Connected Vehicle-Enabled Weather Responsive Traffic Management

Final Report

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16. Abstract

Weather Responsive Traffic Management (WRTM) is an initiative under the Federal Highway Administration's (FHWA) Road Weather Management Program that supports traffic management agencies and professionals in implementing effective advisory, control, and treatment strategies to mitigate transportation challenges due to adverse weather. Effective deployment of WRTM strategies depends upon an agency's ability to collect and integrate traffic, weather, and road condition data to effectively analyze the impacts of weather conditions and deliver pertinent information back to the travelers. Connected vehicle-enabled weather responsive traffic management (CV-WRTM) is an approach that leverages vehicle connectivity to develop new tools for WRTM. Agencies face significant challenges in translating an interest in CV-WRTM to real-world applications, as there are many unknowns in converting research activities into implementation, including integration with the broader operational decision-making frameworks.

This document summarizes the work completed to strengthen the linkages between WRTM and connected vehicle (CV) technology. It also summarizes the guidance developed under this task to help State DOTs integrate the emerging CV technology with their road weather management practices,

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Finally, the authors thank Roemer Alfelor and the FHWA Road Weather Management Program for their leadership and guidance throughout this effort.

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Acronyms and Abbreviations

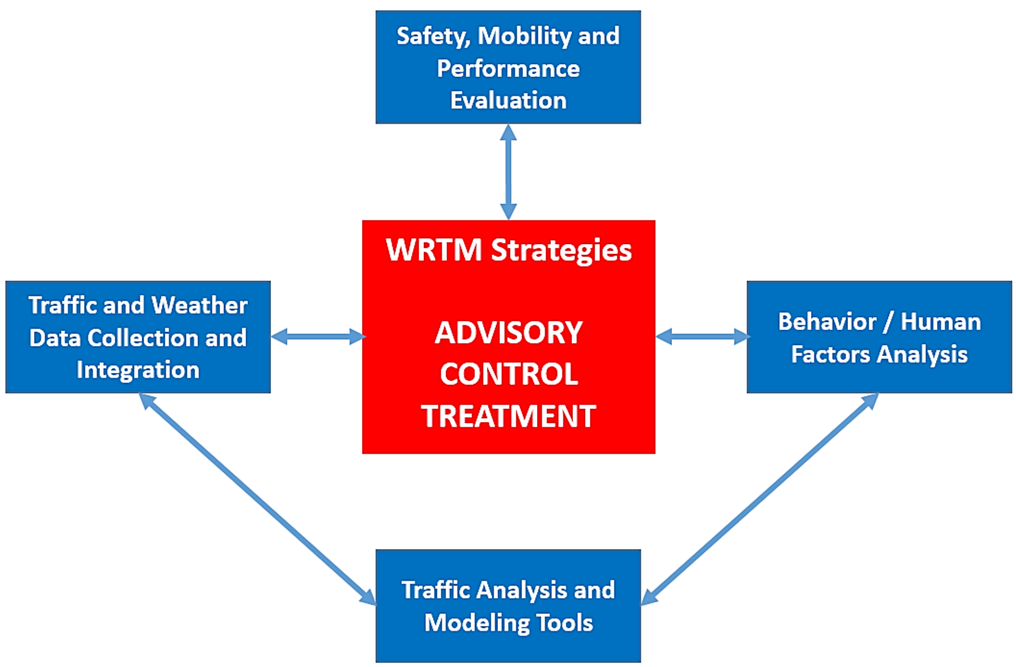
ADOT	Arizona DOT
API	application programming interface
ATM	active traffic management
AVL	automated vehicle location
BSMs	basic safety messages
CAMP	Crash Avoidance Metrics Partnership
CAN	controller area network
ConOps	concept of operations
CSW	curve speed warning
CV	connected vehicles
CVRIA	Connected Vehicle Reference Implementation Architecture
CV-WRTM	connected vehicle-enabled weather responsive traffic management
DMS	dynamic message sign
DOT	department of transportation
DSRC	dedicated short-range communication
DUAP	Data Use and Analysis Processing
DUST	Dual Use Safety Technology
EDC	Every Day Counts
EEBL	emergency electronic brake light
E-MDSS	enhanced maintenance decision support system
ESS	Environmental Sensor Stations
FCW	forward collision warning
FHWA	Federal Highway Administration
FRATIS	Freight Advanced Traveler Information System
GAO	Government Accountability Office
GPS	Global Positioning System
HAR	highway advisory radio
IMO	Integrated Mobile Observations
IMRCP	integrated model for road condition prediction
INFORM	INformation FOR Motorists
IRIS	Integrated Roadway Information System
ISP	information service provider
ITS	intelligent transportation systems
MADIS	Meteorological Assimilation Data Ingest System
MDC	mobile data collectors
MDOT	Michigan Department of Transportation
MDSS	Maintenance Decision Support System
MnDOT	Minnesota DOT
MoPED	Mobile Platform Environmental Data

NCAR	National Center for Atmospheric Research
NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NYSDOT	New York State DOT
OBU	on-board units
OEM	original equipment manufacturer
PII	personally identifiable information
RITIS	Regional Integrated Transportation Information System
RNTW	routing, navigation, traffic, and weather
RSAS	Surface Assimilation Systems
RSE	roadside equipment
RUC	Rapid Update Cycle
RWIS	road weather information system
RWMP	Road Weather Management Program
RW-PM	Road Weather Performance Management
SCMS	Secure Credential Management System
SDDOT	South Dakota Department of Transportation
SPaT	Signal Phase and Timing
TMC	traffic management centers
TOC	traffic operations center
UCAR	University Corporation for Atmospheric Research
UDOT	Utah DOT
USDOT	U.S. Department of Transportation
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VDT	Vehicle Data Translator
VIDAS	Vehicle-based Information and Data Acquisition System
VMS	variable message sign
VSL	variable speed limit
WISDOM	Weather In-Situ Deployment Optimization Method
WRTM	Weather Responsive Traffic Management
WSR	Weather Savvy Roads
WxDE	Weather Data Environment
Wx-TINFO	weather response traffic information system
WYDOT	Wyoming Department of Transportation

Chapter 1. Introduction

BACKGROUND

Weather Responsive Traffic Management (WRTM) is an initiative under the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) that supports traffic management agencies and professionals in implementing effective advisory, control, and treatment strategies to mitigate mobility and safety challenges due to adverse weather. At its core, WRTM is a set of such strategies that includes advisories, alerts and warnings, speed management, vehicle restrictions, signal timing, as well as improved incident management. The WRTM framework optimizes the different processes and relationships within and across traffic and road weather data collection, performance measurement and evaluation, modeling and simulation and human factors (see Figure 1).



Source: FHWA

Figure 1. The weather-responsive traffic management framework.

Starting from guidance and moving through implementation and evaluation support, the WRTM program has enabled innovative and award-winning practices like citizen reporting systems, weather-responsive traveler information, and weather-responsive active traffic management.

The WRTM program continues to evolve and grow as it addresses new stakeholder needs and undertakes important research initiatives. Recent WRTM implementation support focused on integrating mobile data into traffic management. Through deployments in Wyoming, South Dakota, and Michigan, the program supported real-world use of mobile data for weather-responsive traffic management.

CONNECTED VEHICLE-ENABLED WEATHER RESPONSIVE TRAFFIC MANAGEMENT OVERVIEW

Under the umbrella of WRTM, strategies such as speed management, vehicle restrictions, signal timing, and traffic advisories are used to manage traffic and provide travelers with advanced temporal and spatial notification of hazardous conditions that may be encountered. In extreme cases, operators may consider restricting vehicle access to a corridor or a segment of a corridor.

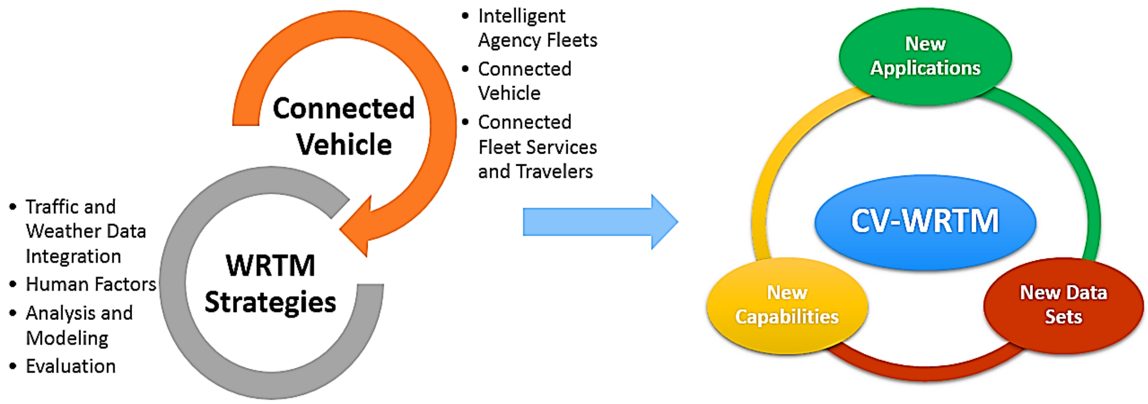
Effective deployment of WRTM strategies depends upon the agency's ability to collect and integrate traffic, weather, and road condition data to effectively analyze the impacts of weather conditions and deliver pertinent information back to the travelers.

Agencies still face several challenges in deploying WRTM, including:

- Limited coverage of road weather information systems (RWIS) on roadways, leading to gaps in road condition information. The cost of installing and maintaining RWIS stations and sensors is significant. Constrained budgets make it difficult to further expand the agencies' RWIS networks quickly.
- Difficulty in communicating with travelers on the roadways, especially about rapidly changing conditions. Adverse road conditions may be detected in areas without dynamic message signs or highway advisory radio coverage.
- Evolving operational integration methods between maintenance and operations units.

To deal with these challenges, agencies must look at the potential of wireless connectivity between vehicles, infrastructure, and traffic management centers (TMC) to realize effective WRTM implementation. Connectivity presents unique capabilities to enhance WTRM strategies by: (1) enabling the transfer of data between and across users and transportation agencies, (2) expanding the coverage of the transportation network, and (3) providing more disaggregated information on the network.

The next generation of WRTM technologies needs to take advantage of the potential offered by connected vehicles (CV). As shown in Figure 2, connected vehicle-enabled weather responsive traffic management (CV-WRTM) is an approach that leverages vehicle connectivity to develop new tools for WRTM. Agencies today face significant challenges in translating an interest in CV-WRTM to real-world applications, as there are many unknowns in converting research activities into implementation, including integration with the broader operational decision-making frameworks.



Source: FHWA

Figure 2. CV-WRTM: leveraging connected vehicles for weather responsive traffic management.

PROJECT OVERVIEW

In the past five years, the WRTM initiative has supported a roadmap of activities that have emphasized practical operational approaches to improving practices at State departments of transportation (DOT). This task represents the continued evolution of the program and provides an opportunity to strengthen the linkages between WRTM and connected vehicle (CV) technology. A suite of new opportunities for WRTM is now a reality. Combining the best of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) applications with new data collection, assimilation and dissemination approaches has the potential to improve advisory, control and treatment strategies. The overarching goal of this task is accelerating the deployment of CV-WRTM. The most important outcome for the products generated from this effort is real-world implementation of some of the concepts and guidance developed.

The primary technical tasks that encompass the project include:

- Establish the State of the Practice - Document existing and recently implemented WRTM strategies that utilize road weather data from fixed and mobile sensors.
- Review Road Weather Messaging – Survey and evaluate the effectiveness of common road weather messages for conveying road weather connected vehicle information, including search and documentation on messaging and its effectiveness.
- Develop CV-WRTM Guidelines – Develop deployment guidelines and implementation strategies with input from national experts on WRTM.
- Support CV-WRTM Implementations – Select and provide technical assistance to two State DOTs in implementing CV-WRTM applications. Use and evaluate the CV-WRTM Guidelines in the implementations.
- Conduct the 4th National WRTM Workshop – Plan, organize and conduct the fourth national WRTM Workshop and Stakeholder Meeting with a focus on connected vehicle-enabled applications.

REPORT ORGANIZATION

The final report consists of the following chapters:

- Chapter 2, State of the Practice Review, summarizes the state of the practice related to CV-WRTM activities and efforts.
- Chapter 3, Road Weather Messaging Review, summarizes currently used approaches for communicating and messaging related to road weather and evaluates them for their effectiveness both in a WRTM and a CV-WRTM context.
- Chapter 4, CV-WRTM Guidelines Development, describes the CV-WRTM guidelines, including the three implementation pathways and sample applications of CV-WRTM for road weather management.
- Chapter 5, CV-WRTM Implementation Projects, summarizes the development, implementation, and evaluation of the Washington State DOT and Delaware DOT CV-WRTM deployments.
- Chapter 6, Findings and Recommendations, describes major project findings and identifies specific recommendations to move the CV-WRTM program forward. This chapter also includes a summary of the stakeholder workshop.

Chapter 2. State of the Practice Review

This chapter presents a comprehensive review of the state of practice related to connected vehicle-enabled weather responsive traffic management (CV-WRTM) implementations and other relevant efforts. This review, together with other information generated from the other tasks, was used in developing the CV-WRTM Deployment Guidelines described in Chapter 4. The review is organized as follows:

- Federal government initiatives.
- State/local and other initiatives.
- Relevant parallel efforts.

FEDERAL GOVERNMENT INITIATIVES

This section presents U.S. Federal Government initiatives that have occurred or are underway with regards to the use of CV technology for road weather management.

Integrated Mobile Observations Project

The purpose of the Integrated Mobile Observations (IMO) project is to develop and implement vehicle-based road weather data collection and processing systems to support road weather analysis and management throughout the United States. IMO first identifies and obtains information, disaggregated into 1 second intervals, from a vehicle equipped with a phone and other sensors and data collectors. Equipped vehicles collect and share information on items such as time, Global Positioning System (GPS) location, speed, photos, environmental condition, and onboard diagnostic keys. Data files are then created in time intervals (e.g., 5 minutes), sent via cell phone to a server, validated, and then shared with weather analysts throughout the country. The data provided is meant to support weather models and weather-related traffic management, traveler information systems, winter maintenance operations, and transportation asset management systems, among other applications.

Michigan, Minnesota and Nevada Departments of Transportation (DOTs) worked independently using different strategies to gather weather-related data and send it to weather analysts. Michigan DOT equipped 60 vehicles with different hardware and software, logging 400,000 miles and over 172 gigabytes of valid data, mainly along Interstate 94, in a 17-month period.(3) The information is shared with different analysts, including the National Center for Atmospheric Research (NCAR), Mixon-Hill (Data Use and Analysis Processing (DUAP) System), Atkins (Regional Integrated Transportation Information System (RITIS)), Iteris (Maintenance Decision Support System (MDSS)), and Leidos & Synesis Partners (FHWA Weather Data Environment (WxDE)). Similarly, Nevada DOT equipped 36 vehicles that traveled along segments of Interstate 80.(22) Minnesota DOT (MnDOT) equipped snowplows with automated vehicle location (AVL) capability, with a total number of active AVL units from 78 to 225 in IMO Phase I. MnDOT was also able to use mobile data to produce an "End of Shift" report detailing chemical usage, and establish a controller area network (CAN) interface using both J1939[1] and J1979[2] protocols.[(28)]

IMO is now being supported as part of the Every Day Counts (EDC) Weather Savvy Roads (WSR) initiative, and several other State DOTs are considering deploying similar technology on their fleets.

Performance Measurement Prototype

The FHWA developed a framework to develop, test, deploy and evaluate a Prototype Road Weather Performance Management (RW-PM) Tool. The RW-PM Tool is a system for continuously monitoring and optimizing traffic management and road weather treatment during adverse weather events.[(21)] The goal is to counteract, to the extent possible, the negative impacts of adverse weather events on roadway safety, mobility, and productivity.

The tool would use different types and sources of data including RWIS, publicly available traffic mobility data sources, subscription-based traffic mobility data sources, DOT traffic speed sensors, and CV location, speed, heading, and road weather data. By optimizing the use of available (and newly collected) information, the tool could help agencies:

- Provide more informed traffic and road weather maintenance management responses.
- Collect more robust, higher resolution, and higher density traffic mobility and road weather data.
- Allocate staff, equipment, and material resources more efficiently.
- Deploy maintenance forces in a timelier and more effective manner in response to dynamic variations in weather.
- Improve traffic mobility during an adverse weather event.
- Return mobility to normal more quickly following an event.
- Support more informed and safer travel route and behavior decisions by drivers.

Weather ResponsiveTraffic Management Pilot Implementations

FHWA recently completed implementation projects for WRTM that use data collected from mobile vehicles. Three are described below from Wyoming, South Dakota, and Michigan.

Weather Responsive Road Condition Reporting Application – Wyoming Department of Transportation (WYDOT)

The Wyoming WRTM Road Condition Reporting Application ("App" henceforth) addressed both maintenance staff activities to report road conditions and the TMC staff actions taken based on the reported information. The primary focus was on the development of a new software application to improve the way maintenance staff report road conditions.[(17)] Figure 3 shows a screenshot of the application. Traffic management center (TMC) operator actions taken based on input from the field maintenance staff included updating the traveler information system, changing variable speed

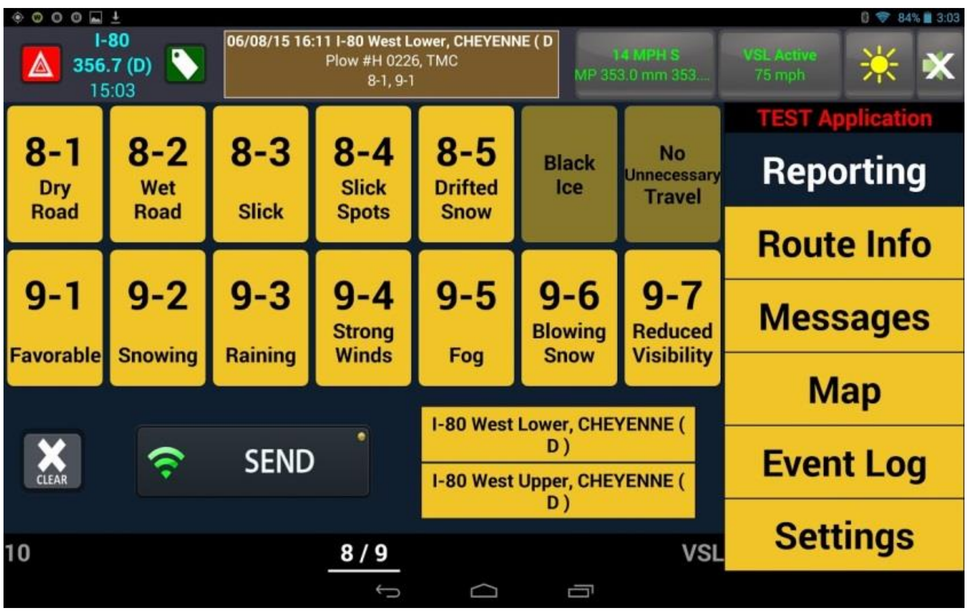
[1] SAE standard J1939 is the vehicle bus recommended practice used for communication and diagnostics among vehicle components.
[2] SAE standard J1979 defines on-board diagnostics parameter identification (PID) codes, which are used to request data from a vehicle.

limits, changing message signs, or closing roads. All functions were previously performed manually or by phone by the WYDOT staff, and now the App allows these processes to be automated using computer systems.

The App was built to run on a tablet computer and utilized Wyoming's extensive statewide communication system backbone called WyoLink. The WYDOT WRTM project was intended to improve:

- The efficiency of road condition reporting by maintenance staff.
- The ability of TMC operators to take action based on the road conditions reported.
- The timeliness of updated traveler information.
- The situational awareness of maintenance staff in the field regarding road weather conditions.

This initial project implementation included 20 tablets with the new software application pre-loaded. The tablets were installed in WYDOT plow trucks to report road conditions during the 2014-2015 winter season. The implementation also included changes to data management systems in the TMC to accept the road condition reports from the tablets and assist TMC operators to perform the duties associated with this new implementation.



Source: FHWA

Figure 3. Weather Responsive Road Condition Reporting Application.

The evaluation indicated improvements in road condition reporting efficiency, managing traffic during weather events, timeliness of road condition reporting to the public, and maintenance staff situational awareness. Specifically, implementation of this WRTM project resulted in the following when compared to previous approaches:

- Twice as many road reports submitted.
- Three times more variable speed limit (VSL) change requests.
- VSL and dynamic message sign (DMS) change requests were more timely and accurate.

- Maintenance staff submitted road reports more often and used less time making the reports.
- All maintenance staff surveyed said this project improved their operations.

WYDOT continues to enhance the road condition reporting app. Planned enhancements include developing web apps to create electronic versions of paper forms currently used in maintenance operations such as those used for vehicle inspection and repair requests.

Weather Responsive Regional Traveler Information System – South Dakota Department of Transportation (SDDOT)

The South Dakota Weather Responsive Regional Traveler Information System project implementation was divided into two elements to improve both road weather data collection and the content and amount of traveler information being provided to motorists in South Dakota.[(18)]

The first project element developed a special software application that allowed plow drivers to enter road conditions directly into the Integrated Roadway Information System (IRIS) using the mobile data collectors (MDC) that already existed in the trucks. This was an improvement over the current process because it provided drivers immediate and direct access to IRIS instead of using the radio to inform a supervisor, who would then enter the road conditions into IRIS at their desk, or the maintenance staff, who would enter it in the office at the end of a run or shift.

The second project element focused on providing motorists 24-hour road condition threat forecasts on the SafeTravelUSA website, 511 phone system, and mobile phone applications. The 24-hour road condition forecasts came directly from the SDDOT maintenance decision support system (MDSS) and were presented to the public, through their traveler information systems, as possible future “threats” when road conditions might be deteriorating into an unsafe situation.

The evaluation indicated improvements in, and expansion of, road weather information provided to travelers, and the travelers expressed perceived value in receiving the information. A significant amount of new traveler information was made available on SDDOT’s website, phone system, and mobile phone applications; namely, more than 100,000 road condition threat forecasts and 42,000 hours of National Weather Service (NWS) alerts were issued. Results of an Internet survey indicated that travelers appreciated the new information (specifically the road condition forecasts) and adjusted their travel plans based on the new information provided by SDDOT.

SDDOT is planning to continue providing the 24-hour road condition threat forecasts and NWS alerts, with possible enhancements to the information display. They also planned to deploy the IRIS application in plow vehicles to improve road condition reporting throughout South Dakota.

