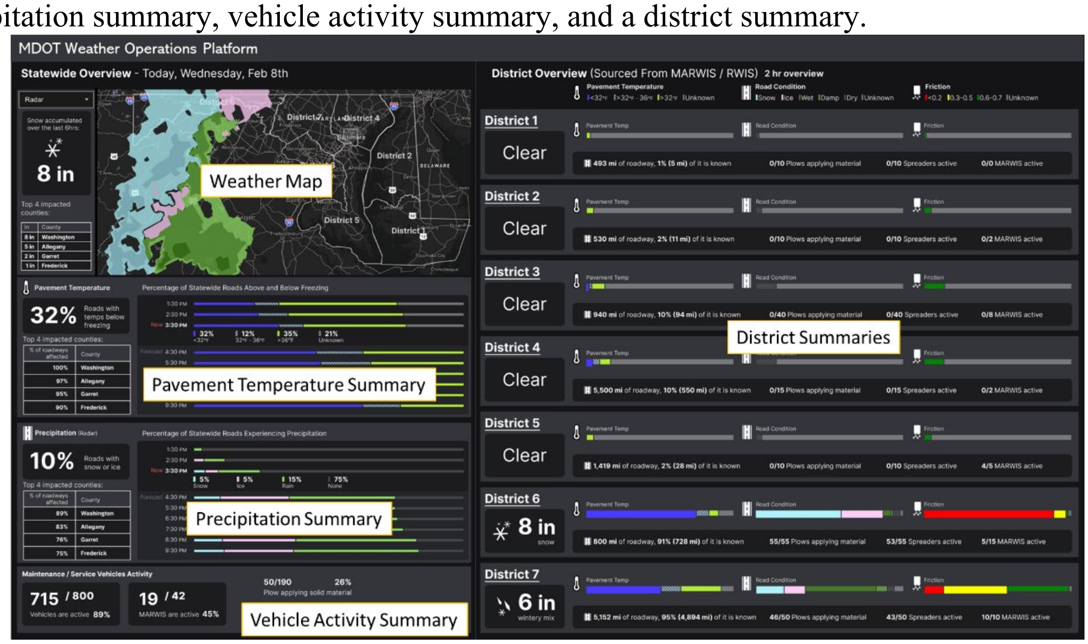


Figure 18: Comprehensive Weather Operations Decision Support Platform – State View

Within the state summary view weather map portion of the display, users can change the weather data source, view a summary of the statewide measurements, and a list of the most impacted counties. Figure 19 shows the location of each of these features while Figure 20 shows the display when the temperature data source is selected.