Weather Responsive Traveler Information System – Michigan Department of Transportation (MDOT)

The MDOT weather responsive traveler information system project deployed a system to collect both fixed and mobile road weather data and process that data to support traveler information and traffic operations. The system relayed roadway pre-trip or en route weather information, which enabled the traveling public to make informed travel decisions to improve mobility and safety. Additionally, winter maintenance personnel may use the weather information system in the future to increase efficiency of roadway treatments.

The data sources for the weather response traffic information system (Wx-TINFO) include both fixed and mobile observations. The primary coverage of the mobile observations was the I-94 corridor in southern Michigan, where most of the Integrated Mobile Observations (IMO) 2.0 instrumented vehicles were operating. The MDOT Vehicle-based Information and Data Acquisition System (VIDAS) project also had vehicles collecting mobile observations throughout the entire state, covering all MDOT regions, including a percentage of vehicles in locations with fixed Environmental Sensor Stations (ESS).

As part of the Wx-TINFO system, the MDOT DUAP System, maintained and operated by MDOT contractors, aggregated and synthesized the data to identify weather related information, including event type, location, and safety recommendations. The information was then disseminated to the various stakeholders. The weather advisory information was communicated through a variety of media, such as MDOT's dynamic message signs (DMS) (using ATMS software) and MiDrive web site.

The evaluation indicated an increase in the average number and percentage of DMS that displayed weather-related information during NWS advisories and warnings. MDOT's MiDrive website visits also increased by about 20 percent during storms that resulted in 1 inch of snow or more. In addition, travelers indicated in a web-based survey that they were familiar with weather-related DMS messages, to which they were likely to respond by either slowing down or changing trip plans, and felt that the DMS messages improved safety and reduced delay.(32)

Pikalert Vehicle Data Translator Project

Vehicle Data Translator (VDT) is a system that collects, processes, and shares mobile data already resident on a vehicle along with supplementary weather data from external sources (e.g., radar, gridded weather observations, satellite data, surface stations, National Weather Service products, and social media).(8) The earliest versions of the VDT were developed using 9 to 11 vehicles operating in a development test environment in Detroit during the winter and spring of 2009 and 2010. At a high level, the VDT first collects and sorts mobile data while controlling for quality; second, performs more robust quality checks and generates basic road assessment data; and last, combines mobile and ancillary data to create advanced road assessment data for precipitation, pavement condition, visibility, and all-hazards, which can then be shared between and across vehicles and agencies for assessment and information dissemination.

The VDT is also a part of the Pikalert System, which provides high precision road weather guidance by assessing current weather and road conditions based on observations from CVs, RWIS, radar, and weather model analysis fields. For Pikalert, the VDT ingests all formatted mobile weather observations and then performs a series of quality checks, and generates statistics for road segments.(5)

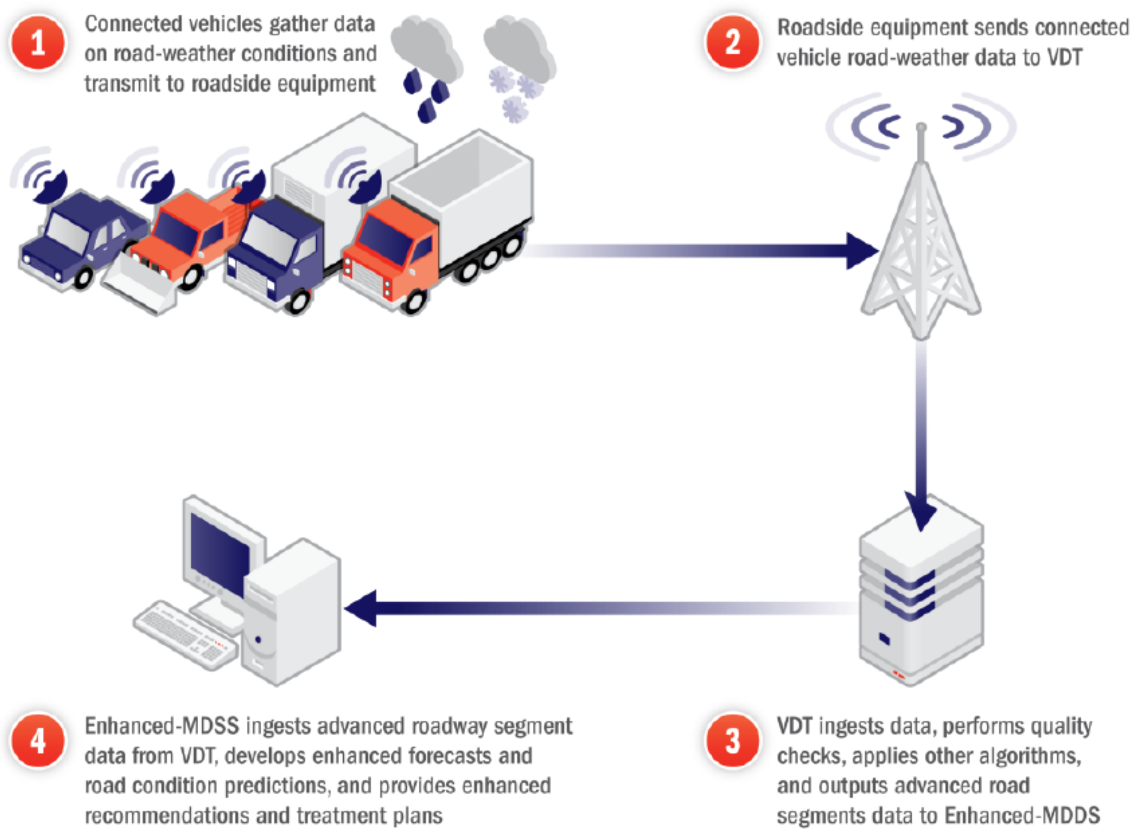
Road Weather Connected Vehicle Applications - Concept of Operations Development

In 2013, the U.S. Department of Transportation (USDOT) developed a concept of operations (ConOps) to define the priorities for road-weather applications that are enabled by CV. In particular, six CV road weather applications concepts and scenarios were identified and described in the document. The applications described in the ConOps described ways by which data from connected vehicles might be used to improve safety, agency operations, and traveler information.[15] Short summaries of the six applications concepts are provided below.

Enhanced Maintenance Decision Support System

The enhanced maintenance decision support system (E-MDSS) uses data from connected agency fleet vehicles and other vehicles operated by the general public to generate improved plans and recommendations to maintenance personnel, as shown in Figure 4. Connected vehicles will improve the robustness and level of granularity of the data, yielding to more informed decisions and augmented capabilities of traffic management. In turn, the system will provide enhanced treatment plans and recommendations to the snowplow operators and drivers of agency maintenance vehicles.

Information from the E-MDSS application provides traffic operators the capability to monitor treatment and road conditions better and at a more granular level than previously possible. E-MDSS outputs can support TMC decision-making for variable speed limits, vehicle restrictions and maybe even impact closure decisions made by the agency. E-MDSS data may also support better forecasts of segment conditions which can be shared with the public.

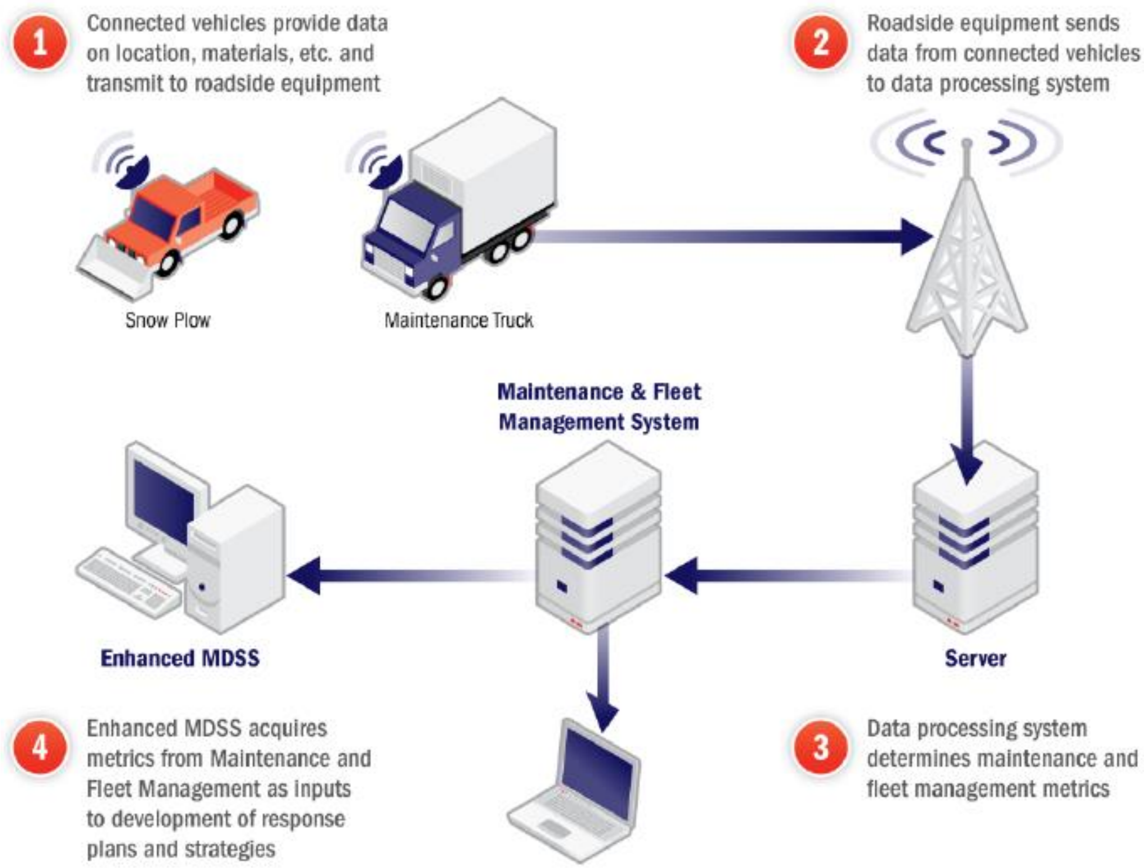


Source: FHWA

Figure 4. Schematic of the enhanced-maintenance decision support system application.

Information for Maintenance and Fleet Management Systems

CV information can also account for non-road weather data, such as the status of vehicle components, current location of maintenance vehicles and other equipment, and the types and amounts of materials onboard maintenance vehicles. This information can then be used to automate the inputs to Maintenance and Fleet Management Systems on a year-round basis and can also be passed on to an E-MDSS to refine the recommended winter weather response plans and treatment strategies, as shown in Figure 5.

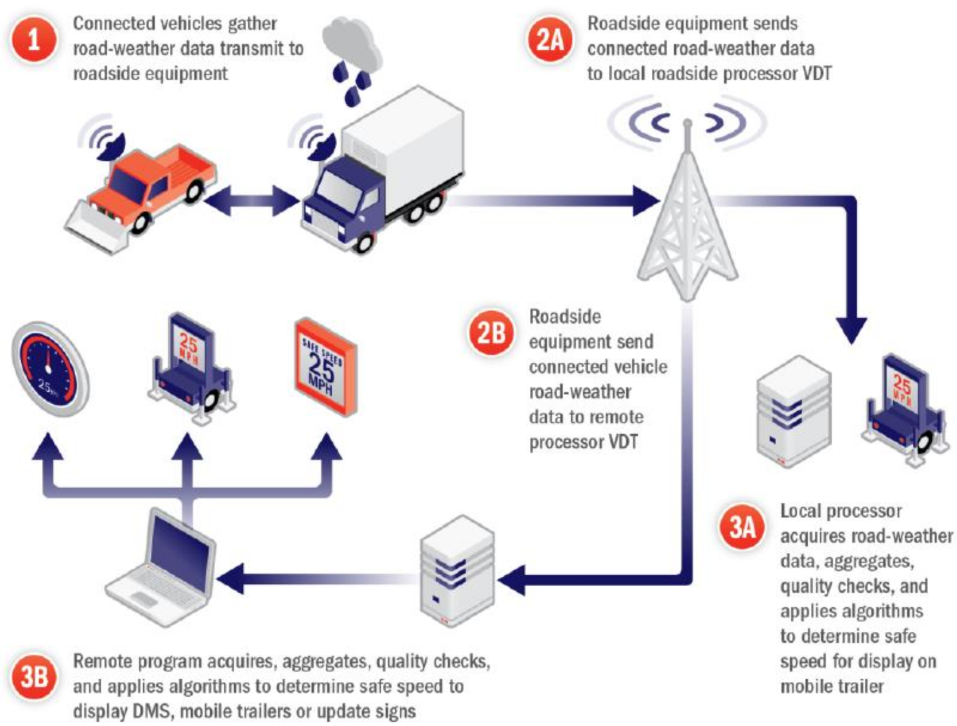


Source: FHWA

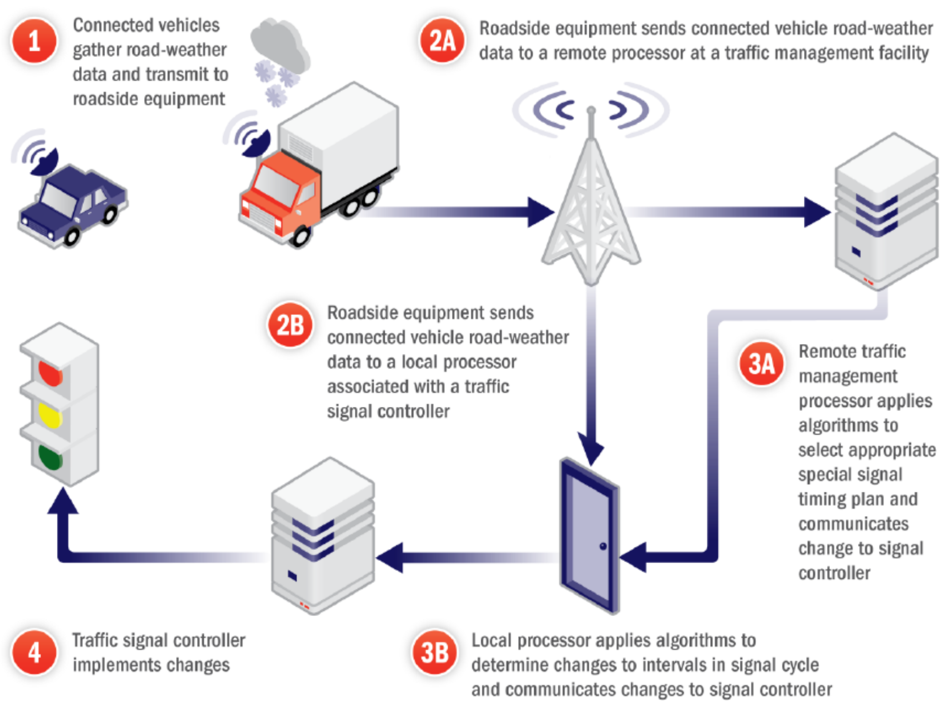
Figure 5. Schematic of maintenance and fleet-management system with connected vehicle road weather information.

Weather-Responsive Traffic Management

Two connected vehicle systems concepts of operations were developed to enhance Weather-Responsive Traffic Management, specifically traffic control. The first was for VSL systems to dramatically improve safety during severe weather events. The second was for signalized intersections to optimize signal system performance when severe weather affects road conditions. Both applications would expand current WRTM strategies for VSL and weather-responsive traffic signal timings to include connected vehicle data (Figure 6).



a) Variable Speed Limit System



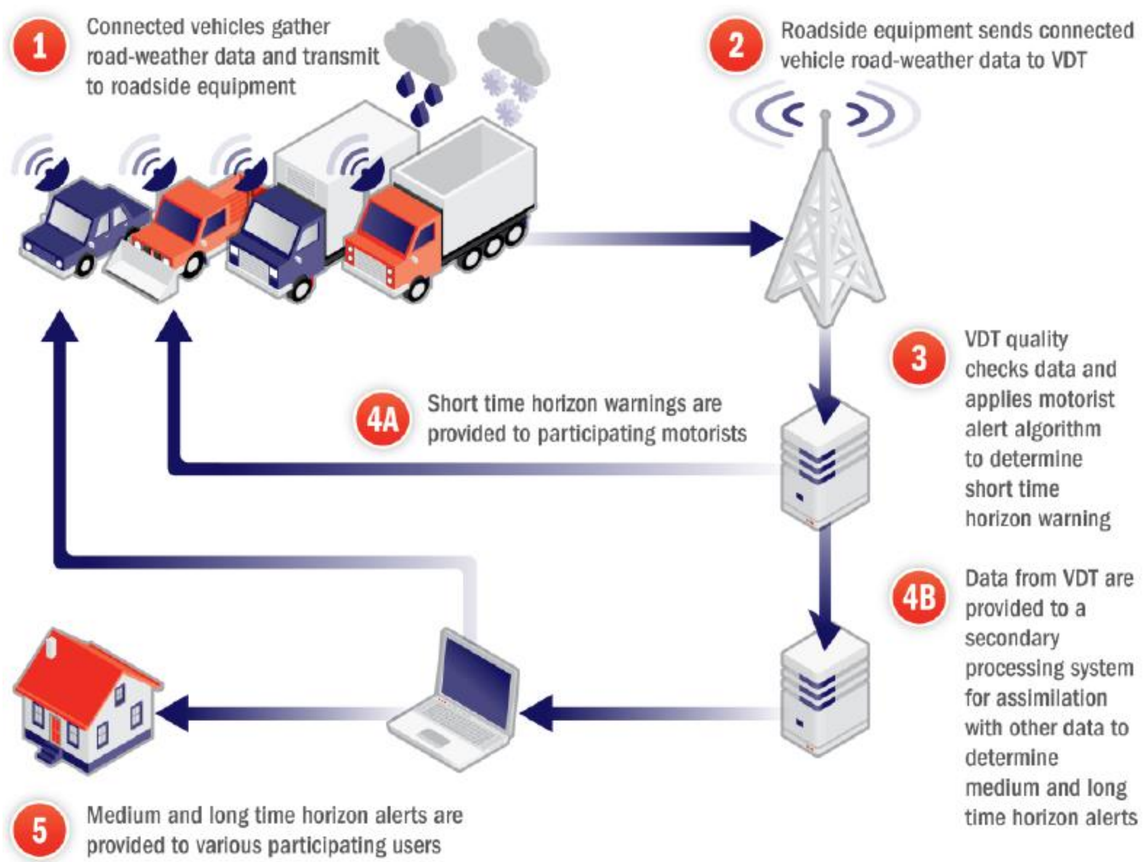
b) Signalized Intersection System.

Source: FHWA.

Figure 6. Compound diagram depicts schematics of weather-responsive variable speed limits and weather-responsive signalized intersection system.

Motorist Advisories and Warnings

Short-, mid-, and long-term advisories can be made more accurate and, with increased coverage, use segment-specific weather and road conditions information originating from CVs. Figure 7 shows how connected vehicle data can improve both spot-specific warnings as well as area-wide advisories.

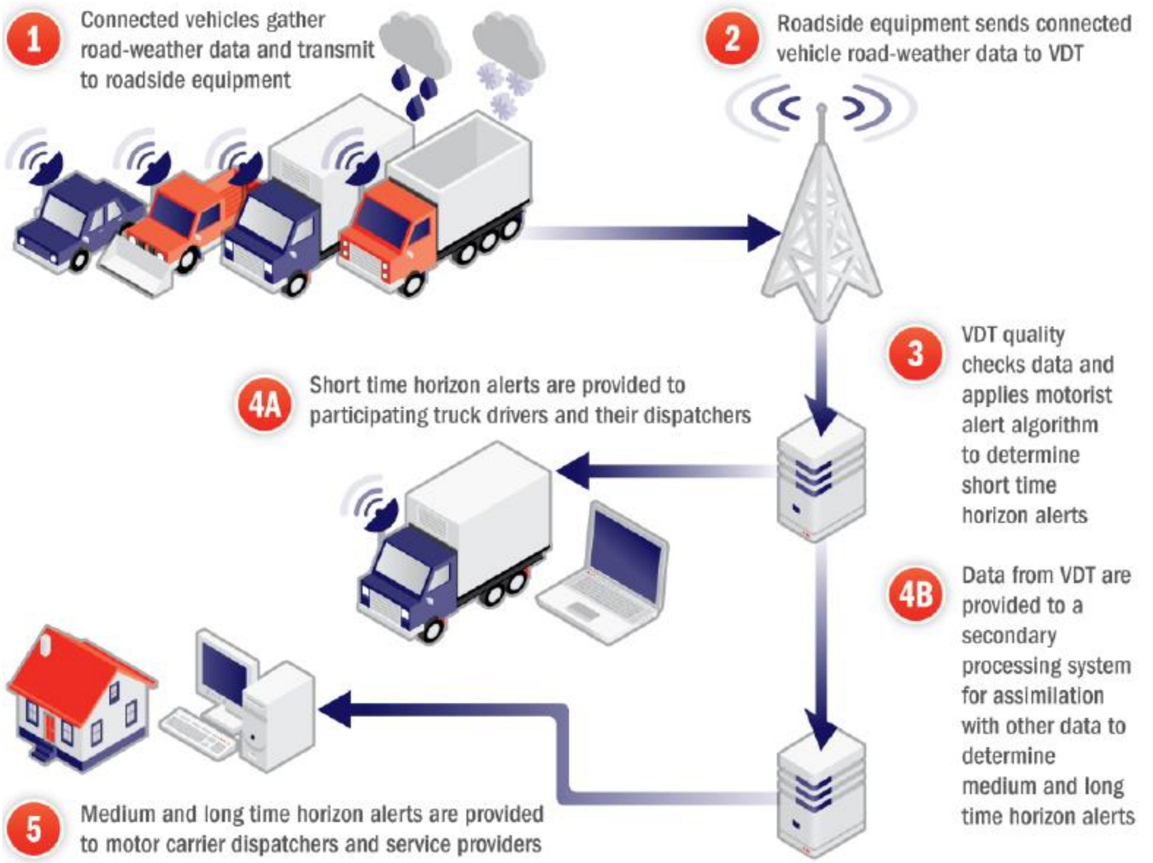


Source: FHWA

Figure 7. Schematic of a motorist advisory and warning system for road weather.

Information for Freight Carriers

Like the previous application, the ability to gather road weather information from CVs will significantly improve the ability of freight shippers to plan and respond to the impacts of severe weather events and poor road conditions in the short, mid, and long term periods. Figure 8 shows the schematic of the concept of operations (ConOps) for CV-enabled freight operations.

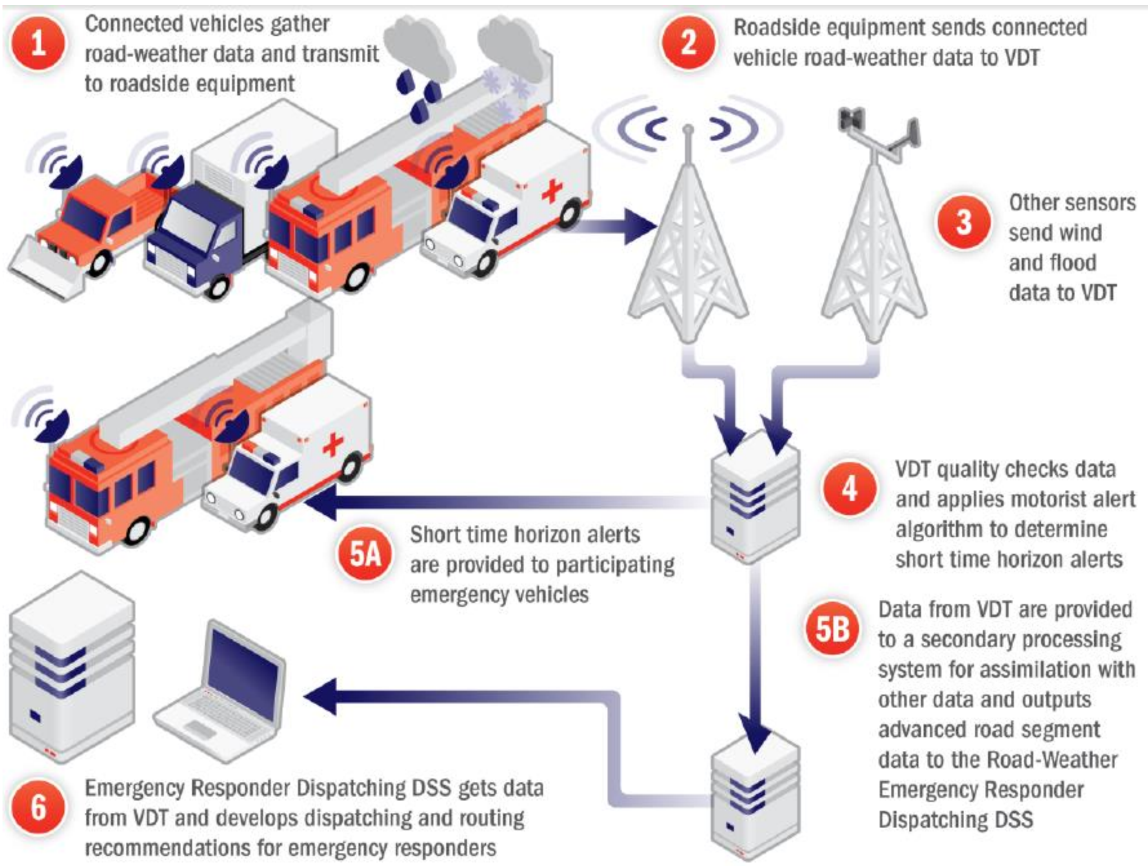


Source: FHWA

Figure 8. Schematic of road weather advisory and warning system for freight carriers.

Information and Routing Support for Emergency Responders

Location-specific, low latency road weather information from CVs combined with other surface weather observation systems can be used to determine response routes, calculate response times, and influence decisions to hand off an emergency call from one responder to another in a different location, as shown in Figure 9.



Source: FHWA

Figure 9. Schematic of road weather emergency responder dispatching decision support system.

Wyoming Department of Transportation's Connected Vehicle Pilot Program

The WYDOT CV Pilot Deployment Program is intended to develop a suite of applications that utilize vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technology to reduce the impact of adverse weather on truck travel in the I-80 corridor. These applications support a flexible range of services from advisories, roadside alerts, parking notifications and dynamic travel guidance. Information from these applications is made available directly to the equipped fleets or through data connections to fleet management centers (that will then communicate it to their trucks using their own systems).

Through the pilot, information about adverse road conditions, traffic congestion, and weather issues are made available directly and shared between equipped fleets. Information is also shared through linkages with fleet management centers (who will then communicate it to their trucks using their own radio systems). WYDOT hopes to improve safety and reliability on the I-80 corridor, especially during periods of adverse weather and when work zones are present. Through the anticipated outcomes of the pilot, fleet managers will be able to make better decisions regarding their freight operations on I-80, truckers will be made aware of downstream conditions and receive guidance on parking options as they travel the corridor, and automobile drivers will receive improved road condition and incident information through various existing and new information outlets.

These features will be realized by collecting and transmitting data (via dedicated short-range communication (DSRC) and other communication channels) from specially equipped commercial vehicles, specialty vehicles (e.g., WYDOT snowplows), and public fleet vehicles (e.g., highway patrol vehicles) on I-80. At a minimum, data collected from these vehicles include basic safety messages (BSMs) and environmental data on weather and road conditions.

Data gathered from the connected vehicles on I-80 will be ingested, quality-checked and used to generate localized alerts and advisories for truckers on the roadway which will be communicated to both fleet management centers, nearby State DOTs, general travelers as well as the connected vehicles via roadside equipment with DSRC connectivity.

Vehicle-to-Infrastructure Deployment Guidance

V2I communication is key when attempting to deploy a CV-enabled WRTM system, as it provides the capability to share detailed information with higher frequency and increased coverage. While V2V technology may provide situational awareness information and support safety-critical applications, applications that rely on V2I technology can be used to provide better advisories to the traveling public at locations upstream of the weather conditions. These may include parking availability, diversions, and other decisions that have value when presented at critical junctures on the route.

Federal guidance on effectively deploying roadside infrastructure that includes DSRC connectivity is now emerging.

Vehicle-to-Infrastructure Safety Applications

FHWA developed a ConOps and systems requirements for five V2I safety applications, and the underlying connected vehicle system for crash avoidance, for the USDOT. One of these applications was the spot weather information warning (SWIW) system.(30) The document describes the SWIW application as a cooperative vehicle and infrastructure system that assists drivers in avoiding crashes in areas prone to adverse weather impacts by warning the vehicle driver that a crash-imminent situation is possible, particularly in extreme situations where precautions are not taken, such as reducing speed or seeking an alternate route.

Weather-related Applications for Commercial Trucks

The federal efforts below have focused on developing applications for commercial vehicles, and road weather has been an important element of these projects.

Truck Vehicle-to-Vehicle Safety

Six applications were developed for commercial vehicles and demonstrated as part of the Safety Pilot project by U.S. DOT to showcase V2V safety.(2) Of these applications, the forward collision warning (FCW) and emergency electronic brake light (EEBL) are two pertinent applications for WRTM. Another application for curve speed warning (CSW) could potentially have weather-related applications as well, especially as road conditions may reduce safe traveling speeds on curves.

Freight Advanced Traveler Information System (FRATIS)

The FRATIS system is a part of the Dynamic Mobility Applications Program, which seeks to reduce the number of bobtail trips (i.e., empty trailers or trucks without trailers), terminal queue time, overall travel time, fuel consumption, and the level of pollutants and greenhouse gas equivalents.[(24)]

Among its several components, the system includes a routing, navigation, traffic, and weather (RNTW) components intended to provide real-time information on traffic changes, weather conditions, and incidents occurrence, allowing for real-time dynamic routing for each driver in conjunction with each work order. The premise for this component is that drivers will seek the fastest truck-appropriate route that avoids traffic and weather-related congestion, reducing the driver's travel and idle times.

The FRATIS pilot deployment was performed in the Dallas-Fort Worth region of Texas in March 2014. Given location-related effects—namely the lack of adverse weather and the drivers' detailed knowledge of primary and alternate routes—the benefits of providing RNTW services could not be measured in depth. However, participants recognized its value, especially for regional drivers that may travel to unfamiliar locations with more widespread and frequent adverse traffic and weather conditions.

Safety Pilot

The Safety Pilot Model Deployment Project is a USDOT effort in collaboration with the University of Michigan Transportation Research Institute and its partners to collect data to evaluate the deployment, security, interoperability, and scalability of V2I and V2V communications. The project supports the estimation of the effectiveness of V2V-based safety applications utilizing 5.9 GHz DSRC. The model deployment geographic area for this project is Ann Arbor, Michigan, and includes 73 lane-miles of equipped roadways with 29 roadside equipment boxes and 2,800 cars, trucks, and transit buses. The safety pilot had limited weather-related applications, but did test FCW and EEBL in both cars and trucks.

Weather Data Environment

WxDE was developed by the FHWA Road Weather Management Program (RWMP) to collect and share transportation-related weather data. The WxDE focuses on weather data related to connected vehicle applications. It collects data in real time from both fixed environmental sensor stations and mobile sources, and provides value-added enhancements to this data by computing quality-check values for observed data and computing inferred weather parameters from vehicle data (e.g., inferring precipitation based on windshield wiper activation). The WxDE archives both collected and computed data. It supports subscriptions for access to real-time data in near real time generated by individual weather-related CV projects.[3]

[3] The Weather Data Environment is available at: https://wxde.fhwa.dot.gov/.

The WxDE has entered a new phase where the focus of new development is on integrating functionality from the University Corporation for Atmospheric Research's (UCAR's) Pikalert® Vehicle Data Translator (VDT) system.[4] Key capabilities to be incorporated include:

- Ingesting weather and other operational data from vehicles and weather data including surface observations, radar, satellite, and model data.
- Performing quality checks on mobile observations referencing ancillary weather data from radar, satellite, RWIS and model analysis data using algorithms based on and potentially enhanced from the *Clarus* System.
- Mapping both ancillary weather data and mobile observations data to road segments.
- Forecasting untreated road weather conditions.
- Performing road hazard assessments based on both quality-checked observations and forecast data using special inference algorithms.
- Generating alerts on road segments.

The WxDE provides a foundational capability for testing algorithms and applications that use mobile data in a research environment. Of particular interest for WRTM is the ability to consolidate various mobile and fixed data sources and weather models to generate an assessment of current and forecast segment conditions.

STATE, LOCAL, AND OTHER INITIATIVES

Increased use of mobile observations will support a wide variety of strategic and tactical decision-making for State DOT maintenance and traffic operations. In a recent State DOT survey conducted for the RWMP with 40 State DOT responses, respondents were asked whether their agencies collect real-time field data from maintenance vehicles and from what percentage of the applicable fleets. Overall, 50 percent of States surveyed collect real-time field data from maintenance vehicles. The results of the survey show that collecting data fleet-wide is starting to become a practice; as many as three DOTs reported using 100 percent of the fleet to collect data, compared to zero in 2013.[(12)]

However, the same survey noted that some State DOTs (23 percent) have developed applications that input real-time data from vehicle fleets, but fewer (5 percent) have developed applications that utilize data derived from vehicle fleets and vehicle-to-infrastructure connectivity. However, there is much potential for growth as expressed by significant interest from States that are considering the use of cutting-edge technologies to develop applications (58 percent).

The following sections provide an update of State and local initiatives that relate to road weather management and connected vehicles.

[4] This analysis and subsequent development services are made possible through the use of the PIKALERT® system. Copyright © 2014, UCAR. PIKALERT is a trademark of the University Corporation for Atmospheric Research ("UCAR"). PIKALERT was developed with funding from the U.S. Department of Transportation under contract number DTFH61-08-C-00004.

Connected Vehicle Pooled Fund Study Research: 5.9 GHz Dedicated Short-Range Communications Road and Weather Condition Application

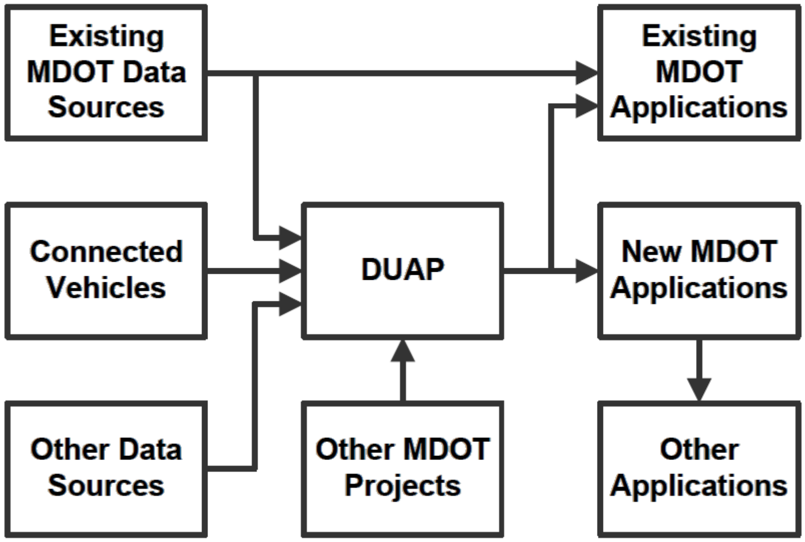
The Connected Vehicle Pooled Fund Study (CV-PFS) is a collaboration of State DOTs and the FHWA that leverages resources and avoids duplication of effort by joining forces on planning and research CV-related projects.

The CV-PFS funded a project to develop and test the collection of road and weather condition information from public agency vehicles using 5.9 GHz DSRC between the vehicles and the roadside. Hardware procured for the project included six DSRC on-board units (OBU), three DSRC roadside units (RSU), and two mobile road weather sensor units providing additional on-board road weather data gathering. The software developed in the project for the OBU can be configured to collect data from the vehicle's CAN bus, the aftermarket weather sensing device, and road treatment equipment (if present), in addition to the GPS. Data are transmitted to the DSRC RSU using IPv6 messaging and are stored as files on the RSU. Data can be retrieved from the RSU by agency network administrators and systems over a backhaul connection. Hardware and software developed in this project were provided to New York State DOT (NYSDOT) to support operation of snowplow trucks and HELP vehicles along and near the Long Island Expressway with monitoring and data retrieval through NYSDOT's INformation FOR Motorists (INFORM) system.(31)

Data Use Analysis and Processing

The DUAP system developed by Michigan DOT enables the use of data from connected vehicles throughout the road network, making it an essential component of MDOT's Wx-TINFO project.(20) The system itself collects, aggregates, processes, and provides interactive views of the connected vehicle data in a flexible manner that accommodates data of varying types, dimensions, and resolutions.

An example of the application of a DUAP system is illustrated in Figure 10. The DUAP system is implemented within Michigan Department of Transportation's (MDOT) current operational structure. The system draws data from existing MDOT data sources and other relevant data sources, stores those data, and applies algorithms to the available data—new and previous—in order to integrate it with connected vehicle data and, therefore, better support existing and new MDOT applications. The integrated system output can be returned to the existing MDOT applications as an enriched data stream or could be used in new applications for MDOT. Other MDOT projects may have influence on, or facilitate, the data integration. Applications outside MDOT may get data through a new MDOT gateway application.



Source: FHWA

Figure 10. Michigan Department of Transportation's data use analysis and processing data flows.

The DUAP system handles the heterogeneous nature of existing and potential data sources, such as Michigan Intelligent Transportation Systems Center's loop detector data (speed, volume, and occupancy at a particular time for each road loop), Chrysler test-fleet data (latitude, longitude, date/time, vehicle speed, ambient air temperature, barometric pressure, and front windshield wiper status), MDOT test fleet accelerometry data, and Android accelerometry data. The DUAP system allows the agencies to develop aggregated traffic performance measures and applications based on detailed CV data, such as segment-specific mean speed values, origin-destination studies, and pavement condition analysis.

RELEVANT PARALLEL EFFORTS

The following sections highlight relevant parallel efforts that may influence the adoption of connected vehicle technology for WRTM.

Connected Traveler Technology

As connected vehicle technology develops, advancements in the use of third-party applications are also growing. The following examples highlight developments that use the connectivity provided by smart phones for road weather management.

Waze Partnerships by State Departments of Transportation

State DOTs are getting involved in data sharing partnerships with Waze for its free navigation app that uses information from millions of drivers to "outsmart" traffic in real-time. This agreement entails a non-exclusive cross-license of their traffic data to each other with the objective of enhancing their individual ability to provide needed traffic information to the traveling public.

Waze is an app for iOS, Android, and Windows smart phones that computes real-time road conditions based on traffic data from local drivers that report traffic incidents, road hazards, construction sites and more. Furthermore, the drivers' GPS patterns help build and modify an up-to-the-minute accurate local map as they drive. This information is then used to calculate the fastest routes for any destination and help citizens avoid road congestion. At the time of its acquisition by Google in 2013, Waze had nearly 50 million users worldwide.(33)

Examples of States that have entered a two-way data-sharing partnership with Waze are Florida, Pennsylvania, Oregon, Kentucky, New York, California, Utah, Massachusetts, Maine, Vermont, New Hampshire, Iowa, with most of these agreements occurring in 2015. (See references 9, 10, 23, 4, and 6). An article noted that Vermont, New Hampshire, and Maine are using Waze to alert snowplow drivers as well.(16)

Other Smart Phone-based Applications for Road Weather

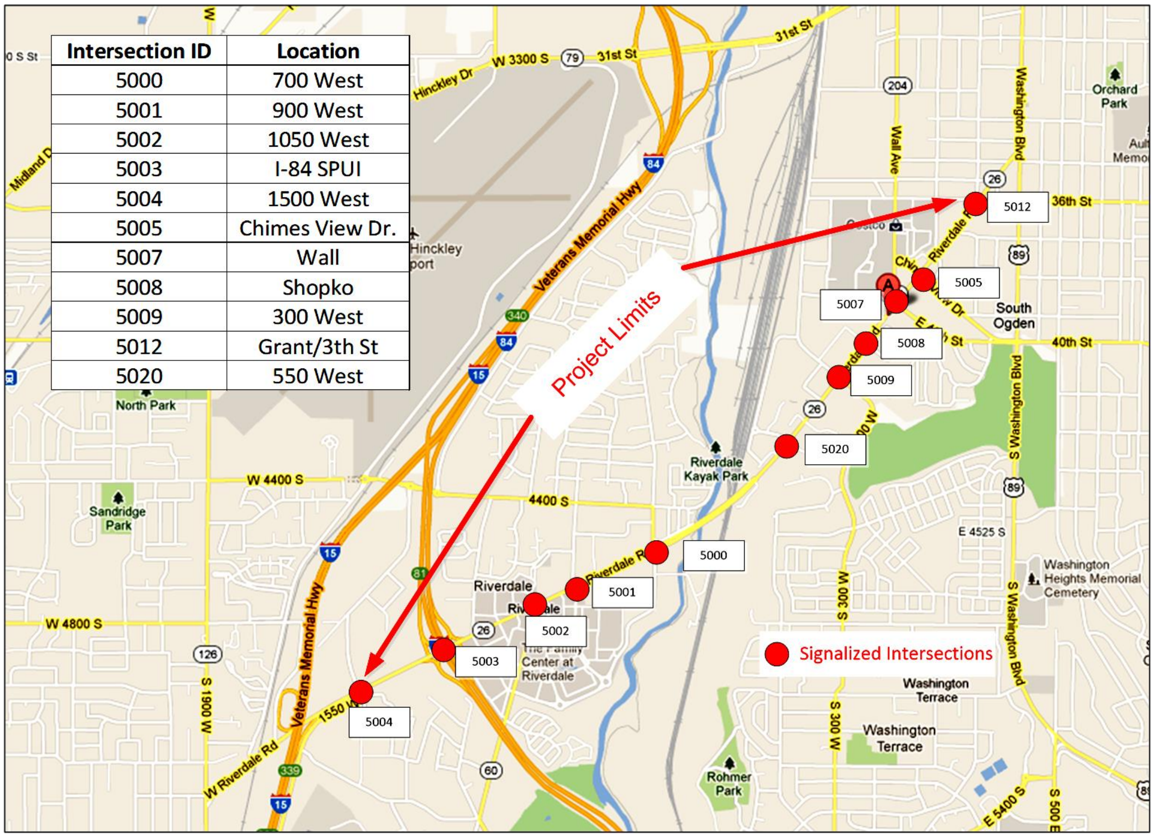
State DOT's in Utah, Wyoming, Idaho, Colorado and California have also developed mobile apps that disseminate weather and road conditions. Private companies like INRIX have also unveiled a road weather tool that reports road conditions based on crowdsourced information.(7) A new start-up company called Sfara uses smart phone-based sensors to automatically detect the user's movement and provide crash and roadside assistance.

Advances in Weather Responsive Traffic Management

In parallel to the developments in the connected vehicle world, developments in WRTM have also occurred. Some of the notable improvements in practice are described below.

Weather Responsive Traffic Signal Timing – Utah DOT (UDOT)

The primary goal of the Utah Weather Responsive Traffic Signal Timing project was to demonstrate that UDOT's traffic signal systems could be more responsive to changes in traffic demands and travel speeds during severe winter events. As part of this implementation project, UDOT developed and tested an advanced concept for expanding operations of weather responsive signal operations on the Riverdale Road corridor in Ogden, Utah. About 30,000 vehicles use this roadway during a typical weekday. Commercial activity in the corridor is significant with shopping areas on both sides of the road for large portions of the corridor.(1) A map of the project site is shown in Figure 11.



Source: FHWA

Figure 11. Schematic of Riverdale Corridor, the site for weather-responsive signal timing deployment.

UDOT deployed weather monitoring stations, advanced detection systems, and the signal performance metrics system to operate the corridor traffic signals in a weather responsive mode. During weather events, operators in the TMC were able to monitor both weather conditions and traffic performance in the corridor. As corridor travel speeds begin to drop and the percentage of vehicle arriving on the green phase began to decrease, operators in the TMC implemented new coordination timing plans t designed specifically to address deteriorating roadway and weather conditions. UDOT intended to achieve the following operational objectives as part of this deployment:

- Maintain a high level of progression on the main-street approaches throughout the duration of the weather event.
- Maintain an acceptable level of the throughput of traffic for the conditions of the roadway.
- Maintain equitable service to cross-street traffic during inclement weather events.

This project was designed, built, tested and evaluated in 2012. The evaluation was conducted during the winter of 2012-2013. The evaluation indicated improvements in UDOT's ability to respond and deploy signal timing adjustments during weather events to maintain high quality of progression, maximize signal system performance, and still maintain equitable service to the cross street traffic.

This WRTM strategy implementation allowed UDOT to understand the level of effort required to monitor the corridor during weather events, the nature and the frequency of adjustments to signal plans, and the required performance measurement tools to manage the system. The results of the evaluation are important for developing and implementing weather-responsive traffic signal timing strategies using CV data by any transportation agency.