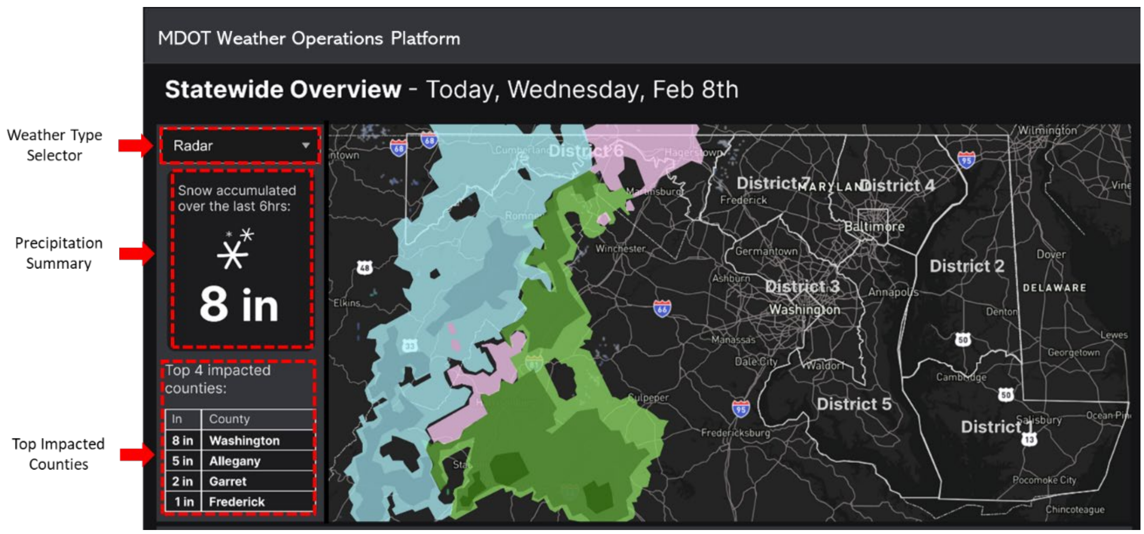


Figure 19: State Summary View – Weather Map Radar Display

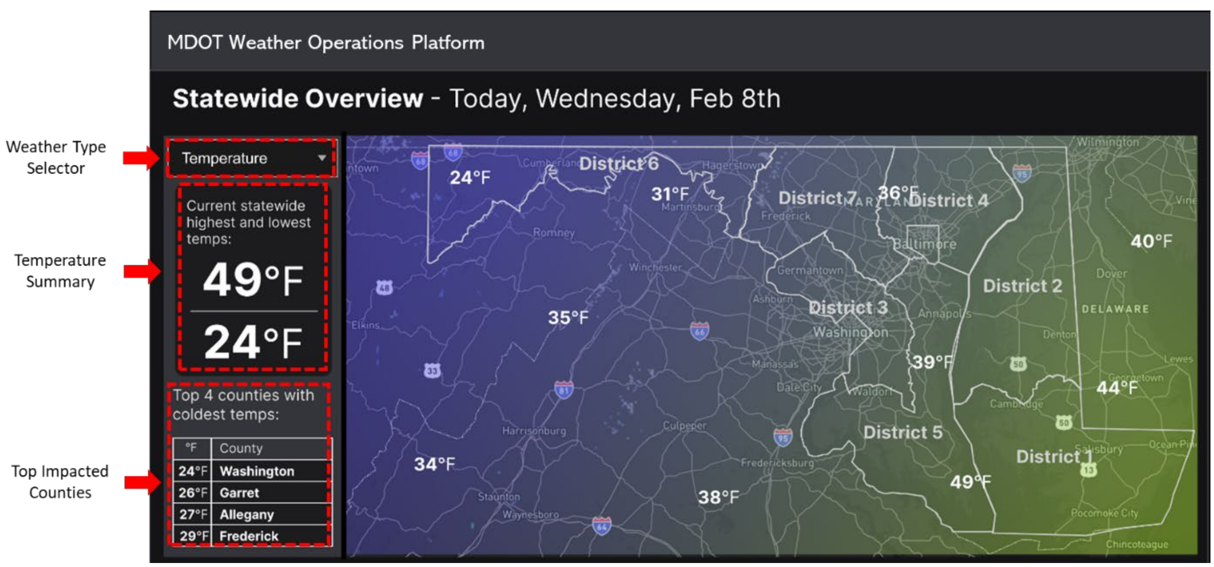


Figure 20: State Summary View – Weather Map Temperature Display

Next, the bottom left quadrant of the state summary view provides summaries of pavement temperature, road surface conditions, and maintenance vehicle activity. For pavement temperatures and road surface conditions, a summary of the road network in the state being impacted by inclement weather. The display also provides information on the recent history of readings as well as the predicted temperature and road conditions. The vehicle activity summary provides information on the number of active vehicles, active MARWIS devices, and a summary of vehicles applying de-icing materials. The functions are presented in Figure 21.

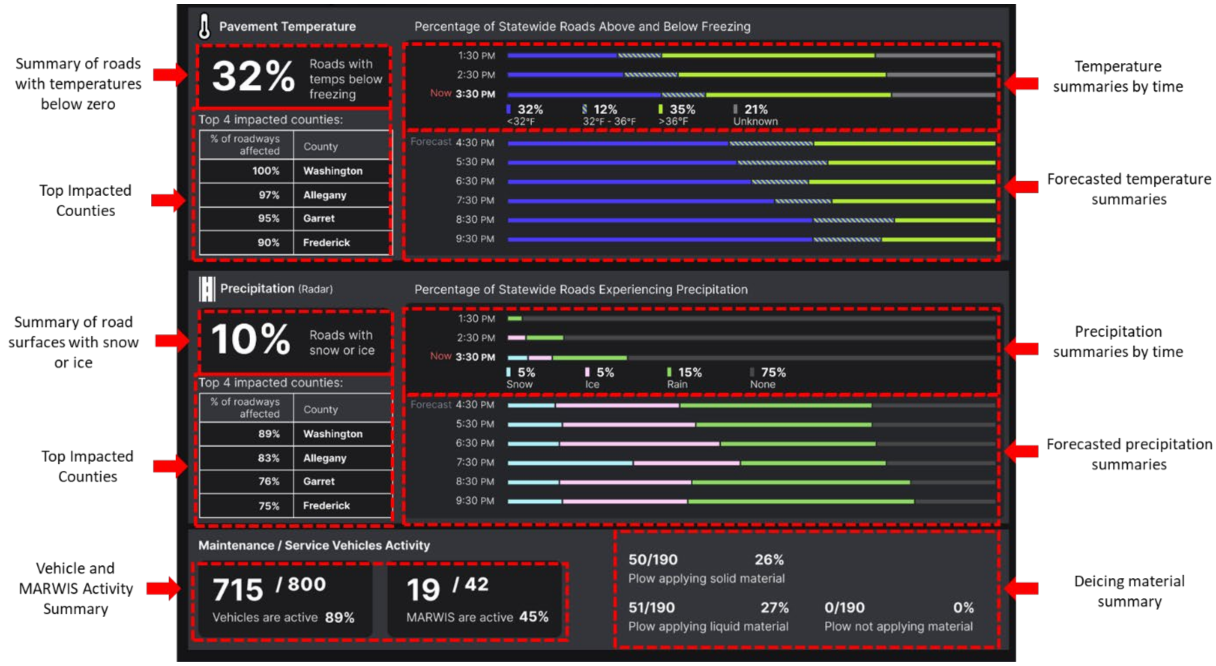


Figure 21: State Summary View – Pavement Temperature, Road Surface Conditions, and Maintenance Vehicle Activity

The right half of the state view display presents a summary of district performance. Here, users can discover summaries on precipitation as well as the percentage of roads under various pavement temperatures, road conditions, and friction levels. These features are called out in Figure 22.

Figure 22: State Summary View – District Summaries

Upon investigating the district summaries, the user will click on the district of interest to navigate to the district view. The district view zooms into the district of interest to provide a zoomed in map of weather data along with a series of charts that summarize the conditions on roadways in the target district. Figure 23 presents the district view interface components.