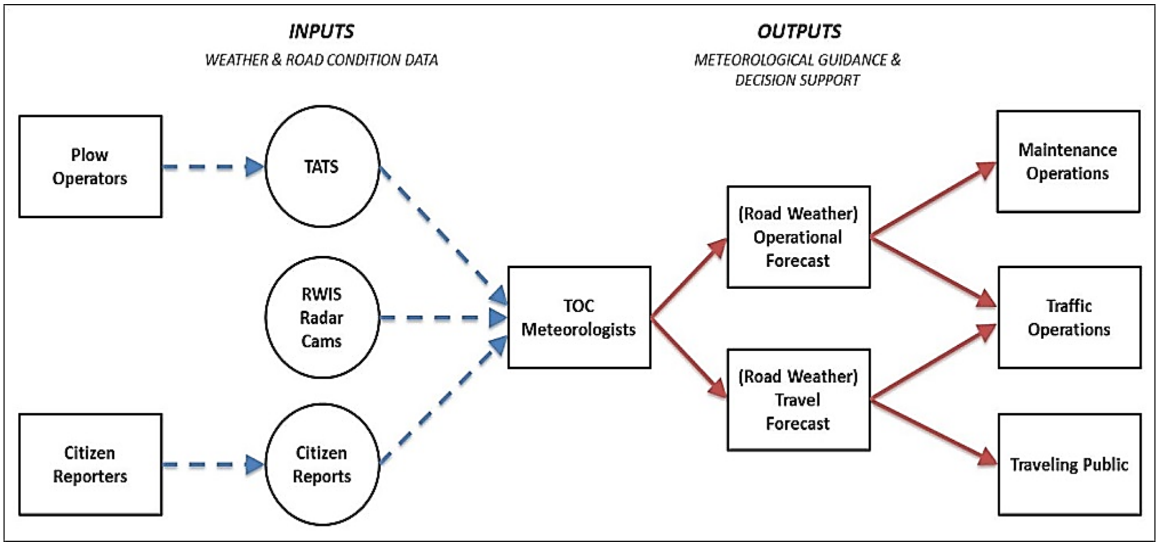
Weather Responsive Traveler Information System – Utah DOT

The primary goal of the Utah DOT Weather Responsive Traveler Information project was to provide both traffic operations center (TOC) operators and travelers with more accurate and timely road weather and travel impact condition information and forecasts. UDOT already had one of the most sophisticated TOCs in terms of how they obtain and integrate road weather information in traffic management decisions. The UDOT Weather Responsive Traveler Information System implementation project made significant operational improvements in the timeliness and accuracy of the information provided to travelers. Specific objectives were to:

- Develop and implement an initial citizen reporting system. This system used the current UDOT Traffic smart phone applications to allow citizens to report back to UDOT conditions on their roadways (for the initial system, a separate smart phone citizen reporting app was developed). The initial implementation included UDOT employees only—each reporter was trained on how to record observations and submit reports.
- Increase the frequency of weather forecasts from three future forecasts in 6-hour increments (18 hours total) to eight future forecasts in 3-hour increments (24 hours total).
- Provide road weather forecasts to six additional State routes of significance (US-191, US-89, US-189, SR-20, SR-210, and SR-190), in addition to the seven interstates and U.S. highways already receiving public forecasts.
- Make appropriate software changes to manage the additional data and forecasts and disseminate them to travelers using the UDOT Traffic website, 511 phone system, and smart phone applications.

Figure 12 illustrates the flow of weather and road condition data from the field, including citizen reporters, to UDOT TOC meteorologists providing forecasts for maintenance operations, traffic operations, and the traveling public.

This project was designed, built, tested, and implemented in 2012. The evaluation was conducted during the winter of 2012-2013. The evaluation indicated that citizen reports help fill observation gaps with accurate road condition information. UDOT operations will provide the public with increased road condition reports and forecasts, and the traveling public will perceive benefit from the information and make more informed travel decisions.[11]



Source: FHWA

Figure 12. Flow of information for the Utah Department of Transportation weather responsive traveler information system.

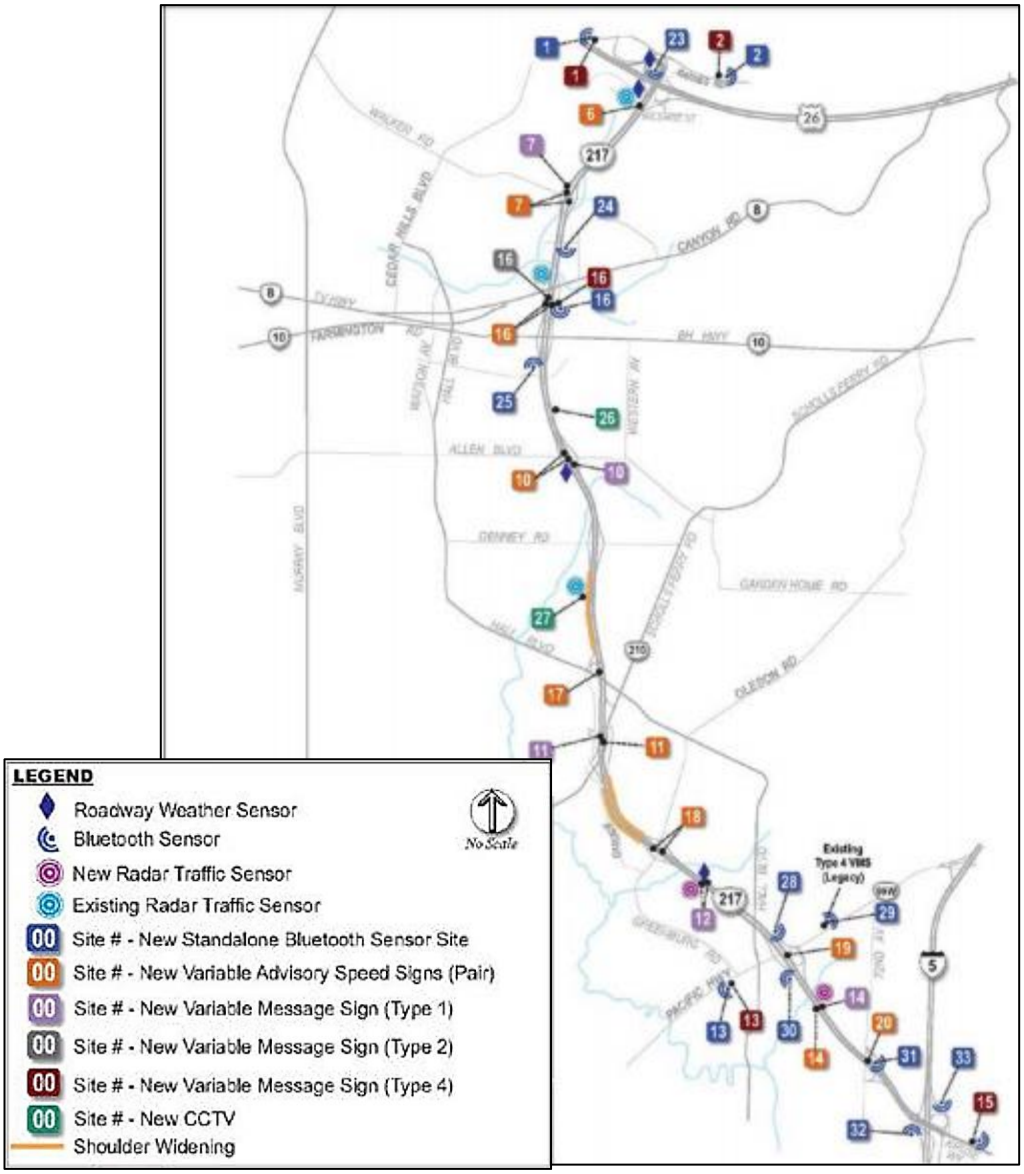
Since the project was completed in 2012, UDOT actively promoted the citizen reporting system and now has over 500 reporters across the state. This expansion is currently benefiting TOC operators and the traveling public by filling the information gaps and helping the DOT to better manage their highways during weather events and providing accurate current and forecasted road condition impact information to travelers.

Weather Responsive Variable Advisory Speed System – Oregon DOT (ODOT)

The purpose of the Oregon Route (OR) 217 active traffic management (ATM) project is to develop systems that improve safety and travel time reliability along the OR 217 corridor in Washington County, just outside Portland, Oregon. The VMS on OR 217 and on key arterial approaches provided travelers with estimates of travel time and information about incidents, the end of queues, and congested traffic conditions. Variable advisory speed signs alerted drivers to the recommended driving speed, based on current traffic and road weather conditions. Providing relevant and timely information means drivers make better decisions, safety is improved, and travel time is more reliable.(27)

OR 217 (Beaverton-Tigard Highway) is a 7.5-mile limited-access expressway between US 26 (Sunset Highway) and Interstate 5 (Pacific Highway) and is the major north-south route through the cities of Beaverton and Tigard in Washington County. The highway, which carries approximately 110,000 vehicles per day, often operates at or above capacity during the weekday peak periods. The traffic congestion and closely spaced interchanges contribute to a crash rate that exceeds the statewide average for this type of facility. OR 217 and the project extents are shown in Figure 13.

The OR 217 ATM project was composed of six systems that work together to address safety and reliability goals. These systems include travel time, queue warning, congestion responsive variable speed, weather responsive variable speed, dynamic ramp-metering and curve warning. These systems interact together and share much of the same physical and informational infrastructure. System information is obtained and exhibited through physical infrastructure. The OR 217 ATM system utilizes a robust set of sensors including Bluetooth, radar and inductive loop detectors to gather vehicle speed, occupancy and volume data along with roadway weather sensors to detect hazardous roadway conditions. This information is processed and distributed to the motorist by means of variable message and variable speed signs located throughout the corridor.



Source: FHWA

Figure 13. Oregon 217 advanced traffic management deployment site.

The system was evaluated to assess its effectiveness in managing traffic along the OR 217 corridor during weather events. Evaluation activities focused on safety and mobility improvements. The system became operational in July 2014 and the evaluation used data collected for one year through July 2015. A summary of the pertinent evaluation findings are as follows:

- The number of crashes decreased by 20.8 percent over the previous year.
- Throughput (number of vehicles passing through the corridor) increased by 5 percent during commute times.
- Corridor reliability improved with average delay times decreasing by 10 percent.
- Crashes dropped on ramps with new curve warning system signs from an annual average of 29.7 to 14.7. The signs activate when detectors sense hazardous wet, snowy or icy conditions. The signs are on three of the ramps linking U.S. 26 with OR 217.
- The number of crashes that resulted in a fatality or severe injury dropped from five to two (60 percent improvement).
- The number of rear-end and side-swipe collisions dropped by 18.6 percent.

Based on the success of this project and lessons learned, ODOT developed a ConOps for statewide variable speed limit system that includes a congestion-responsive subsystem, a weather-responsive subsystem, and an operator control subsystem. The ConOps defines both regulatory and advisory speed limit systems on rural and urban highways and interstates. It identifies seven statewide variable speed systems either in operation or under development; at least one in each of ODOT's five districts. It also describes guidelines for establishing variable speed zones, operational needs, system description, operational and support environments, and operational scenarios.

Integrated Road Condition Modeling and Prediction System

The increasing availability of traffic, road and weather data from traditional intelligent transportation systems (ITS), social media and connected vehicles will create tremendous opportunities for improving safety and mobility across all transportation modes and facility types. These data will not only provide a more complete and timely view of existing road conditions, but also create new potential for predicting future road and travel conditions. The FHWA Road Weather Management Program recently developed an integrated model for road condition prediction (IMRCP) to investigate and capture that potential.

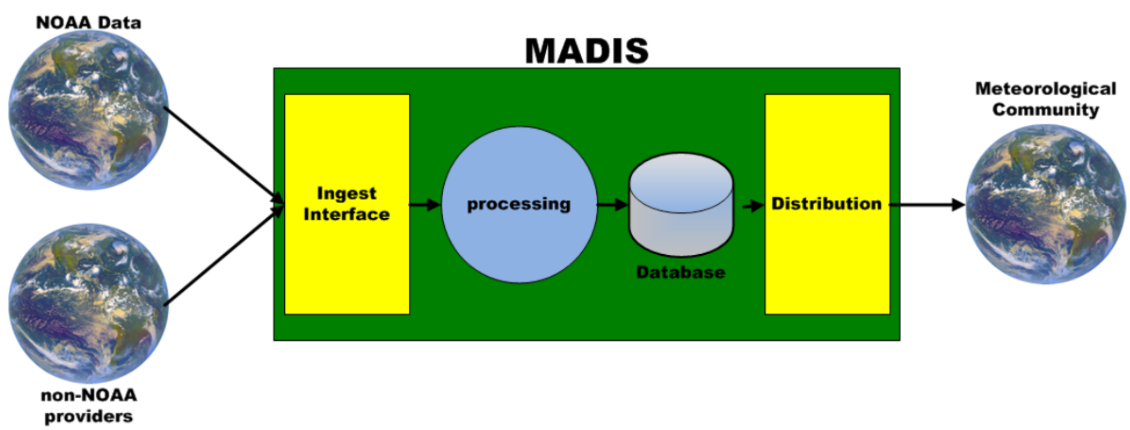
Transportation agencies have developed and expanded deployment of systems that gather road and weather condition information to support particular operational needs. Winter maintenance decision-support systems, for example, use information from roadside environmental sensing stations with meteorological forecasts to improve the treatment and clearance of roadways during winter storms. Operators in traffic management centers depend on traffic monitoring systems across their networks to provide data to support decisions n appropriate signal timing and ramp metering plans. It is less common, however, for data gathered to support particular operational functions to be shared or incorporated with other operational decisions, particularly those based on prediction of future operating states.

The goal of the IMRCP project is to investigate and produce a prototype prediction capability that considers operational impacts of road conditions across multiple disciplines and stakeholder perspectives including operations, maintenance, meteorology, emergency response, transit, commercial operations, and the traveling public. The system needs to assess and predict the impacts of traffic operations, weather and hydrological conditions, incidents, maintenance operations, work zones, and special events. The IMRCP system intends to factor in mobile data (from equipped vehicles) into the ensemble modeling framework developed as part of the project.

The Meteorological Assimilation Data Ingest System (MADIS)

The Meteorological Assimilation Data Ingest System (MADIS) was created in 2001 to prototype new data collection, integration, quality control, and distribution techniques for real time and archived data. The objective of MADIS is to integrate and check observations from the National Oceanic and Atmospheric Administration (NOAA) and other agencies to make datasets easily accessible and usable for operations, research, and commercial purposes.[19] The MADIS database is global and dates back to July 1, 2001 (though North America accounts for the highest spatial and temporal densities). NOAA data includes surface, wind, and maritime information from different meteorological surface stations (e.g., Climate Reference Network), radiosonde,[5] NOAA profiler network, hydrological surface, satellite wind, sounding and radiance, Weather In-Situ Deployment Optimization Method (WISDOM), and Rapid Update Cycle (RUC) Surface Assimilation Systems (RSAS). On the other hand, non-NOAA surface, wind, and maritime data is obtained from public and private sources, both within and outside the U.S., such as the Citizens Weather Observer Program, Road Weather Information Systems, and Multi-Agency Profilers. MADIS has an application program interface that allows the user to read and reformat the output files for easy upload into their systems or applications.

In summary, MADIS serves as a bridge between meteorological data and its users by ingesting data from different sources, decoding it, and finally encoding it again into a common format with uniform observational units and time stamps, all while controlling for quality of the data (see Figure 14).



Source: NOAA[25]

Figure 14. Meteorological Assimilation Data Ingest System operational framework.

This application supports WRTM efforts by providing an operational system that merges connected vehicle data with traditional weather and road condition information for use by application developers nationally. Developers can use MADIS data to build applications that are multi-jurisdictional and based on quality-checked data.

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[5] Radiosonde is an instrument lifted to various levels of the atmosphere and transmitting measurements by radio

Mobile Platform Environmental Data (MoPED)

Mobile Platform Environmental Data (MoPED) gathers vehicle and environmental data and shares them with MADIS, enabling location-based weather intelligence. The objective is to provide more frequent information of events that occur at the mesoscale level in order to improve situational awareness, which could affect risk assessment in travel decisions.(14) This tool allows NOAA to provide robust forecasts, watches, and warnings in areas that are usually un-sampled. Additionally, the mobile platforms can serve as confirmation/validation to radar imagery.

MoPED relies on information obtained from equipped commercial vehicles, such as those of the Con-way fleet,[6] as they travel major transportation routes (including state and local corridors), providing extent coverage through urban, suburban, and rural areas between the origin and destination points. The equipment takes meteorological observations every 10 seconds at a microscale level of spatial detail and transmits it in 1-minute intervals. In this sense, the use of mobile data from MoPED supplements fixed weather stations from airports and RWIS as it could detect small-scale phenomenon (e.g., thunderstorm or flash flood) that could occur between fixed station points. The information collected includes ambient air and pavement temperature, barometric pressure, relative humidity, precipitation, and light signatures, among others.

MoPED can be obtained from connected vehicles that support or feed into WRTM strategies but data collected from vehicles participating in the MoPED program can support WRTM applications as well.

[6] At the end of 2012, MoPED equipment was installed in roughly 1,450 Con-way vehicles.

Chapter 3. Road Weather Messaging Review

This section reviews currently used approaches for communicating and messaging related to road weather, and evaluates their effectiveness for weather-responsive traffic management (WRTM). The research involved keyword searches of relevant databases with an emphasis on recent information. The review also sought relevant information from other disciplines outside of transportation. The team reached out to the Transportation Management Center Pooled Fund Study members along with engineers, intelligent transportation systems (ITS) managers, and transportation management center (TMC) operators at State departments of transportation (DOT) via email and telephone to gather relevant information.

The following sections describe existing road weather messaging initiatives, emerging technologies and trends, and types and examples of road weather messages.

ROAD WEATHER MESSAGING INITIATIVES

Kansas City (KC) Scout Advanced Traffic Management System (Kansas and Missouri DOT's)

KC Scout is a comprehensive traveler information and traffic management center and is a joint effort of the Missouri and Kansas DOTs. To implement road weather messaging in the center, several road weather information system (RWIS) sensors were installed and National Weather Service warnings were integrated into the advanced traffic management system, and a library of approved VMS severe weather message sets were added to the list of messages along with an expansion of the internal/external traveler information output.

Nancy Powell, a supervisor at KC Scout, said in an interview on February 26, 2016, that one challenge faced by their center is lack of data on the benefits and usefulness of the weather messages displayed on their variable message signs (VMS).[7] Another challenge is deciding when to provide information in advance of a storm- sometimes predicted storms do not result in travel and safety problems initially anticipated, and TMC operators do not want to "cry wolf." Weather information is also relatively low priority for VMS displays, so it is usually pre-empted by collision or lane closure information if incidents occur during the storm.

A mobility survey conducted in the spring of 2015 gathered driver feedback about preferred ways to receive real-time pre-trip and en route traffic information. Survey results indicated that before making their trips, drivers preferred to use the KC Scout website map and mobile app. While en route, VMS was the preferred means drivers used for obtaining real-time traffic information. The

[7] Interview with Nancy Powell, KC Scout.

survey also asked drivers about the information they would like to see on VMS. Drivers ranked VMS messages in the following order of importance:

1) Incident and lane closure information.
2) Roadwork information.
3) Weather information.

Dual Use Safety Technology (DUST) Severe Weather Warning System (Arizona DOT)

The Arizona DOT DUST Warning System was developed to help mitigate road weather management challenges along I-10. The primary focus of DUST is visibility hazards caused by blowing dust on a 60-mile portion of I-10 between Bowie, Arizona, and the New Mexico State line. A secondary focus is unexpected snow and ice on the Texas Canyon portion of I-10.

The warning system includes static signs (with and without flashing lights) triggered by high winds, highway advisory radio (HAR) with pre-recorded messaging, and VMS. The system has the ability to send alerts based on weather sensor data to subscribed email addresses to alert law enforcement or highway operations staff of potentially hazardous conditions.

Bill Harmon, District Engineer at Arizona DOT Southeast District, said in an interview on February 25, 2016 that their implementation challenges included minimizing the burden or workload for the public with messages delivered by the system, and to ensuring that the information is accurate. These challenges were overcome partly through a simple messaging approach that delivers messages such as “High Winds, Dust Possible.”[8] Anecdotal evidence indicates that people preferred the custom-written DMS messages to the automated emails.

Washoe and Pleasant Valley Wind Warning System (Nevada DOT)

The Washoe and Pleasant Valley Wind Warning System includes a wind specific HAR system, flashing beacons added to static signs, and lane restrictions on I-80 in Washoe Valley. The system, largely targeted toward drivers of high-profile vehicles, is currently being updated and will have 33 static flashing-beacon signs. Under high wind conditions, signs will inform high-profile vehicle drivers to tune to the HAR station and possibly exit in advance of the road section experiencing high winds.

A 2011 evaluation of the wind warning system prior to the system updates found that 75 percent of survey respondents felt that the system was necessary for safety.[9] The survey also found that some commercial vehicle drivers ignored the warnings because they felt the wind speed threshold of 35 mph was too low and not indicative of a real threat. Additionally, the alternative route around the high-wind area requires a much longer travel time. To increase confidence in the system, Nevada DOT increased the warning threshold to 50 mph. The system also provides definitions of high profile vehicles on the signs themselves, since drivers are not always aware which vehicles are subject to the warnings.

[8] Interview with Bill Harmon, ADOT.
[9] Interview with Jae Pullen, NDOT.

Snoqualmie Pass Traveler Information System (Washington State DOT (WSDOT))

Snoqualmie Pass is a high mountain pass on I-90 about 50 miles east of Seattle. At an elevation of 3,000 feet, the pass is prone to severe snow (often more than 400 total inches of snow per year) that can make the roadway dangerous or impassable.

In 2011 WSDOT began providing information to drivers on its website, smart phone app, and on travel time signs on I-90. The website (www.wsdot.com/traffic/passes/snoqualmie/) provides travel times for the 74-mile stretch of mountainous terrain as well as a color-coded traffic map with live traffic cameras and additional information on current weather and road conditions, forecast, and travel restrictions. Roadside travel time dynamic message signs (DMS) are also present on the approaches to the mountainous sections of Snoqualmie Pass.(29)

EMERGING TECHNOLOGIES AND TRENDS

New and emerging technologies have the potential to revolutionize the collection, transmission, and delivery of information to travelers and transportation managers. While these changes will have broad implications for the transportation system, this chapter will focus on implications for WRTM.

For decades, agencies have installed sensors and cameras along highways to gather data about traffic volume and speed, precipitation, temperature, wind speed, etc. The value and cost-effectiveness of these sensors tended to increase as improvements in technology resulted in improved accuracy, reliability, connectivity, and reduced cost.

While developments in sensor and camera technology have been largely incremental, connected vehicle (CV) technology represents a leap forward. CV technology and applications are still in the development and research phase, so the potential functions and benefits have not been realized. Nonetheless, architecture is being developed to help organize and standardize CV applications. The Connected Vehicle Reference Implementation Architecture (CVRIA) is an effort overseen by the U.S. Department of Transportation (USDOT) in cooperation with various stakeholders to define a common language and early deployment concepts for CV (https://local.iteris.com/cvria/html/about/architecture.html). The CVRIA currently lists 100 CV applications within the Environmental, Mobility, Safety, and Support categories. The CVRIA includes six applications under the Road Weather subcategory, including providing information for emergency responders, for freight carriers, for maintenance and fleet management systems, and for the general public; a maintenance decision support system; and variable speed limits for WRTM. Within the vehicle-to-infrastructure safety subcategory, the spot weather impact warning application "will alert drivers about unsafe conditions or road closure at specific points on the downstream roadway as a result of weather-related impacts, which include, but are not limited to high winds, flood conditions, ice, or fog."[10] Other CV applications such as signal phase and timing

[10] Office of the Assistant Secretary for Research and Technology (OST-R), ITS Joint Program Office, *Connected Vehicle Reference Implementation Architecture*, "Spot Weather Impact Warning," available at: http://www.iteris.com/cvria/html/applications/app74.html

are not specific to WRTM, but are highly relevant. Additional information about each application is available at http://www.iteris.com/cvria/html/applications/applications.html.

Dedicated short-range communication (DSRC) devices that enable CV allow direct, real-time wireless communication between vehicles and infrastructure, and provide the capability to automatically control infrastructure (e.g., signal phase and timing adjustments, automatic DMS activation) in response to conditions. Each CV-equipped vehicle will transmit information about its location, movement, and other metrics, and these data can be used to calculate relevant information about traffic flow, congestion, incidents, etc. CV information can also be relayed to traffic managers in real time, giving TMCs more timely, more detailed, and more complete data on the roadway network than has been available in the past.

While CV has great potential to improve the collection and transmission of roadway and weather data, the real key to the success of CV is how to present and use that data. Various stakeholders may have very different needs. TMC operators may need information about transportation system performance or about specific incidents or locations. They may need to know snowplow locations and routes. Emergency responders may need to know a passable route to an incident location during a weather emergency. The traveling public in general may need to know the best and safest routes and hazardous locations to avoid.

CV can continue to be compatible with traditional messaging systems such as DMS, HAR, websites, etc., but a major trend that has been emerging before the development of CV systems is personalized information delivered directly to individuals. In the fairly recent past, drivers on the road typically could only get traffic information from commercial radio stations, HAR, or perhaps DMS. With the widespread adoption of smart phones, however, drivers now have access to navigation apps with real time traffic conditions (e.g., Google Maps), crowdsourced incident and condition reporting (e.g., Waze), social media (e.g., traffic/weather alerts from government entities via email, text message, Twitter, etc.), and even weather websites or apps (e.g., The Weather Channel, Weather Underground). These sources can provide drivers with personalized information on demand or when significant events occur without the need for location-specific and expensive messaging systems such as DMS. It is important to note, however, that site-specific messaging systems will still serve a purpose, especially in locations where weather events predictably occur repeatedly in the same location (e.g., high wind corridor, snowy mountain pass). This is a trend that is likely to continue with the adoption of CV.

While CV technology has not yet rolled out broadly, there have been many research efforts and pilot implementations conducted to determine how best to capture and utilize weather information using CV, mobile sensors on vehicles (including vehicle controller area network (CAN)-bus data), and stationary sensors. This research and the technological underpinnings of the applications are reviewed in Hammit and Young (2015). Hammit and Young also conducted new research investigating the feasibility of supplementing current WRTM data with CV data. The study found that data collected from the vehicle CAN-bus and transmitted via CV can be used to inform weather alerts and variable speed limits in rural areas. However, given that CAN-bus data sets are largely proprietary and vary in structure across vehicle makes and models, it is not currently feasible to implement an off-the-shelf CAN-bus reader technology. Federal requirements for standardization of some aspects of CAN-bus data might make this more feasible in the future.

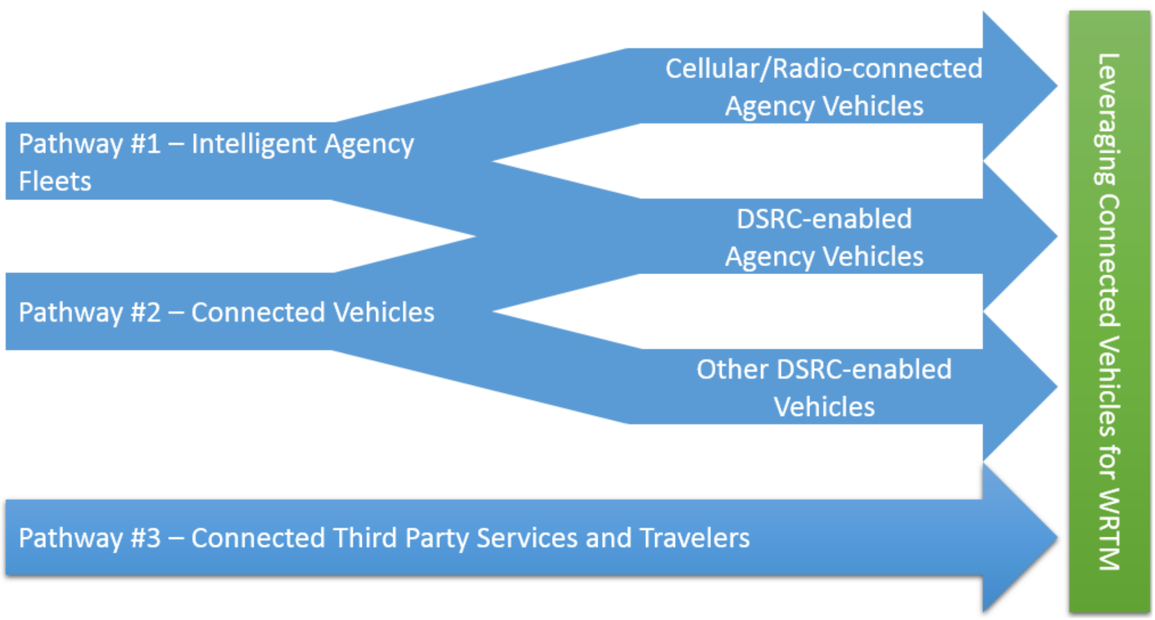
MESSAGE TYPES AND EXAMPLES

Table 10 in Appendix A lists the different types of messages, organized by dissemination method, that provide WRTM information to the public. In addition, the top row of the table provides example guidance for message construction and dissemination.

The table provides examples of weather-related messages, alerts, warnings, and notifications provided to the public. These messages provide drivers with information about current, on-road driving conditions as well as potentially dangerous future driving conditions so that they can be informed about upcoming weather hazards.

Chapter 4. Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management Strategies

The *Guidelines for Deploying Connected Vehicle-Enabled Weather Responsive Traffic Management (CV-WRTM) Strategies (FHWA-JPO-17-478)* helps State departments of transportation (DOT) clearly identify the steps they need to take to move towards CV-WRTM implementation. The document provides high-level guidelines on advancing these strategies through three distinct but related implementation pathways. The pathways, shown in Figure 15, are not mutually exclusive, and all lead to the same end. They build on each other, and each pathway provides unique value to potential system deployments. Furthermore, effectively using connected vehicle technology for WRTM requires new capabilities, partnerships, and agreements, as well as the improvement of existing technology, regardless of the pathway followed.



Source: FHWA

Figure 15. Supportive pathways for connected vehicle-enabled weather responsive traffic management.

PATHWAY 1 – INTELLIGENT AGENCY FLEETS

Overview

This pathway connects the agency's fleets to support WRTM strategies, typically targeting vehicles that are frequent users of the roadway during adverse weather conditions, such as snowplows, highway patrol vehicles, and maintenance vehicles. Building on the voice/radio connectivity that exists today, this pathway adds significant data collection and reporting capabilities, which can support WRTM.

Table 1 identifies a potential implementation roadmap for intelligent agency fleets. At the basic and intermediate levels of use, agency fleets rely on cellular, Wi-Fi hotspots, or agency-owned radio networks to transmit the data. At these levels, agencies can collect a wide variety of weather, road weather, and road condition data and share it back to a management center when connectivity is present. At the advanced level, another communication modality, dedicated short-range communication (DSRC), is introduced. DSRC enables communication between equipped vehicles and appropriate roadside equipment (which can then back-haul the data to the management center). At this level, the pathway merges with Pathway 2 (see Pathway 2 – Connected Vehicles) for agency vehicles. Note that Pathway 2 may include non-agency vehicles.

Table 1. Implementation Roadmap for Pathway 1 – Intelligent Agency Fleets.

Basic	At a minimum, the following fleet-related elements are required to begin the evolution toward connected vehicle-enabled weather responsive traffic management: • Automatic vehicle location. • Remote communication through cellular links and/or through agency-owned radio channels. • Able to share both voice and data. • Snowplows can report some basic and aggregated core maintenance data some in real time, others not. Core maintenance data include: plow up or down, material usage tracked at high-level corridor segments, general material usage status information (e.g., Full/Empty). • Operator reports subjective information on both road weather and vehicle condition to the agency through radio/cellular.
Intermediate	As the sophistication of agency grows, the following elements can be added to the fleet platforms: • External environmental sensors that collect and report atmospheric and road weather conditions. • Interfaces for drivers that enable electronic reporting of road condition (as opposed to voice reports). Drivers also receive alerts and advisories through this interface. • Ability to capture and transmit images of road condition. • Connection to the vehicle network to collect vehicle status data.

Advanced (merges with Pathway 2)	Lastly, the addition of dedicated short-range communications (DSRC) in fleets enables communication not only with the transportation management centers but also with other equipped vehicles. At the very minimum, DSRC-enabled agency fleets will be able to: • Broadcast basic safety messages (Part I). • Broadcast probe data message which compiles various vehicle status and environmental information. • Receive traveler information messages.

Source: FHWA

Weather ResponsiveTraffic Management Applications Supported

Pathway 1 supports a wide variety of weather responsive traffic management strategies in use today. Table 2 summarizes the nature of applications enabled by this pathway.

Table 2. Application Supported by Pathway 1.

Basic	Basic data from connected agency fleets can support: • Weather-responsive traveler information – Improve notification of road conditions on dynamic message signs and 511 Systems. • General improvements in maintenance tactics and treatment strategies.
Intermediate	Intermediate data from connected agency fleets can support: • Weather-responsive active traffic management – Improve activation of traffic management strategies such as variable speed limits, vehicle restrictions, road closures. • Weather-responsive traffic signal control – Advanced traffic coordination strategies using data from connected fleets. • Enhanced maintenance decision support system.
Advanced (merges with Pathway 2)	In addition to the applications listed above, advanced data from connected agency fleets can support: • Spot weather impact warnings. • Vehicle-to-vehicle applications (such as forward collision warning, electronic emergency brake light).

Source: FHWA

Institutional Issues

Institutionally, agency-owned fleets offer a clear opportunity to move toward CV-WRTM. In fact, the connectivity of agency-owned fleets is expected to grow to support better maintenance practices. However, certain institutional issues should be addressed as the agency proceeds with this pathway.

- **Ensuring an effective data sharing arrangement between various groups within the agency.** Institutionally, the data coming from vehicles should be managed to support the needs of both maintenance and traffic operations.
- **Ensuring driver support and buy-in of technology**. Snowplow drivers and other fleet drivers have an important and difficult job during adverse weather. Ensuring that any on-board equipment and interfaces are designed with their needs in mind is essential.
- **Making a business case for DSRC connectivity in agency fleets**. Institutionally, the case for connectivity with agency fleets is clear. Direct connections with drivers enable more proactive management of the roadways, and having real-time data from the field enables improved notification to travelers. At this point, the business case for adding DSRC connectivity to agency fleets is still not clear. Emerging evaluations from the early connected vehicle (CV) adopters (US Department of Transportation (USDOT) CV Pilot grantees, other State DOTs pursuing CV technology) will provide this business case.

Constraints and Challenges

Some of the constraints and challenges in this pathway include:

- **Age and diversity in agency vehicle fleets** – Vehicle fleets at agencies turnover very slowly, and different procurement processes over time can result in a diverse fleet mix with different makes and model years. This diversity complicates any adoption of on-board equipment, requiring a careful analysis of installation, wiring, communication, and integration with the vehicle network.
- **Proprietary interfaces of legacy systems and vehicle networks** – Existing legacy systems on fleets such as AVL and sensors for material management are typically proprietary, and interfacing to them can be challenging when new on-board equipment is procured.
- **Limited ability to grow fleet size** – With this pathway, agencies are limited by the vehicles they own. On the positive side, these vehicles are likely to be on the roadway when needed most. However, advanced applications that utilize DSRC benefit from numerous vehicle-to-vehicle (V2V) and vehicle to infrastructure (V2I) interactions. More vehicles on the roadway reporting data also improves situational awareness of conditions.

Performance measures

Performance for this pathway can be measured by the improvements of traditional WRTM advisory, control and treatment strategies using data collected from fleets. Table 3 list some potential measures for this pathway classified into system performance (i.e., those that related to the CV system) and impact (i.e., those that relate to the impact of the CV system on the end-users, both operators and drivers).

Table 3. Potential performance measures for Pathway 1.

Performance Measure Category	Potential System Performance Measures for Pathway 1
Road weather data collection	Number of road weather condition reports (quantity).
	Miles of road weather condition reports (coverage).
	Refresh time of road condition reports (latency).

Performance Measure Category	Potential System Performance Measures for Pathway 1
Generation of alerts/advisories	Percentage of system generated alerts/advisories accepted by operators.
Dissemination of traveler information	Number of updated traveler information reports and updates to intelligent transportation system (ITS) devices.
	Staff time to process road weather condition reports and update traveler information and ITS devices.
	Qualitative improvements in traveler information.
Project outcomes	Greater compliance of measured vehicle speeds compared to posted speed.
	Reductions in vehicle speed variation.
	Reductions in crash rates and crash severity.

Source: FHWA

System Development Guidelines

System development for this pathway usually begins with a concept of operations document and then follows a system engineering process for requirement specification, design, procurement, testing and acceptance.

Some key considerations for system development include:

- **Communication costs need to be factored in early** – Data costs quickly add up as fleets become connected. Existing constraints, budgets, and policies for managing communication costs must be discussed early and factored into the system design.
- **On-board connections between different systems** – In-vehicle connectivity between systems that rely on Bluetooth or Wi-Fi connectivity need to be tested to ensure reliable communications from the various sensors and the on-board unit.
- **Data Capture and Management –** The system development should consider subsystems that collect, aggregate, process, quality-check, and provide interactive views of the connected vehicle data in a flexible manner that accommodates data of varying types, dimensions, and resolutions.

PATHWAY 2 – CONNECTED VEHICLES

Overview

As defined earlier, a connected vehicle can transmit and receive Basic Safety Messages (BSM) using the ITS band of 5.9 GHz (5.85 – 5.925 GHz). In addition to the connected fleets in Pathway 1, this section focuses on the role of private connected vehicles that are anticipated in the future for supporting WRTM.

The following sections from USDOT's Connected Vehicle Basics website[11] provide the context for the pathway:

- The USDOT notes that "NHTSA (National Highway Traffic Safety Administration) aims to deliver a Notice of Proposed Rulemaking on V2V communications technology for light vehicles—however, there is no specific date for this.[12] Equipment suppliers have indicated that they could have an adequate supply of readily available, mass-produced, internal components for a V2V device approximately 2.5 to 3 years after NHTSA moves forward with some type of regulatory action."
- Since 2002, the USDOT has been engaged in research with automotive manufacturers on V2V crash avoidance systems that use very high-speed wireless communications and vehicle positioning technology. In 2006, the USDOT joined Crash Avoidance Metrics Partnership (CAMP), a partnership of automotive manufacturers, to develop and test prototype V2V safety applications. The overarching goal was to determine whether this technology would work better than existing vehicle-based safety systems, like adaptive cruise control, to address imminent crash scenarios. CAMP includes Ford, General Motors, Honda, Hyundai-Kai, Volkswagen, Mercedes-Benz, and Toyota.
- V2V communications represent an additional step in helping to warn drivers about impending danger. V2V communications use on-board dedicated short-range radio communication devices to transmit messages about a vehicle's speed, heading, brake status, and other information to other vehicles and receive the same information from the BSM messages, with range and "line-of-sight" capabilities that exceed current and near-term systems—in some cases, nearly twice the range. This longer detection distance and ability to "see" around corners or "through" other vehicles help V2V-equipped vehicles perceive some threats sooner than sensors, cameras, or radar can, enabling them to warn their drivers accordingly.
- Connected vehicle technology also enables vehicles to exchange information with infrastructure, such as traffic signals, through V2I communications. V2I communications help to extend the benefits of connected vehicles beyond safety, to include mobility and the environment.

V2I deployment is not mandated and is not part of the NHTSA advanced notice of proposed rulemaking which focuses on the V2V communications. However, V2I deployment provides a real opportunity to address one of the main challenges of WRTM: how to communicate with en route travelers beyond current fixed solutions like dynamic message signs (DMS) and highway advisory radio (HAR). In a report on V2I deployment, the Government Accountability Office projected the long-term horizon for V2I and V2V deployment as shown in Figure 16.

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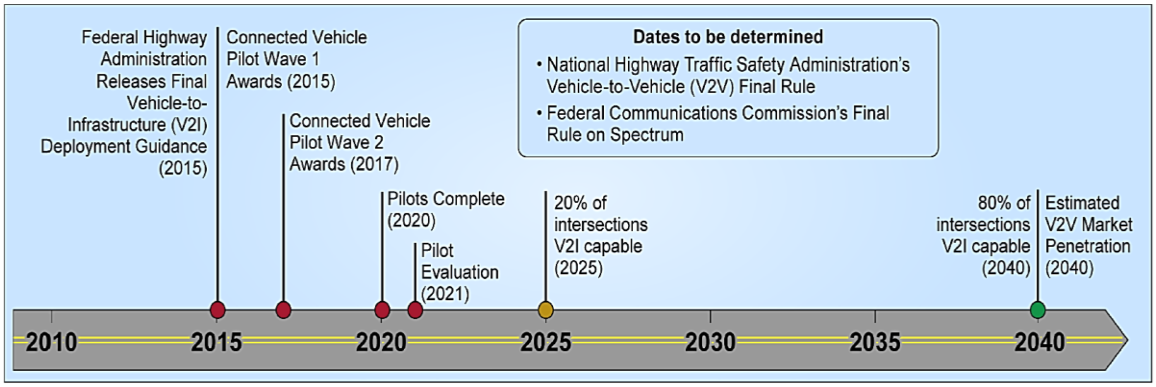
[11] Available on the ITS-JPO website, http://its.dot.gov/cv_basics/index.htm

[12] According to the official statement made on November 8, 2017 (https://www.nhtsa.gov/press-releases/v2v-statement)



Source: GAO[13]

Figure 16. Deployment horizon for V2I technologies.

Table 4 identifies a potential implementation roadmap for leveraging the anticipated DSRC connectivity in light vehicles in the next 3-5 years for WRTM. Note that there are broader applications of V2I deployment for general traffic management and operations that are not included in the table.

Table 4. Implementation Pathways for vehicle-to-infrastructure deployment for weather-responsive traffic management.

Basic	Agency installs DSRC-enabled roadside equipment (RSE) along key interstate hotspots for spot-specific active warning on road conditions. RSEs will support communications for localized alerts (curve speed warnings, situational awareness messages for visibility, road conditions, etc.).
Intermediate	In addition to the basic development, the agency uses RSEs to manage control strategies like variable speed limits and vehicle restriction warnings along priority corridors during weather events.
Advanced	In addition to interstate highways, agencies have connected intersections along the key corridors for Signal Phase and Timing (SPaT) and intersection movement assist applications and have developed weather-responsive algorithms.

Source: FHWA

Weather ResponsiveTraffic Management Applications Supported

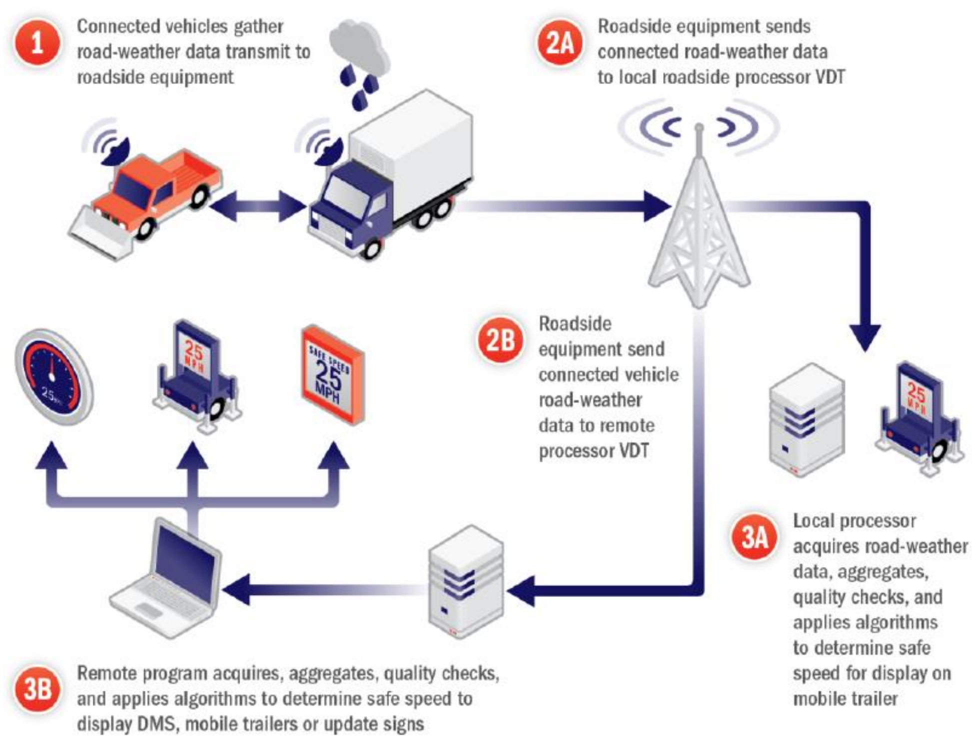
CV environment enables a wide variety of new and modified strategies that provide advisory, control and treatment recommendations to highway operations. The Connected Vehicle Reference Implementation Architecture (CVRIA) provides the following applications directly related to weather:

- Road Weather Information and Routing Support for Emergency Responders.
- Road Weather Information for Freight Carriers.
- Road Weather Information for Maintenance and Fleet Management Systems.
- Road Weather Motorist Alert and Warning.
- Variable Speed Limits for Weather-Responsive Traffic Management.
- Spot Weather Impact Warning.