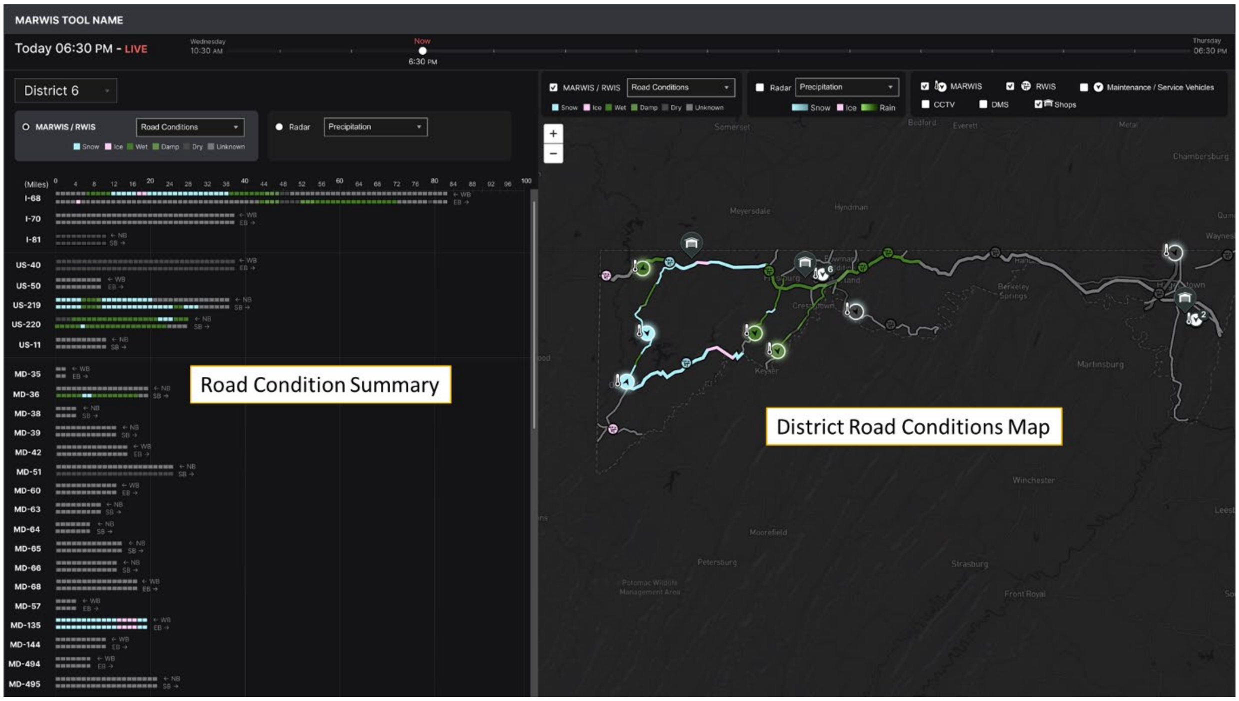


Figure 23: Comprehensive Weather Operations Decision Support Platform – District View

The left half of the district view interface provides a summary of road conditions in the target district. Figure 24 highlights some of the key features of the road conditions summary portion of the interface, including a time slider to look at historical and predictive weather conditions, a drop-down district selector, and road milage condition graphs that show the mile-by-mile weather conditions for directional road segments.