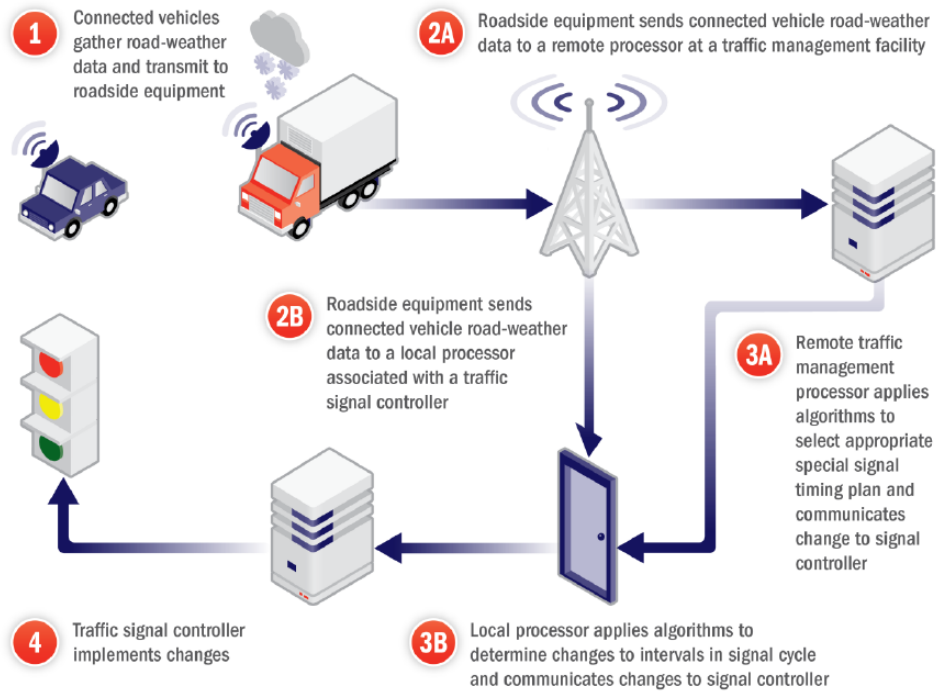
In addition, the following applications could be used during weather events to support WRTM:

- Enhanced Maintenance Decision Support System.
- Freight-Specific Dynamic Travel Planning.
- Parking Availability.
- Do Not Pass Warning.
- Situational Advisory.
- Signal Phase and Timing.
- Curve Speed Warning.
- Reduced Speed Zone Warning / Lane Closure.
- Restricted Lane Warnings.

In 2013, the USDOT, through the Road Weather Management Program, developed a concept of operations (ConOps) to define the priorities for CV-enabled road weather management applications. Two connected vehicle systems ConOps were developed to enhance WRTM for: (1) variable speed limit (VSL) systems, dramatically improving safety during severe weather events and (2) signalized intersections, to optimize signal system performance when severe weather affects road conditions. Both strategies expand current WRTM strategies for VSL and weather-responsive traffic signal timing to include connected vehicle data. (Figure 17).



a) Weather-Responsive Variable Speed Limit System

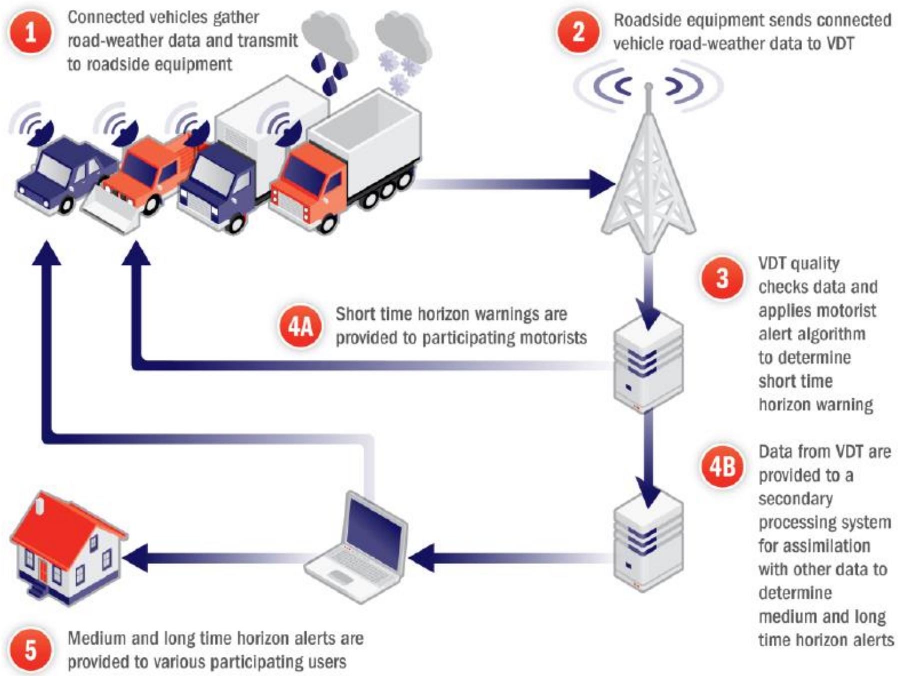


b) Weather-Responsive Signalized Intersection System

Source: FHWA.

Figure 17. Compound figure depicts schematics of weather responsive variable speed limit and signalized intersection systems.

Short-, mid- and long-term advisories can be made more accurate, and with increased coverage, using segment-specific weather and road conditions information originating from connected vehicles. As a third concept, Figure 18 shows how connected vehicle data can improve both spot-specific warnings as well as wide-area advisories.



Source: FHWA.

Figure 18. Schematic of road weather motorist advisory and warning system.

Institutional Issues

In this early phase of CV deployment, institutional issues are just emerging with more unknowns than solutions. The 2015 GAO study cited earlier noted,

> …there are a variety of challenges that may affect the deployment of V2I technologies including: (1) ensuring that possible sharing with other wireless users of the radio-frequency spectrum used by V2I communications will not adversely affect V2I technologies' performance; (2) addressing state and local agencies' lack of resources to deploy and maintain V2I technologies; (3) developing technical standards to ensure interoperability; (4) developing and managing data security and addressing public perceptions related to privacy; (5) ensuring that drivers respond appropriately to V2I warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I…[13]

As early deployers begin to transition to daily operations, additional issues may emerge, starting with the following:

- **Business case/benefit-cost of V2I deployment** – With the anticipated widespread penetration of DSRC-enabled vehicles several years away, agencies today are faced with a dilemma on the business case for investing in roadside equipment and application development. Costs of V2I deployment are still vague and based only on a few testbeds, and benefits of applications are not yet proven.
- **Evolution of V2I standards –** While standards development for CV technology is in full swing, early stablished standards are focused on V2V applications. V2I standards are still

in the development stages, as are certification approaches for the equipment. These make system procurement a challenge.

- **Understanding original equipment manufacturer (OEM) roadmaps and directions –** As agencies develop applications, it is unclear if OEM-installed equipment can appropriately process V2I messaging across the country. For example, if OEM-developed equipment is focused only on V2V communications (or can only receive BSMs), an agency's investment in traveler information messages may be unfounded.
- **Public perception, privacy, and liability issues –** While V2V is more easily described in terms of privacy protection, V2I creates a lot more privacy issues around the ability to trace vehicle paths, especially in low-volume scenarios. These concerns are largely addressed in CV technology deployments by the concept of "privacy by design" that is inherent with the DSRC messaging standards and the Secure Credential Management System (SCMS). CV applications that may need personally identifiable information (PII) by design, such as those involving financial transactions, have a higher level of concern. Privacy may also be an issue for deployments where individuals are recruited for research purposes. An operational deployment of WRTM applications is not likely to either need PII to ensure its effectiveness or require that users be uniquely identified.

The American Association of State Highway and Transportation Officials V2I Deployment Coalition is also a valuable resource and forum for the consideration of institutional and technical issues around V2I deployment.

Constraints and Challenges

There are several challenges associated with this pathway that need to be addressed as an agency moves forward with deployment.

- **Added expense of maintaining CV equipment –** RSUs represent another field device that needs to be managed at a service level commensurate with the applications that are being deployed.
- **Limitations in ability to build out roadside network –** While RSUs can be easily installed along facilities where power and communications are available, they may not be the best locations for applications. Some applications may require the installation of RSUs at strategic locations (such as port of entries, parking lots, key interchanges) where installations can be significantly more expensive.
- **Consistent messaging –** Today, road weather information is communicated differently by different agencies. Due to various typologies for road conditions and different criteria for alerts and advisories, a lack of consistent messaging becomes a fatal flaw when the need arises to communicate with on-board equipment in vehicles across the nation. Since OEMs are limited and the on-board equipment is going to adhere to certain standards, inconsistent use of standards may minimize the utility of V2I applications.
- **Emerging applications and standards can lead to early investments becoming obsolete –** Early system implementers face another challenge with rapidly evolving technology and equipment in this space. RSU specifications are evolving and so are on-board equipment standards.

- **Security –** New to the CV environment and previously not a major concern for WRTM, security and privacy concerns around both the data collected by the CV environment as well as physical and virtual security of the vehicles and RSUs need to be addressed.
- **Weather condition variability** – Weather related projects have unique characteristics that tend to challenge performance measurement activities. The variability of weather events and entire winter weather season presents challenges to application development and testing.
- **Driver behavior and CV-WRTM technology adoption** – New technology that requires change in the way people do things is always challenging. For a CV-WRTM system, a myriad of agency personnel may be affected: TMC staff, snowplow drivers, commercial vehicle truck drivers, commercial vehicle company dispatch center personnel, etc. How these stakeholders adopt the new technology and information that will be available is unknown; the lack of technology adoption and information use may affect the evaluation outcomes.

Performance measures

The performance of Pathway 2 can be measured using many of the performance indicators for Pathway 1. However, given the added complexity of the system, other system performance and overall project impacts/benefits need to be included. Although this will generally be project-dependent, Table 5 presents some potential CV-WRTM performance measures for Pathway 2 in addition to those for Pathway 1.

Table 5. Potential performance measures for Pathway 2 – Connected Vehicles.

Performance Measure Category	Description
Effectiveness of infrastructure-to-vehicle, vehicle-to-infrastructure, and vehicle-to-vehicle technologies	Percent of connected vehicles that took appropriate action following receipt of an alert. Appropriate actions may include: • Parked. • Reduced speed. • Came to a stop safely. • Detoured.
Implementation of traffic management strategies	• Increase in activation of WRTM strategies based on connected vehicle data. Strategies that may be affected include variable speed limits, vehicle road restrictions, and closures.
Project outcomes	• Number of connected vehicles involved in a crash. • Initial crashes. • Secondary crashes (total and specifically rear-end crashes).

Source: FHWA

System Development Guidelines

Guidance on effectively deploying roadside infrastructure that includes DSRC connectivity is emerging from FHWA. An growing list of guidance documents is available on the USDOT ITS-JPO website (https://www.its.dot.gov/v2i/).

PATHWAY 3 – CONNECTED THIRD-PARTY FLEET SERVICES AND TRAVELERS

Overview

As connected vehicle technology develops, the number of third-party providers who collect and distribute data from vehicles is growing. This pathway uses the connectivity provided by smart phones for road weather management, avoiding the necessity of DRSC communication equipment on the vehicles. Data from these third-party sources can provide information that is often difficult or costly for a public agency to collect. Furthermore, the Long Term Evolution (LTE) wireless standard for communications with which new vehicles are now equipped allows for alerts and warnings to be delivered directly to the vehicle using cellular communications instead of relying on smart phones carried in by the driver.[13] Table 6 shows the implementation roadmap for this pathway.

Table 6. Implementation roadmap for connected third-party fleet services and travelers.

Basic	At its most basic level, agencies receive information from third parties, but the information is limited to speed along traveled road segments.
Intermediate	Agencies receive a rich set of data from third parties. Different types of information become available in addition to speed, such as mobile weather data, incidents, work zones, and other crowd-sourced road condition information.
Advanced	At this level, agencies engage in a two-way data exchange agreement with third parties. Agencies receive all processed information collected by one or more third parties as well as share all information collected through their internal systems. The end-result is a more balanced, comprehensive and accurate dataset that both entities can use.

Source: FHWA

Many other companies, products and services exist, and many more are being developed, that provide relevant road condition and vehicle information, some of them targeting specific issues or travelers. These include traffic navigation providers who incorporate weather data collection,[14] mobile weather data collection providers[15], and freight telematics providers,[16] all of whom are capable of collecting useful data from mobile fleets to support WRTM.

From a strictly road weather perspective, NOAA-supported initiatives like Mobile Platform Environmental Data (MoPED) rely on information obtained from equipped commercial vehicles, providing extensive coverage through urban, suburban and rural areas between the origin and destination points. The equipment takes meteorological observations every 10 seconds at a microscale level of spatial detail and transmits it in 1-minute intervals. In this sense, the use of

[13] In 2016, Audi announced its new traffic light information system, which is enabled by V2I communication between the on-board LTE data connection and Traffic Technology Services, Inc. servers (Audi, 2016).
[14] Examples include Waze, Inrix.
[15] For example, WeatherCloud.
[16] Examples include Omnitracs, Telegois.

MoPED data supplements fixed weather stations from airports and road weather information systems (RWIS) as it could detect small-scale phenomena (e.g., thunderstorm or flash flood) that may occur between fixed station points and help fill gaps in State agency data collection coverage. The information collected includes ambient air and pavement temperature, barometric pressure, relative humidity, precipitation, and light signatures, among others. State DOTs, such as Utah, Wyoming, Idaho, Colorado and California, have also developed mobile apps that provide weather and road condition information.

Weather Responsive Traffic Management Applications Supported

This pathway supports WRTM applications similar to Pathways 1 and 2, albeit to a more limited degree. In this sense, the information obtained from third parties can be used for the following applications that are directly related to weather:

- Road Weather Information and Routing Support for Emergency Responders.
- Road Weather Information for Freight Carriers.
- Road Weather Information for Maintenance and Fleet Management Systems.
- Road Weather Motorist Alert and Warning.
- Variable Speed Limits for Weather-Responsive Traffic Management.
- Spot Weather Impact Warning.

In addition, the following applications can be used during weather events to support WRTM:

- Enhanced Maintenance Decision Support System.
- Freight-Specific Dynamic Travel Planning.
- Parking Availability.
- Situational Advisory.
- Signal Phase and Timing.
- Curve Speed Warning.
- Reduced Speed Zone Warning / Lane Closure.
- Restricted Lane Warnings.

Institutional Issues

Institutionally, this pathway bypasses data safety, security and management issues as agencies become a consumer of data. Nonetheless, agencies still need to define clear policies regarding some of the “gray areas” of these applications.

- **Laws banning the use of cellphones or texting while driving**. In order to promote and support private development of information service providers, some agencies and States might need to review law(s) that may hinder drivers’ access to information while on the road.
- **Privacy, security, and data management and ownership**. While the agency might not be responsible for the treatment of the information provided, it should establish conditions under which data will be accepted or shared and who has ownership of the data.
- **Ensuring an effective data sharing arrangement between various groups within the agency.** Institutionally, the data coming from third parties needs to be managed in such a manner that it can support the needs of both maintenance and traffic operations.

Constraints and Challenges

With pathway 3, agencies become data consumers, thus bypassing key issues like data privacy, safety, and management. Nonetheless, constraints and challenges still exist that need to be addressed as an agency moves forward with the agreements for implementation.

- **Leveraging existing efforts.** Many agencies are already engaged in data collection and analysis efforts, and have developed methodologies and systems that may need to be updated (and in some case upgraded) to manage the new type and (potentially significantly increased) amount of information that is being provided.
- **Performance contracting and metrics.** Rigorous quality assurance and quality control (QA/QC) processes are needed to ensure that the acquired service and data meet the agency's needs and expectations.
- **Penetration rate.** The quality of the data, and inherently the performance of the third party, is highly dependent on the penetration rate and coverage of the application. Agencies need to develop a robust threshold or definition of the minimum amount of data points necessary for data analysis per segment.
- **Cost of data acquisition.** Collecting crowdsourced information can be less expensive than deploying the equipment necessary to obtain the same quantity and coverage of information. However, many alternatives exist that can significantly vary the cost of acquiring the data. The decision of what to obtain needs to be based on a thorough assessment of the agency's needs.
- **Policies for data acquisition/sharing/relay.** Agencies may need to update their current local and State policies to comply with the necessary agreements for data management being collected by, shared with, and/or relayed by third parties.

Performance Measures

Similar to Pathway 1, performance for this pathway can be measured by the improvements of advisory, control, and treatment strategies using data obtained from third parties. Table 7 list some potential measures for this pathway.

Table 7. Potential performance measures for Pathway 3 – Connected Third-party Fleet Services and Travelers.

Performance Measure Category	Potential Measures for Pathway 3
Road weather data collection	Number of road weather condition reports (quantity).
	Miles of road weather condition reports (coverage).
	Refresh time of road condition reports (latency).
Alert generation	System generated alerts/advisories accepted by operators.
Data quality	Percentage of data that meets minimum quality threshold.
Dissemination of traveler information	Number of updated traveler information reports and updates to ITS devices.
	Staff time to process road weather condition reports and update traveler information and intelligent transportation system devices.
	Qualitative improvements in traveler information.
Project outcomes	Vehicle speeds compared to posted speed (third-party users and all vehicles).
	Vehicle speed variation.

Source: FHWA

System Development Guidelines

System development for this pathway focuses mainly on the agency's internal policies and agreement types necessary for use and distribution of the data. Additionally, agencies are likely required to define expected criteria on data quality, latency, and availability for receiving and distributing data from third-party providers. Agreements are also likely to clarify data ownership and data rights issues between the agency and the third party. These may include developing a common understanding on data usage restrictions and limitations in data sharing that may be necessary from a private sector standpoint.

Regardless of the pathway selected, four different phases address the planning, design, development, implementation and maintenance activities associated with the deployment of a CV-WRTM system (Figure 19). Each step details the activities within the phase's scope.

Source: FHWA

Figure 19. Recommended steps for implementing connected vehicle-enabled weather responsive traffic management strategies.

- **Phase I** introduces the steps necessary to plan for CV-WRTM. Ideally, the steps should be followed during the conceptualization stage or at the beginning of the planning stage of any envisioned CV-WRTM strategy.
- **Phase II** builds upon the findings in Phase I to develop a cohesive and coherent concept of operations and the necessary safety, performance, and human factors documents.
- **Phase III** develops specific information needed to design the CV-WRTM system, including partnerships, procurement, and deployment plans.
- **Phase IV** describes what will be required to manage and maintain the new system in order to achieve expected and desired performance levels.

With connected vehicle technology evolving rapidly, these guidelines provide a State or local DOT with the concise summary of information and resources necessary to begin using connected vehicle data for weather-responsive traffic management. While not meant to be a step-by-step guide or prescriptive guidelines, the document provides resource tips for the reader to access the latest guidance material available for this area.

IMPLEMENTATION PROCESS FOR CONNECTED VEHICLE-ENABLED WEATHER RESPONSIVE TRAFFIC MANAGEMENT

Table 8 shows an overview of the suggested CV-WRTM implementation process, consisting of the phases described in the System Development Guidelines section. Each phase includes questions that stakeholders should address at different stages of the project (i.e., planning, conceptualization, development and deployment). Note that these questions should serve as examples; therefore, stakeholders may want to add to the list to satisfy their particular needs. Many of the steps provided here are consistent with sound systems engineering practices, particularly those related to CV-WRTM. For more general guidance on systems engineering (for example, specific to concept of operations development), consult the FHWA systems engineering guidance.[17]

Table 8. Suggested connected vehicle-enabled weather responsive traffic management implementation process.

<table>
<tr><th colspan="3">Phase I - Planning for Connected Vehicle-Enabled Weather Responsive Traffic Management (CV-WRTM)</th></tr>
<tr><td colspan="3">This planning phase of a CV-WRTM project should seek to:
Understand and identify user needs for CV-WRTM.
Assess current capabilities and gaps for the agency.
Explore concepts and applications that meet user needs.
Set realistic expectations for CV-WRTM including what is possible with the current and anticipated technology levels.
Perform a risk/feasibility analysis.
The outputs from these steps will identify the needs of the different stakeholders and current gaps in the system that should be addressed, to the extent possible, with the CV-WRTM application. As such, these first steps lay the foundation of any CV-WRTM project, providing direction (i.e., objectives) and helping the decision-makers identify the best application (or applications) to accomplish their objectives.</td></tr>
<tr><td>Step 1 – Needs Assessment</td><td>The first step is to identify the needs of the different stakeholders that may be impacted by the desired CV-WRTM strategy). The needs of RWM managers are many. However, it is important to identify what traveler, agency and the other stakeholders' needs are unmet through current operations that can be best addressed by CV-WRTM.</td><td>Key Output: Initial list of User (Stakeholder) Needs.</td></tr>
<tr><td>Step 2 – Current Capability Assessment</td><td>The second step of the process is to identify the existing capabilities and assets of the stakeholders along with the geographical scope of the project (i.e., develop an inventory). Three main questions should be addressed:</td><td>Key Output: A report of available physical (e.g., infrastructure and fleets),</td></tr>
</table>

[17] FHWA's System Engineering for ITS guidance can be found at http://www.fhwa.dot.gov/cadiv/segb/. The latest version of the guidance in Version 3.0.

	• What are your current capabilities for WRTM and CV? • What inventory of technology and assets can you leverage for CV-enabled WRTM? • What institutional capabilities exist in your region?	technological (e.g., hardware and software) and human (e.g., staff and subcontractor) resources.
Step 3 – Concept Exploration	The next step is to begin concept exploration for meeting the user needs and gaps in the region. The agency needs to first understand the state-of-the practice and the state-of-knowledge of the desired CV-WRTM strategies.	**Key Output**: Initial report of the vision and goals of the desired CV-WRTM system.
Step 4 – Feasibility Assessment	Before proceeding with concept development, an early assessment of risks and overall feasibility is recommended. With the ongoing evolution of technology development and regulation in this area, it is imperative to understand what factors drive the risk and feasibility of the project, and how they may change in the future. However, note that with limited results and effectiveness, feasibility assessment is more of an art than a science.	**Key Output**: Initial risk and feasibility assessment report.
Phase II – Concept Development		
The second phase of CV-WRTM is to develop the concept to meet the user needs initially identified in Phase I. During this section, a detailed concept of operations will be created along with other supporting planning documents necessary to support progress toward system design.		
Step 5 – Concept of Operations (ConOps) Development	The ConOps describes the proposed system as seen and understood by the stakeholders. The ConOps relies on information gathering efforts and a development workshop, which helps identify user needs for the system. The ConOps does not specify how but rather what should be achieved. It focuses on user needs, the enhancements to current practice enabled by the CV technology, the functionality desired to meet the user needs, and impacts during the development phase. The descriptions of user needs and functionality in this document will be used to develop the system requirements and ultimately will drive the design and development of the system.	**Key Output**: A Concept of Operations document.
Step 6 – Safety, Security, and Privacy Concept Development	All CV-WRTM strategies could deal with sensitive information and interaction with the users. The system needs to ensure that it will operate in a safe, secure and private manner. • Safety relates to minimizing sources of safety risks to the users, such as power outages,	**Key Output**: Two main conceptual documents should be developed during this step: • Safety

	communication failures, unexpected environmental and operational events, and intentional system intrusions. • Security relates to the environment of the systems' components and of information flows between those components • Privacy relates to the safekeeping of sensitive information, especially those of the user (i.e., Personal Identifiable Information).	Manageme nt Plan • Security Manageme nt Operational Concept
Step 7 – Performance Measurement Plan	Performance measures are necessary to evaluate the success of the project. Through this, it is possible to: • Establish evidence of CV-WRTM system performance and benefits. • Provide information to prioritize resources and justify future investments. • Share results with other states to assist them with their potential CV-WRTM projects. • Contribute to the growing WRTM benefits database and encourage deployment of CV-WRTM applications.	**Key Output**: A Performance Measurement Plan
Step 8 – Human Factors Plan	It is expected that CV technology will impact every day activities and operations of the users of the transportation network—including drivers, operators, and managers. As such, it is important to understand how all potential users will interact with and react to the CV-WRTM system during adverse weather.	**Key Output**: A Human Use Plan
Phase III – System Requirements, Design, Development and Deployment		
Moving from concept to system design and development includes a process of requirements definition, system design, testing, and acceptance. In addition, partnership roles and procurement methodology have to be clearly identified in this phase. Development approaches in this phase should conform to standard systems engineering practices.		
Step 9 – Systems Requirements	At this step, the implementing agency needs to describe the requirements for the physical objects and applications identified in the Concept of Operations document. The end-result should be testable requirements based on the user needs identified by the pilot site. These requirements should serve as the bases for system design activities.	**Key Output**: A System Requirements Specification (SysRS)

Step 10 – Application Development Plan (ADP)	This step assesses any gap between the System Requirements Specification (Step 9) and the functionality in available CV-WRTM application software, and identifies the means by which any such gap will be addressed. The ADP will in most respects look like a Project Management Plan for a systems development project. It will identify the scope of development, the resources, and the schedule. The scope of work will follow established system engineering practices for software development. At this level, the source, if any, of the base application software package should be identified.	**Key Output**: An Application Development Plan
Step 11 – System Design	This step to design the system is the culmination of all previous efforts thus far. At this step, requirements are assigned to the system components, which the system architecture will continue to refine, especially where they interface with the external environment. The system development needs to be managed as a project unto itself, and in order to provide transparency and confidence to the stakeholders should be monitored using a modified earned-value management system.	**Key Output**: An System Architecture and Design Plan
Step 12 – Partnership Development	Initial deployments are expected to be DOT-centric but new partnerships may be needed to support an effective deployment. For example, if non-DOT fleets are to be equipped, then partnership agreements are needed with fleet providers. New agreements for service for CV equipment need to be described as well. For financial sustainability, partnership agreements need to define the business model that works for the CV-WRTM pilot.	**Key Output**: A Partnership Status Summary
Step 13 – System Testing and Deployment	System testing demonstrates that the developed and deployed system fulfill their requirements and meet the objectives described in the ConOps. Formal testing is complete only after the system has been deployed in its operating environment and stakeholders have accepted that the system is performing as expected. A System Test Plan (STP) lays out the intent and pattern of the tests to be performed, identifying the components and deployments to be tested, the relationship of the tests to the system requirements, and the resources needed. The scope and specifics of testing for CV-WRTM deployments will depend on the particular applications and settings of the deployments.	**Key Output**: A System Test Plan and an Application Deployment Plan

Phase IV – Operations and Maintenance		
The final phase ensures continued operation of the system as designed. This phase includes monitoring the performance of the system and continually improving the system		
Step 14 – Operations and Maintenance	CV-WRTM systems will likely include new highly technical systems, communication techniques, data management and operational processes, and sophisticated software and databases. This will require new management/operations procedures, IT and database operations and maintenance approaches, and equipment maintenance resources. Understanding the system owner's needs in this regard and securing the dedicated required resources early in the project are essential to a successful CV-WRTM project implementation. Step 14 is closely linked to Step 7, Performance Measurement Plan, because it addresses database management, maintaining reliable systems with a high level of up time, and monitoring system performance. If the CV-WRTM system is not well managed and maintained, it is unlikely that the data will be available to measure the performance of the system.	**Key Output**: A System Operation and Maintenance Plan

Source: FHWA

Chapter 5. Connected Vehicle-Enabled Weather Responsive Traffic Management Implementation Projects

The Federal Highway Administration (FHWA) Road Weather Management Program Office funded two State agencies to conduct Connected Vehicle-Enabled Weather Responsive Traffic Management (CV-WRTM) implementation projects with the goal of evaluating the CV-WRTM Guidelines and demonstrating CV-WRTM strategies and operational benefits. An invitation and request for proposals was posted, and transportation agencies were selected based on their proposals, namely Washington State Department of Transportation (WSDOT) and Delaware Department of Transportation (DelDOT).

The agencies were asked to use the CV-WRTM Guidelines described in Chapter 4, and propose as many pathways and applications that are implementable. Table 9 illustrates their proposed pathways and applications.

Table 9. Connected vehicle-enabled weather responsive traffic management pathways and applications proposed by the Washington State and Delaware Departments of Transportation.

Pathways and Applications	Washington State DOT	Delaware DOT
PATHWAYS		
1-Intelligent Agency Fleets	●	●
2-Connected Vehicles		
3-Connected Third-party Fleet Services and Connected Travelers	●	
APPLICATIONS		
CV-WRTM Variable Speed Limits		
I2V Situational Awareness	●	●
V2V Situational Awareness		

Source: FHWA

WSDOT focused on public-private and third-party partnerships to share agency snowplow and specialty fleet data through an enhanced traveler information application programming interface (API) with a goal of increasing safety and creating a more weather-aware motorist. The agency's CV-WRTM implementation pilot demonstrated data flow from agency vehicles to a newly built API that was made available to potential internal and external users.

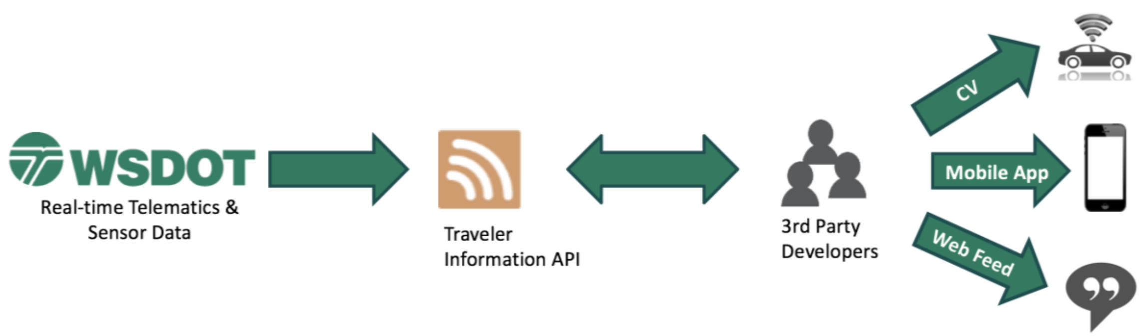
DelDOT, focused on adding mobile road weather devices to agency vehicles to help fill gaps in data collection coverage and using the data to improve traffic management operations and expand upon traveler information. Additionally, the new road weather data would assist in dispatching snowplows, maintenance vehicles and portable intelligent transportation systems (ITS) equipment; as well as, identifying weather hotspots in order to better locate fixed devices for permanent system monitoring. The agencies were asked to use the guidelines to assist with planning, development, and implementation and to provide feedback regarding the usefulness of the guidelines and recommended improvements at the end of the project.

The following sections describe each of the CV-WRTM Implementation Projects and the results of the deployments.

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

Introduction

Through public-private and third-party partnerships, WSDOT proposed to share agency snowplow and specialty fleet data through an updated WSDOT traveler information application programming interface (API) to increase safety and create a more weather-aware motorist. WSDOT accomplished this by joining existing fleet telematics, private CV technologies, and connected third-party services such as smart phone applications. Essentially, as a motorist is traveling on a State highway and agency-owned snowplows are actively engaged in snow-fighting operations, motorists could receive real-time messaging via a smart phone app or connected vehicle safety systems. These messages may warn drivers of adverse weather conditions and advise of nearby impactful work operations. Figure 20 visually outlines the project end-result.



Source: FHWA

Figure 20. Washington State Department of Transportation CV-WRTM implementation project overview and end products.

Communicating road conditions during dynamic situations such as adverse winter weather is often a challenge to many transportation agencies. WSDOT's project goal was to establish an API which makes real-time agency fleet telematics data available to various internal and external clients.

Through partnership with third-party service providers, appropriate warning and advisory guidance could be generated using new mobile data from the enhanced API. This guidance could then be disseminated in near real-time to the service providers' mobile app users and other connected vehicles, including WSDOT vehicle operators. This also provides for heads-up situational awareness of WSDOT field operations such as snowplowing and winter maintenance activities. WSDOT extended the API to include other agency fleet vehicles such as incident response vehicles, which further provided motorists with road or lane closure information in a similar fashion. The API not only provides a source of information for better situational awareness for the traveling public, but also increases the safety of agency operations, including potentially thwarting collisions with snowplows and other maintenance vehicles.

WSDOT accomplished this CV-WRTM project by executing the following four tasks during a very aggressive 9-month timeline:

- **Task 1: Research and Stakeholder Engagement –** WSDOT held a series of meetings and engaged stakeholders to clarify the project deliverables and define milestones. The meetings were collaborative in nature and focused on identifying current data available from the fleet and potential solutions to assist in better defining the final project deliverables and functional level requirements. This task culminated in a project plan which defined the ultimate scope, schedule, and development requirements with timeframes. WSDOT also developed a feasibility assessment paper and a concept of operations document as part of this task.

- **Task 2: Project/Application Development –** WSDOT developed the necessary application with in-house IT staff. Their efforts established business logic and data formatting, developed new databases or made adjustments to existing databases, and developed associated web services to build a working system. The CV-WRTM application was completed and tested at the end of this phase.

- **Task 3: User Acceptability Testing and Final Deployment –** WSDOT worked with stakeholders to beta test the project and push the final product to a production ready environment. This effort included field testing, addressing technical challenges, and repairing sensors on some DOT owned vehicles and infrastructure.

- **Task 4: Evaluation and Reporting –** WSDOT led the evaluation and reporting activities, which focused on determining if the system worked as intended. The new mobile data was provided to third-party information providers and internal WSDOT traffic managers to better understand how this information would be beneficial to improve efficiency and safety. Also, the evaluation assessed and reported on the usefulness of the FHWA CV-WRTM Deployment Guidelines.

System Description

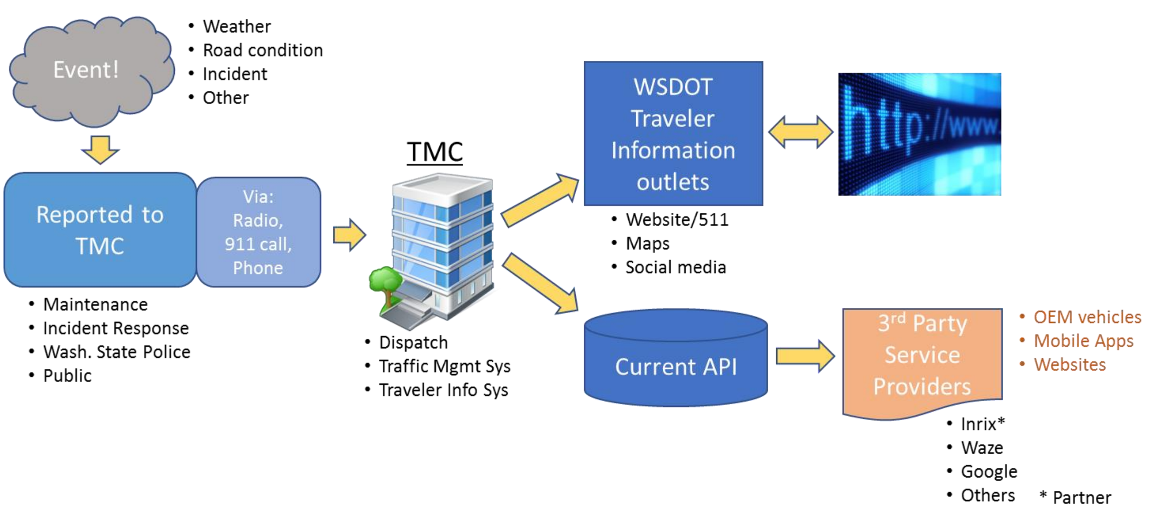
Existing System

The existing WSDOT Traveler Information API is designed to provide users within and outside the agency with a single gateway to all of WSDOT's traveler information data. Access to the API is free to anyone and simply requires a user to register with an email address to obtain an access code. Data is fed to the API through several sources such as TMC operations software, static road weather information systems (RWIS), and other internal WSDOT databases.

Nearly all impactful highway events that occur on a State-operated highway or infrastructure, including those that result from inclement weather, are communicated to one of WSDOT's six traffic management centers (TMC). Maintenance activities, crashes, other incidents, and construction activities make up the most frequently occurring reportable events. Often these reports originate from a motorist who calls the Washington State Patrol communications center or the TMC. Reports can also come from WSDOT employees, such as highway maintenance crews, via land mobile radio to a dispatcher or phone calls directly to the TMC operator.

The TMC operator logs the event and follows certain prescribed standard operating procedures. In most instances, the operator will log the information into an internal system called ROADS. This system feeds several traveler information systems such as the traffic maps on the WSDOT Traffic Alerts website, the 511 system, and Travel Alerts feed and GovDelivery (email and text messaging subscription service). Other ITS systems that are triggered during events are highway advisory radio (HAR), variable message signs (VMS), ramp meters, variable speed limits (VSL), and travel time information signs.

Figure 21 shows the current sources of data for weather and other events. It illustrates how the data is used by the TMCs to feed WSDOT's traveler information systems and by the existing API to feed various internal and external clients of the agency.



Source: FHWA

Figure 21. Data sources and data flows for Washington State Department of Transportation's traveler information system and application programming interface.

Proposed System

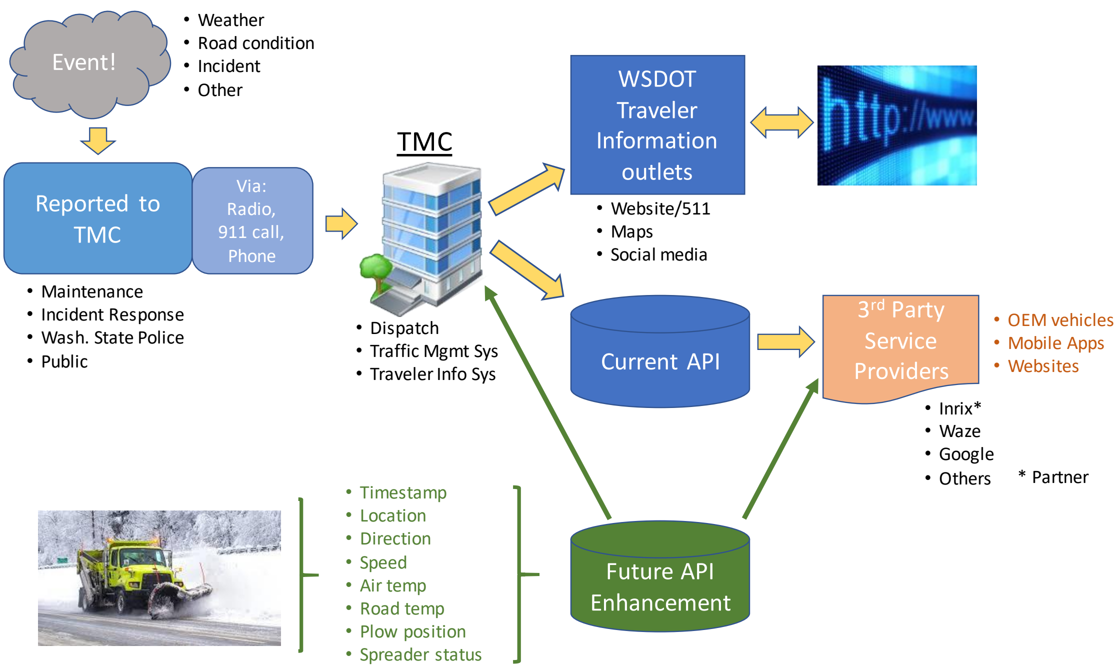
Figure 22 illustrates the addition of connected vehicle data from snowplows and other agency vehicles to enhance the API and improve the road weather information and other messages that are provided by the users of the API (including third-party providers) to the travelers. Mobile data provided by the snowplow included:

- Date/time
- Location

- Direction
- Speed
- Air temperature
- Road surface temperature
- Plow position
- Spreader status

WSDOT application development staff, in coordination with the AVL vendor, worked to develop a data model, subsequent database and necessary web services. The services and database reside in the Amazon EC2 and allow for consumption by third parties with appropriate credentials. Developers incorporated data quality checks to ensure no duplication of records occurs; this is done through a unique ID string that is passed from the snowplow to the database. Further filtering of data is performed after the data has flowed into the database by receiving party. This allows for faster data availability. WSDOT is simply housing the unique raw data points, and the third party then has the ability to conduct further processing.

While there will always be a manual reporting process for roadway maintenance activities and weather-related traffic impacts, the enhanced system incorporated an automated, real-time process into the system. By providing the WSDOT intelligent agency fleet telematics data to the API and enabling internal and external clients to use this data to feed the traveler information systems, highway users will have both spatial and temporal awareness of existing road weather conditions as well as other factors affecting their trips, such as snowplow operations and maintenance activities. WSDOT provided this data to the API based on highest availability of data received, which is estimated to be within approximately 2 minutes of a sensor state change.



Source: FHWA

Figure 22. Enhanced application programming interface and applications using connected vehicle data.

The enhanced API was completed and made available to third-party service providers and WSDOT TMC operations. Additionally, the information was provided to the public via an ARCGIS map on a WSDOT website. However, at the end of the 2017-2018 winter, data was not yet being processed and utilized by the third-party service providers or WSDOT traffic managers. Therefore, many of the anticipated operational benefits were not yet realized. Some of the potential benefits are described below. Additionally, the Message Types and Examples section below discusses the project results and future plans which provide additional insights to realizing the full project potential. Some future expected benefits of this CV-WRTM implementation pilot include:

- *Road Maintenance Decisions and Management* – Knowing the road conditions and ambient and road surface temperatures will help maintenance supervisors improve their ability to more effectively allocate resources. For instance, determining the proper timing of leaving the Interstate winter road maintenance to place resources on the rural highways, and vice versa.
- *Travelers' awareness of Winter Maintenance Operations* – As travelers drive State highways, many are unaware of events or obstructions that lie ahead along their intended route of travel. The WSDOT API will include telematics data via ARCGIS map on a WSDOT website and third-party mobile apps that will allow drivers to be warned in real time as they approach slow-moving snowplow operations or potential freezing roads ahead. They will also be informed as to which roads have been treated or plowed. It is WSDOT's hope that as drivers receive these real-time alerts, they would make conscious decisions to slow down and give-way to WSDOT work operations, as a result mitigating safety hazards such as rear-end collisions with slow-moving vehicles or crashes within work zones.
- *Enhanced Messaging from Third-party Service Providers* – The API is now providing the new mobile data to third-party service providers. Time did not permit them to fully integrate the data into their data processing systems within the project timeline. However, the opportunity exists for them to enhance their existing message sets utilizing this new information. For instance, knowing the road surface temperature is below freezing and the snowplow is plowing and spreading material would allow more direct messages about the winter road conditions to motorists through their website and apps. The location of snowplows could also be relayed to motorists, making them more aware of a potential safety hazard (a slow moving vehicle ahead).
- *Winter Performance Evaluation* – Another area that WSDOT anticipates enhancing as a result of the CV and intelligent agency fleet data integration is Winter Performance management. Through a better understanding of how vehicles respond to a roadway treatment during a snow storm, WSDOT anticipates better understanding of how well the prescribed deicer treatment works in a given scenario and location. This may result in future cost savings, better environmental stewardship, and better response prioritization.
- *Traffic Management/VSL* – Traffic sensors along the roadway collect vehicle speeds, congestion information and traffic flow rates. This information is continuously relayed back to the WSDOT's Traffic Management Centers and analyzed by computers. When circumstances that would benefit from lowered speed limits—like congestion—were identified, the computer reduces speeds incrementally to gradually reduce the approaching flow of traffic to the congested area. With the use of the enhanced API, when adverse weather strikes the highway system, the VSL system can make speed adjustments to keep traffic flowing at safe speeds in the midst of a snow and ice event.