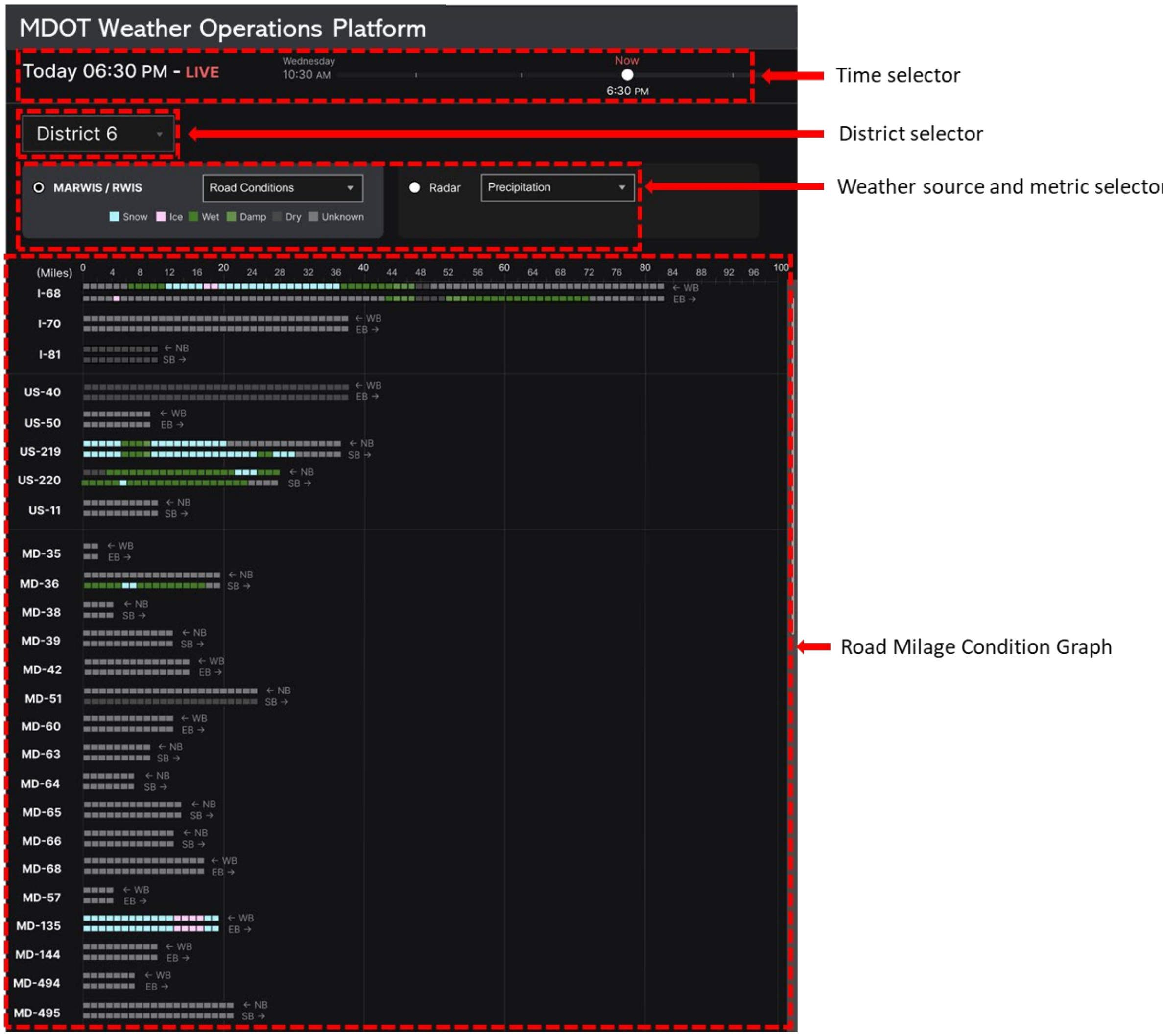


Figure 24: District View – Road Condition Summary Charts

The right side of the district view interface shows a zoomed in map of the district and road segment conditions based on the selected data source. Figure 25 highlights the key features of the district map including the map weather source selector, an interactive legend to turn specific icons on and off, and road conditions map. Here, MARWIS/RWIS road conditions are displayed.

Figure 25: District View – Road Condition Map

Next, the user can click on the road of interest to navigate to the road view. Figure 26 presents the road view for I-68 in District 6. Figure 26 displays the road for I-68 along with labels for the two primary features of this view.

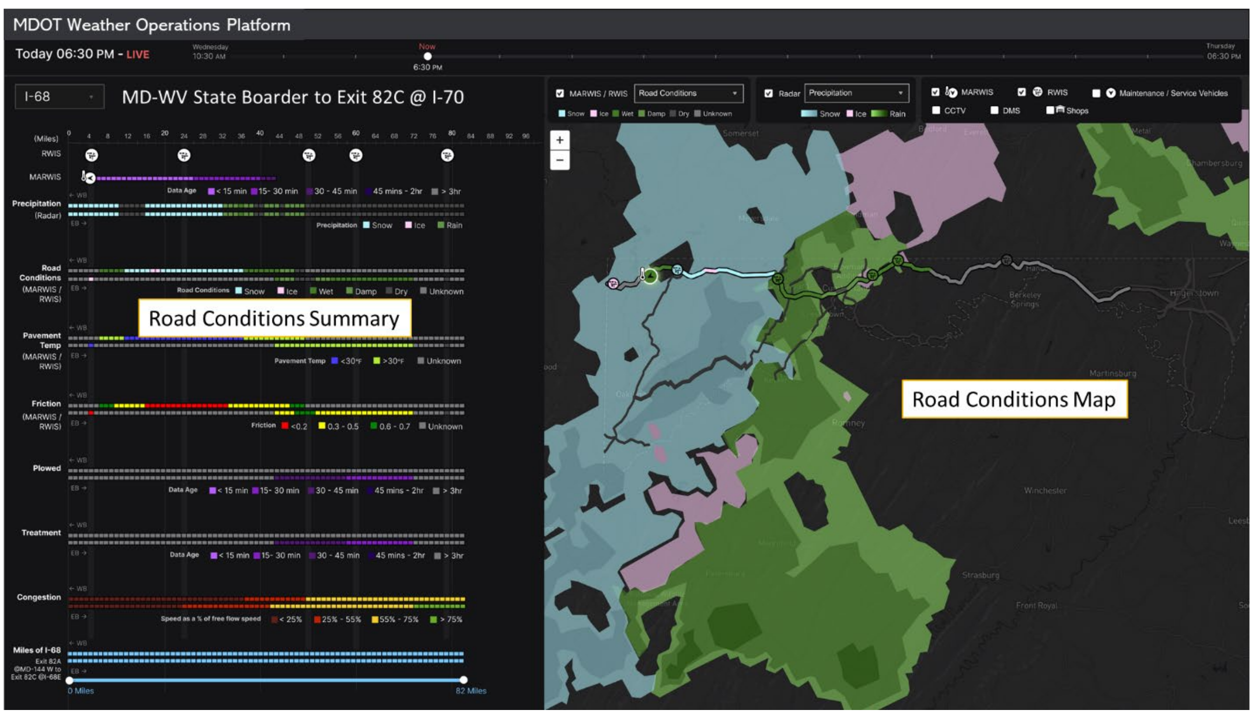


Figure 26: Comprehensive Weather Operations Decision Support Platform – Road View

The left side of the road view (Figure 27) presents details on the location of sensors (MARWIS and RWIS), mile-by-mile weather measurements from the selected data source, and a road milage selector to hone in on specific portions of the target road. The right-side road view provides a zoomed in map of the selected road. Similar to the district view, users can change the data source and turn icons on and off.

Figure 27: Road View – Road Condition Summary

Once the user identifies a specific portion on the target roadway to focus on, the display can be further zoomed by using the road segment selector feature shown in Figure 27. In doing so, the interface updates to display the details of weather data on the target segment. Figure 28 highlights the road selection feature and zoomed in map view. In this display, individual sensor locations become visible on the map. In Figure 27, there is one RWIS station on the left of the map and one MARWIS station that is moving westbound on the selected segment of I-68.

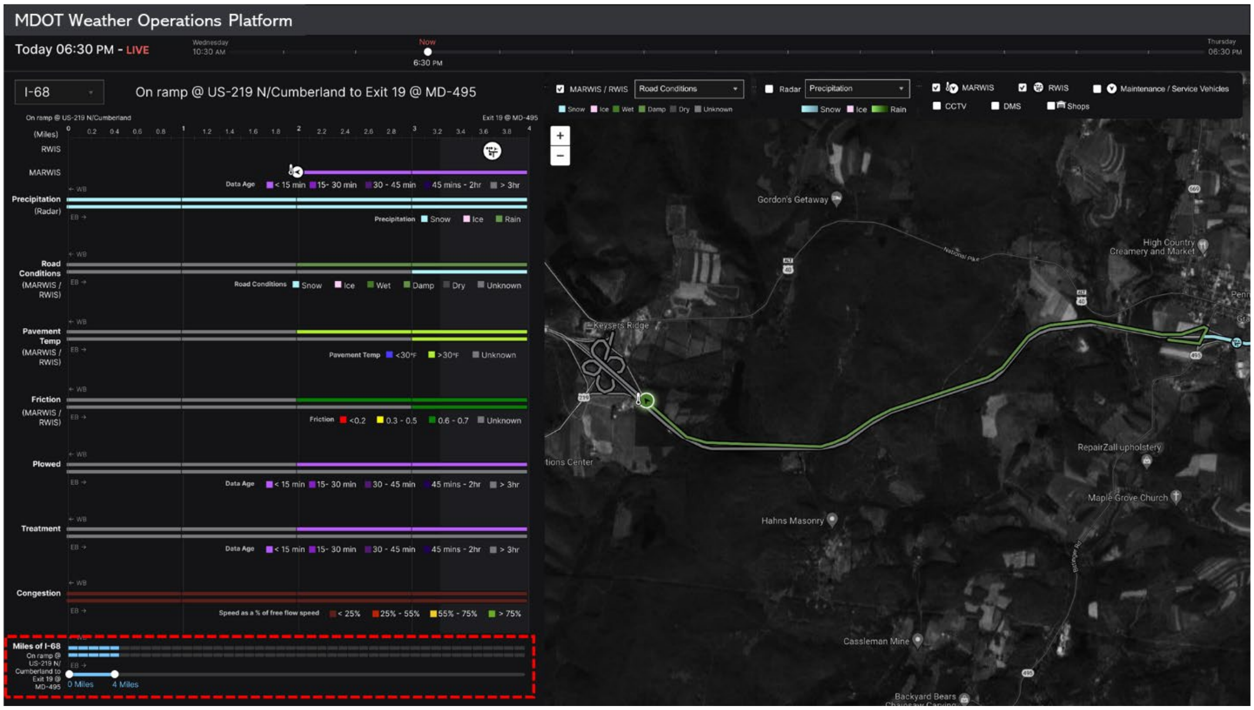


Figure 28: Zoomed In Road View

Upon zooming into the segment of interest, the user can view data from individual sensors. Figure 29 presents the view of a MARWIS sensor driving westbound on I-68. The left portion of the sensor view provides the detailed measurements from the selected sensor. The map view adds the dashboard cam (when available) of the vehicle carrying the select sensor.

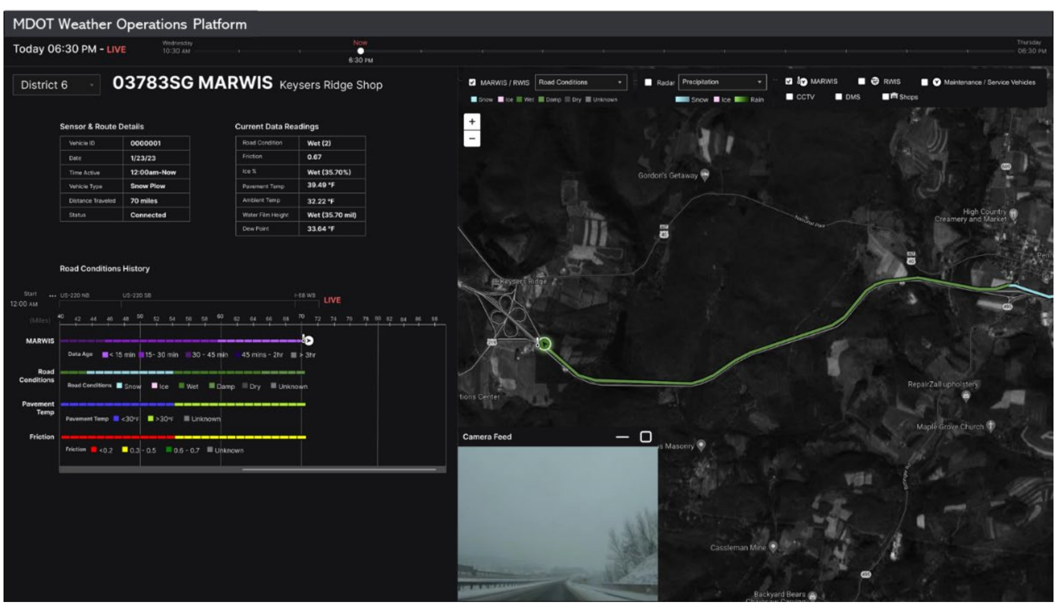


Figure 29: Comprehensive Weather Operations Decision Support Platform – Sensor View

Conclusions and Recommendations

This project made the following contributions to the field of winter weather data integration and decision support:

5. **Documented state-of-practice** in winter weather data analysis by conducting an in-depth literature review. The literature review provided insights on the impact of winter weather on traffic flow and safety. In addition, the literature documented the data sources commonly used for winter weather impact studies. The three primary weather data sources were RWIS, MARWIS, and weather radar.
6. **Discovered applications, challenges, and benefits of integrating MARWIS data** into a winter weather operations and maintenance decision process. These insights were obtained through a nationally distributed online survey of agency highway operations and operations professionals. Most agencies using MARWIS were in a pilot phase.
7. **Established baseline for MARWIS data interfaces** to support winter weather operations and maintenance decisions. This baseline was discovered during the one-on-one agency interviews that included a demo of each agency's software package(s) used to analyze various weather data. Most agencies, including SHA, rely on out-of-the-box software to view MARWIS data in a stand-alone application that is not fused with other data sources such as RWIS and radar data.
8. **Designed a comprehensive winter weather decision support platform** that integrates MARWIS, RWIS, real-time and predictive radar into a single application. The platform designs allow a user to view state-wide performance, discover district(s) of interest, identify roads of concern, zoom into specific segments on the target road, and view data from specific sensors/data sources on the target segment.

The recommended next step for this research is to pursue opportunities to develop a comprehensive winter weather decision support platform. To do so, our research team will need to continue working with MDOT and MARWIS vendor to explore data feed options. Next, a formal comprehensive weather operations platform design requirements document needs to be composed to document critical system functions such as data requirements (feeds, formats, storage, etc.), details of front-end interface functionality, and details of back-end data fusion and processing. Training and other technology transfer activities should also be developed to ensure the platform is utilized by SHA operations and maintenance professionals.

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Appendix A – Online Survey Questions

Survey for MDOT-SHA Research Project (SHA/UMD/6-12): Integrating Road Weather Technology Data in Highway Operations

The Maryland Department of Transportation State Highway Administration seeks to understand how to best integrate road weather data collected from *Mobile* Advanced Road Weather Information Systems (MARWIS) mounted to plows, safety service patrols, or other vehicles into traffic operations and planning programs.

The purpose of this survey is to synthesize effective practices and lessons learned from other state and local DOTs–especially with data visualization and integration with other weather data products and/or Advanced Traffic Management System (ATMS) platforms.

We are requesting your assistance with this survey because of your leadership and expertise in the DOT, and because we believe you are likely to know the right people within your organization that could help you compile the most complete response. The survey is short and should take less than 15 minutes to complete. The survey can be accessed at:

https://survey.alchemer.com/s3/6896365/Integrating-Road-Weather-Tech-in-Highway-Operations

If needed, please take some time to consult with others in your organization who may be using road weather data, especially for operational and planning decisions.

We kindly ask that you complete the survey no later than Friday, July 29th.

If you have any questions or comments regarding this survey, please contact me using my information below. For questions related to the program, please contact the SHA ITS and CHART Systems Deputy Director, Mohammed Raqib, at MRaqib@mdot.maryland.gov .

Mark L. Franz – Principal Investigator

mfranz1@umd.edu

301-314-0422

State of Practice Survey

Contacts: See Attached Spreadsheet

Name:
Agency:
Title:
Email:

1) Does your agency currently use Mobile Advanced Road Weather Information Systems (MARWIS) or a similar mobile weather data collection technology?
   a) Yes (continue to question #2)
   b) No (go to question #13)

2) How integrated is the MARWIS data into your traffic operations programs and supporting systems?
   a) MARWIS data is visible through a stand-alone/segregated platform. For example, MARWIS is delivered to the Ops center via vendor software or some other software.
   b) MARWIS data is integrated into our advanced transportation management system (ATMS) platform. For example, MARWIS is visible directly within our ATMS platform and overlaid on a map with other ATMS data like incidents, speed data, etc. without having to open a separate application or hide other traffic operations data.
   c) MARWIS is fully integrated into our ATMS platform **and** fused with other data (like NWS radar data, stationary RWIS, or other sources of weather data) in real-time and visible within the ATMS platform to provide a complete picture of road weather activities and impacts without having to open up a separate application.
   d) MARWIS data being integrated, fused, **and** shared as a separate feed to others interested or able to use the feed.
   e) Other: Please explain

3) Is there anything within the user interface that is particularly effective in communicating valuable information?
   a) Open response

4) Is there anything within the MARWIS data displays/UI that is ineffective and/or needs improvement to help better convey the information to operations personnel or decision-makers?
   a) Open response?

5) How many of your agency's vehicles are equipped with MARWIS technology?
    a) ENTER #
6) How frequently do you route MARWIS-equipped vehicles over a roadway to ensure the data collected are still useful for decision-making?
    a) After 15 minutes
    b) After 30 minutes
    c) After 1 hour
    d) After 2 hours
    e) After 2+ hours
    f) Other/depends on the situation: please explain.

7) Is the number of equipped vehicles enough to give you the coverage needed? For example, are you able to collect data on all of your roadways every X-minutes to ensure the measurements don't become stale and unusable for decision-making?
    a) Please explain – Open response.

8) What MARWIS type(s)/mode(s)l are you using? (select all that apply)
    a) Lufft MARWIS
    b) Teconer RCM411
    c) Vaisala MD30
    d) Vaisala DSP310
    e) High Sierra Elec. IceSight PreCise
    f) ARC System
    g) RoadWatch
    h) High Sierra Elec. Surface Sentinel
    i) Other (please specify)
9) Please select the three most valuable MARWIS data fields in terms of their importance for making operational decisions?
    a) Pavement temperature
    b) Air temperature
    c) Pavement condition
    d) Wind speed and direction
    e) Precipitation occurrence
    f) Precipitation intensity/depth
    g) Humidity
    h) Visibility

10) Describe how your agency uses MARWIS data. For example, what does MARWIS data uniquely enable your agency to do in the realm of road weather management? Are there any

scenarios that particular MARWIS data is especially useful? For example, wind speed and direction from MARWIS are valuable at bridge locations.

a) Open response

11) Are there any lessons learned that Maryland should know about before implementing their own MARWIS program? Any mistakes that were made in your implementation or things that you would do differently if you were to start again? Any enhancements that you would like to make to your systems?

a) Open response

12) May we follow up with limited additional questions for a possible case study, providing an opportunity to showcase your and your colleagues' practices to other transportation professionals?

a) Yes
b) No

END SURVEY for those who responded YES to question #1.

13) Is your agency considering or planning to integrate MARWIS into their road weather data collection plan?

a) Yes (Go to question #14)
b) No (END SURVEY)

14) Why is your agency interested in MARWIS technologies? What will MARWIS uniquely enable your agency to do in the realm of road weather management? Are there any scenarios that you anticipate MARWIS data being especially useful? For example, wind speed and direction from MARWIS will be valuable at bridge locations.

a) Open response (END SURVEY)