- *Traffic Management/511* – State highway traffic and weather information is available by dialing 511 from most phones. By providing the enhanced API to the Traffic Management System, higher resolution data can be provided to callers between static RWIS stations. Further, dictation over 511 advising the public of “snowplow operations on route” or similar language will also provide valuable information for a more aware traveler.
- *Traffic Management/VMS* – VMS are electronic signs used to provide travelers with information about traffic congestion, incidents, roadwork, travel times, special events or speed limits on the highway. They may also recommend alternative routes, weather-related travel problems, emergency and disaster information, and public service announcements and alerts (AMBER, Blue, and Silver). By bringing the enhanced API into the TMC operations in real-time, operators will be able to make messaging more applicable to the traveling public during adverse weather conditions. Messaging such as “snowplow operations ahead, don’t crowd the plow” or “right lane plowed/treated, stay right” are more specific messages that can aid travelers in understanding road conditions ahead on the route. Additionally, WSDOT anticipates incorporating road weather messages on the VMS such as “roadway slippery” or “winter road conditions advise XX MPH speed.”

Summary Findings

The existing application programming interface (API) was enhanced to add the snowplow mobile data. The API enhancements were developed, tested, and made operational and are currently providing data to interested third-party service providers, WSDOT TMC operations staff, and the public through the WSDOT ARCGIS website. Mobile data was collected from the majority of WSDOT snowplows (about 500 vehicles). Data includes timestamps, GPS data, ambient and road surface temperatures, and spreader location. Plow position was not achieved due to sensor issues. Data was quality checked (road temperature <=32 AND spreader = On) and produced 2,179,037 quality records between October 1, 2017 and March 1, 2018. Both third-party service providers and WSDOT TMC Operations expressed an interest in using the new mobile data to enhance their services.

The project was not able to be fully implemented as envisioned within the original project schedule. This was due to the discovery of numerous technical issues that took time to troubleshoot and resolve. Ongoing efforts are continuing to address these technical issues focused mainly on on-board sensor performance. These issues affected the amount and quality of the data collected. The loss of time resulting from addressing these issues prevented the mobile data from being fully integrated and used by the stakeholders (third-party service providers and WSDOT TMC Operations), so a complete evaluation of impacts and benefits could not be conducted.

WSDOT is committed to continuing to address the technical issues and system enhancements to have a fully functioning system by October 2018 and operating the system through the 2018-2019 winter season. WSDOT will continue to work with internal and external partners to fully realize the benefits of the shared mobile data. Resulting impacts and benefits will be documented and shared with FHWA. WSDOT will complete the evaluation of the system at the conclusion of the winter 2019 season and document the results.

DELAWARE DEPARTMENT OF TRANSPORTATION

Introduction

Through its Integrated Transportation Management System (ITMS), DelDOT has multiple fixed and portable weather-related ITS devices such as non-intrusive weather detectors and road weather information system (RWIS) units. These devices provide information about road condition, surface temperature, friction, air temperatures, dew point, humidity, amount and type of precipitation, visibility, wind speed, roadway chemicals, and freezing point. DelDOT uses fixed hydrology monitors (tidal gauges) to measure water elevation at certain key sites. DelDOT also uses snow depth gauges. Major decisions during severe weather events are supported by this real-time data system. For example, deployment of salt trucks is prioritized based on surface and subsurface temperatures, bridge closures are determined by wind speeds, and road closures may be based on water levels.

The Delaware DOT CV-WRTM implementation pilot project will enhance the awareness of transportation management technicians, maintenance and operations, and the traveling public regarding road conditions during various inclement weather events. Specific project objectives include:

- Adding mobile road and weather data to the existing data obtained through fixed and portable devices to improve operations and provide more robust traveler information.
    - Providing location-specific information to motorists through the DelDOT mobile app, website, radio station, and dynamic message signing.
    - Using mobile weather data to intelligently dispatch snowplows, maintenance vehicles, and portable ITS equipment.
- Understanding how DelDOT can use mobile data to supplement and enhance existing infrastructure data.
    - Expanding point data collection to linear data collection.
    - Validating the accuracy of equipment.
- Identifying weather “hot spots” (e.g., ice, flooding, etc.) in order to better locate fixed devices for permanent system monitoring.

System Description

The DelDOT TMC currently receives weather information from roadside fixed and portable devices. For this project, DelDOT plans to outfit agency fleet vehicles (e.g., transit and other roving maintenance vehicles) with sensors to collect additional road weather mobile data. The mobile data will enhance the existing data by both expanding upon it as well as validating it. All data will flow to the TMC to allow for real-time monitoring and decision making. DelDOT also plans to disseminate information back to the fleet vehicles to allow for real-time situational awareness and deployment of resources to hazard areas. For example, DelDOT may prioritize locations for snow salting and plowing operations and road closures due to anticipated flooding. Information collected can also be used to identify trends and prioritize weather preparation operations in the future. Figure 23 shows how the addition of CV-WRTM mobile data from maintenance, transit, and other agency vehicles (in green) could enhance the collection of weather-related data and improve the road weather information and other messages that are provided to DelDOT stakeholders and the traveling public.

Mobile sensors attached to the fleet vehicles will collect real-time weather information to determine roadway cold/hot spots, friction, percent of roadway with icy conditions, water film height, surface temperature, dew point, relative humidity, and road surface conditions (dry, wet, chemically wet,[18] etc.). This data will be aggregated and stored in a third-party software system in the cloud. As part of this project, DelDOT's web development team will work with the device vendor to develop an API to integrate CV-WRTM mobile data into the DelDOT website and mobile app. This additional (mobile road and weather) data, along with DelDOT's existing data obtained through fixed/portable devices, will provide more robust traveler information. Figure 24 shows a map output of DelDOT's snowplow tracker system used to efficiently allocate resources during storm events. DelDOT anticipates providing location specific information to motorists through the DelDOT mobile app, website, radio station, and variable message signing. Further, they plan to use the mobile weather data to intelligently dispatch snowplows, maintenance vehicles, and portable ITS equipment.

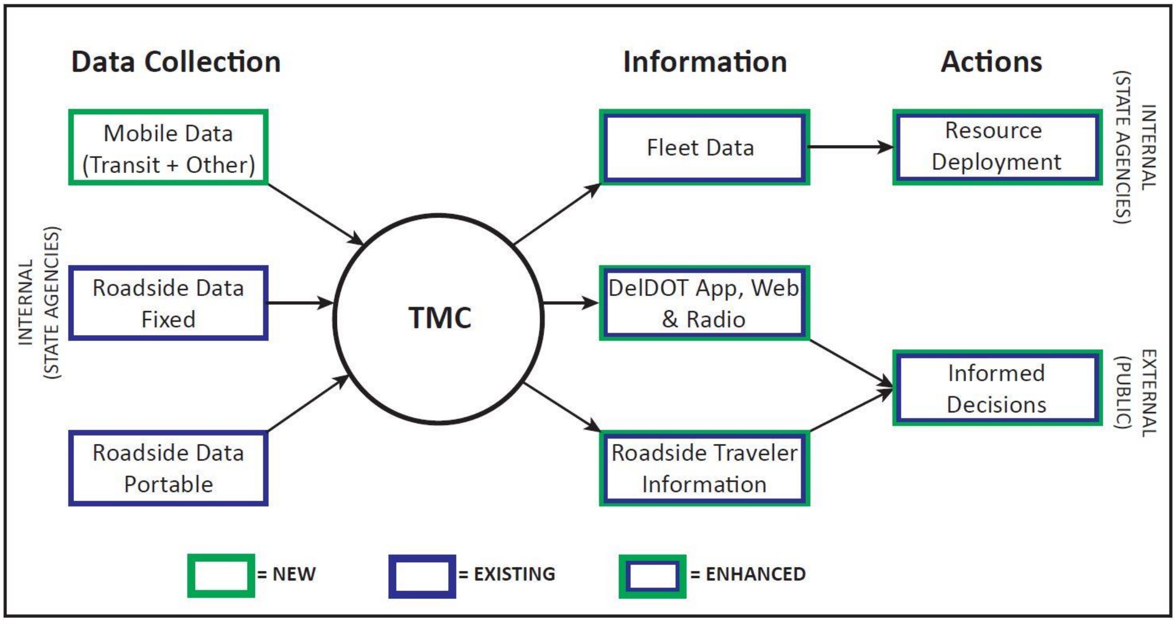


Figure 23. Project data integration diagram.

DelDOT anticipates that agency fleets will use existing cellular communication capabilities for this project. A significant number of DelDOT vehicles are already equipped with cellular communications devices, and a requirement for equipment selection was to integrate with existing vehicle communications hubs.

The project is being executed through the following three tasks:

1. Develop Project Management and Implementation Plan, and Concept of Operations.

DelDOT developed a project management and implementation plan to clearly define scope, schedule, concept of operations, and development requirements with time estimates. DelDOT also

[18] "Chemically wet" pavement can be described as a pavement that is wet when the temperature is below 0 °C because of the application of salt or other chemicals.

facilitated a series of meetings to develop specific needs and requirements as they relate to the mobile weather data collections and dissemination concept. This led into the development of a concept of operations document which included the development of specific functional and business requirements, an analysis of existing off-the-shelf equipment, and the identification of performance measures for use in validating mobile weather detection device deployments and data integration.

Figure 24. Snowplow tracker.
Source: DelDOT

2. Equipment Procurement, Installation, Integration.

At the time of this writing, DelDOT was working through deliverables defined in Task 1 to solicit a vendor and procure and install mobile equipment on their vehicles. Additionally, the software development team at the DelDOT TMC will engage with the vendor in validating the needs and requirements, integrating the equipment into existing in-vehicle communications hubs, and integrating mobile weather data into the TMC Emergency Operations platform and the DelDOT mobile App. DelDOT is currently preparing a memorandum that summarizes the equipment procurement, installation and integration to be performed.

3. Implementation, Operation and Evaluation.

DelDOT will implement, operate, and evaluate the mobile weather equipment, data flows, and information dissemination through the various methods as determined in the Concept of Operations from award through the winter of 2018-2019. The functionality of the devices, their relation to fixed weather installations, their use in identifying hotspots, as well as the ability for the TMC to collect, integrate, and disseminate weather data will be implemented and evaluated against the project goals and defined performance measures.

DelDOT will document the results of this task in a Summary Report produced in the summer of 2019. The Summary Report will include a concise documentation of the work that was performed, the CV-WRTM application that was developed, the outcomes of the implementation, and the results of the evaluation and the usefulness of the guidelines in the project. The Summary Report is intended to inform other agencies that are interested in pursuing the same initiative.

The following operational scenarios illustrate how the CV-WRTM road weather mobile data will be utilized.

- *Winter Maintenance Operations.* DelDOT will deploy CV-WRTM mobile weather sensor devices on maintenance vehicles in each of the four maintenance districts (north, canal, central, and south) as well as select transit vehicles and DelDOT employee fleet vehicles. DelDOT will monitor this data during weather events remotely from their TMC to determine where additional resources need to be deployed, closures or travel restrictions need to be made, or information needs to be provided to motorists or other maintenance fleet personnel. Tablet computers or smart phones will be used in select maintenance vehicles to display CV-WRTM mobile data as well as other data to support maintenance and weather response activities and give operators situational awareness from within the vehicle. Following weather events, DelDOT will conduct after action review meetings to review the event and response and identify successes and areas of improvement.

- *Winter Performance Evaluation.* Another area that DelDOT anticipates enhancing as part of this project is winter performance management. The road weather mobile data will allow DelDOT to prioritize locations for snow salting and plowing operations. Information collected will also be used to identify trends and help to prioritize weather preparation operations in the future. DelDOT will use CV-WRTM devices to verify that static weather sensor devices were properly calibrated by comparing CV-WRTM data at similar locations to determine if any permanent data collection sites need to be retested or repaired. In addition, CV-WRTM historical mobile weather data may be used to identify areas of the DelDOT roadway network that perform as outliers to their general surrounding area; for example, bridges that freeze much sooner or at a specific ambient temperature when compared to its roadway approaches, or a particular low-lying area that is susceptible to collecting standing water at a specific rainfall amount or intensity. This data will allow DelDOT to prioritize maintenance activities, such as the clearing of storm sewers or the deployment of additional permanent monitoring equipment.
- *Traffic Management – Mobile App and Website.* DelDOT's mobile app will be enhanced to disseminate more robust data to travelers through the addition of the road weather mobile data integration. CV-WRTM mobile data will be integrated into the existing Roadway Weather and Snow Plow layers on the Travel Conditions Map as well as into the Advisory Notifications tab. This data will also be integrated into the DelDOT website, where mobile weather data may be displayed in a linear fashion tracing the connected vehicle's path along a certain roadway corridor.
- *Traffic Management – Variable Message Signs*. In addition to posting messages about traffic congestion, incidents, roadwork, travel times, special events, or speed limits on the highway, VMS may also display messages that alert motorists to weather conditions and related travel problems. TMC technicians can make messaging more applicable to the traveling public during adverse weather conditions with the addition of enhanced CV-WRTM mobile data. VMS are critical to those motorists who do not have access to roadway condition data through the mobile app or are operating a single occupancy vehicle and cannot safely interface with a mobile device. DelDOT has already integrated the use of VMS into their weather responsive operations, and the addition of CV-WRTM mobile data will help to enhance the granularity and specificity of VMS messages that can be posted.

Summary Findings

The initiation of the DelDOT CV-WRTM pilot implementation project was delayed and effectively began in the fall of 2018. DelDOT recently completed the procurement process to acquire the new road weather mobile data sensors. However, installation, testing, and full operation were not completed at the time this report was published.

DelDOT views this project as just the beginning to support DelDOT's CV-WRTM program. DelDOT plans to complete this demonstration project and use the outcomes to launch an expanded effort to outfit additional vehicles in the future. Specific activities planned by DelDOT in the next 18 months include:

- Purchase, install, test and operate 8 road weather mobile data sensors and systems on DelDOT vehicles.

- Integrate the new data into the DelDOT TMC as appropriate to enhance traffic and maintenance operations.
- Document the system performance and evaluation results of these initial 8 units through the 2018-19 winter.
- Prepare a project report in the summer of 2019 that documents the accomplishments, challenges, lessons learned, and system evaluation results. Submit this report to FHWA for distribution to the road weather management stakeholder group.
- Consider the expansion of the project to include the purchase and installation of additional road weather mobile data equipment.

TASK 5 CONCLUSIONS

The goal of Task 5 was to continue the evolution of CV-WRTM technology development by demonstrating related strategies in a real-world environment. The activities of Washington State DOT and Delaware DOT have resulted in significant strides toward learning from these pilot efforts to implement CV-WRTM strategies.

Although both CV-WRTM pilot projects made significant progress, neither was able to achieve all or their respective project goals within the original project schedule primarily due to unforeseen technical issues and challenges within the vendor procurement process. The primary lessons learned to date include:

- These types of new technology projects require more time than originally anticipated to plan, develop, deploy, test, and operate. A project timeline of 2 years (incorporating two winter seasons) is recommended.
- Incorporating external third-party partners into the project activities takes more effort and time than originally anticipated. Formal plans and arrangements are recommended to guide this endeavor.
- Internal DOT-dedicated technical support is critical to the success of projects such as this. Technical issues, data integration challenges, and partner coordination activities require a dedicated team of skilled staff to complete these projects.

Both Washington State DOT and Delaware DOT view these projects very positively and see tremendous value in completing the projects as originally envisioned, as well as expanding upon them to realize even greater benefits. Both agencies plan to operate the new equipment and systems through the 2018-19 winter season and will then prepare/submit a final project report to FHWA.

Chapter 6. Findings and Recommendations

STAKEHOLDER WORKSHOP SUMMARY AND FEEDBACK

The Federal Highway Administration (FHWA) Road Weather Management Program (RWMP) conducted the ***4th National Stakeholder Meeting on Weather Responsive Traffic Management (WRTM)*** in Raleigh, North Carolina, on August 29-30, 2017. The 1½-day event was the fourth in a series of biennial meetings that brought together traffic management professionals from the public and private sector throughout the country to discuss their progress, experiences, and needs pertaining to managing traffic in inclement weather.

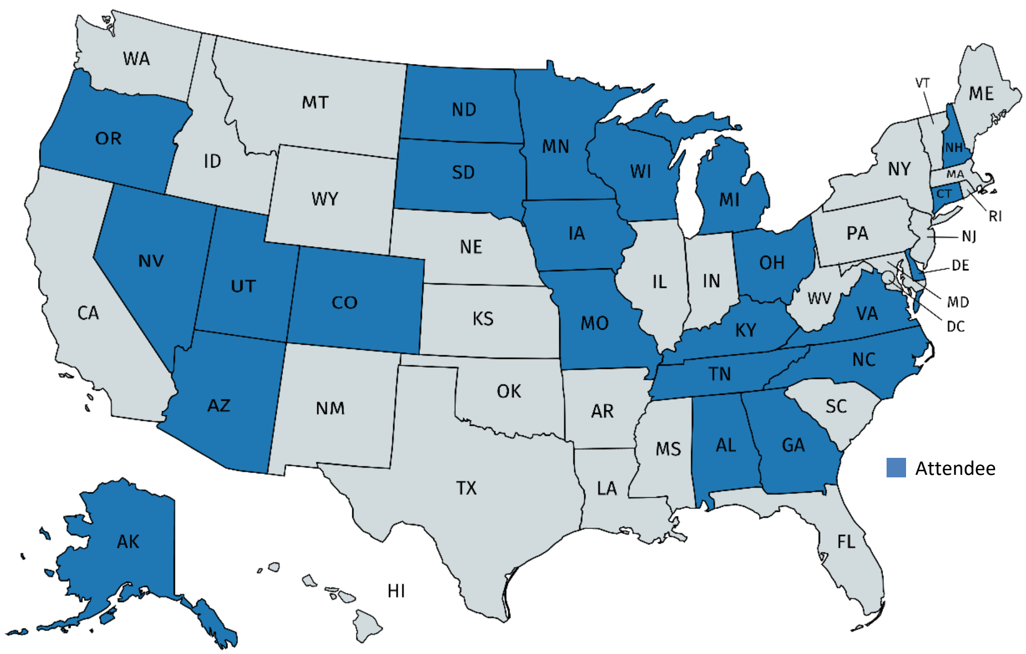
Through presentations and panel discussions, FHWA and the road weather management community shared recent products, tools, methods, and technologies, including application of advanced mobile and connected vehicle data collection and communications technologies. The meeting also included several private sector attendees who exhibited and presented products and services available to support WRTM by transportation agencies.

A total of 23 State departments of transportation (DOT) were represented at the meeting, as shown in dark blue in Figure 25. Correspondingly, participants from each State represented provided feedback on their experience and perception of the meeting. The workshop report includes a summary of all sessions, a full list of participants, and a list of action items and recommendations that were highlighted as of interest to the stakeholder community.[19] Highlights from the participant responses include:

- Guidance on how DOTs can plan to deal with the data collected from connected vehicle (CV) and mobile sources in the development of new WRTM strategies is of great importance, as these strategies need to consider that the time and special data sets will be grossly different from current approaches and will require significant data management changes.
- Information related to the coordination of standards and exchange protocols for mobile data sources is needed. Participants noted there was good discussion regarding third-party information service provider (ISP) issues and suggested that instead of 50 different agreements with those service providers, FHWA should consider pursuing a national agreement/procedure for updating ISPs during extreme events.

[19] The summary report and presentations can be viewed and dowloaded from the Road Weather Management Exchange located at: https://collaboration.fhwa.dot.gov/dot/fhwa/RWMX/default.aspx under 'Documents' menu.

- Many WRTM strategies/tools discussed and presented can be beneficial to transportation agencies. As such, it is important to provide more guidance on how to conduct a benefit-cost analysis to justify intelligent transportation system (ITS) expenditures for better WRTM.
- More discussion is needed regarding the automation of processes to assist operators in the TOC/TMC during an event (e.g., messaging to dynamic message signs (DMS), website, and e-messaging). FHWA should continue helping State DOTs with more system automation, forecasting tools, active traffic management (ATM) systems, and other resources.
- Other items discussed included pre-storm DMS messaging, how to introduce variable speed limits into existing systems, and an updated assessment of highway advisory radio (HAR) usage by DOTs.



Source: FHWA

Figure 25. States Represented at the Weather Responsive Traffic Management Workshop.

KEY FINDINGS AND RECOMMENDATIONS

Below are some of the findings and relevant recommendations generated from the workshop:

- **There is more than one way to integrate connected vehicle technology into WRTM.** Every agency has unique characteristics due to their own operational reality. As such, agencies need to carefully assess their available resources in order to identify the best approach for integrating CV technology into their existing (or planned) WRTM strategies. For instance, an agency may already have a highly connected fleet, and therefore decide to concentrate on expanding the number of “connected travelers” instead.

- **It is possible to leverage CV technology, even if you are not a CV State.** It is not expected—nor is it required—that agencies operate at a highly advanced technological level in order to integrate CV technology into their operations. The data from CVs can be used by a wide range of users beyond the ones that operate CVs and manage the data. Agencies can still make use of the improved datasets from adjacent States to enhance the information distributed through existing (or easier to deploy) technologies, such as 511, smart phone applications and websites, as well as through third-party information providers.
- **Starting with a small number of agency fleets is a good way to enter into the CV environment**. With CV industry still maturing, standards, equipment, and regulations are still evolving. In this scenario, States are necessarily cautious about undertaking connected vehicle-enabled weather responsive traffic management (CV-WRTM) projects. However, starting with a small number of agency fleets through either the Integrated Mobile Observations (IMO) program or the American Association of State Highway and Transportation Officials V2I Connected Fleet Challenge represents an opportunity to understand the communication methods and data architectures required as well as the application development needed to take advantage of CVs.
- **A sustained push towards greater standardization of mobile weather sensor data is likely needed to make sure that weather information is adequately used by various entities within the CV environment**. Currently, data standards for weather-related sensors are still evolving in the CV environment. Greater emphasis on standardization of weather data elements in CV architectures is needed to ensure interoperability of CV systems developed by different States using different vendors.
- **Transitioning to CV-WRTM requires a careful review of data quality and communication interfaces that link the mobile, field and the center subsystems at a DOT.** As CV-WRTM advances, agencies will need to increase their ability to manage large streams of data, but they will also need to ensure the reliability of the communication channels that underlie the CV environment.
- **Support a technology transfer efforts from early adopters of CV-WRTM to the larger community.** Building from the Every Day Counts Weather Savvy Roads initiative, which continues to spur interest in and adoption of IMO, a renewed effort to translate IMO data into CV-WRTM applications is needed. With the current IMO program, agencies are becoming more capable of equipping fleets to collect mobile observations. However, the level of application development is still low. As a follow-on to the current EDC WSR initiative, a CV-WRTM initiative under EDC can provide a national spurt in adoption of CV-WRTM applications.

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Appendix A. Taxonomy of Commonly Used Messages for Road Weather

The column headings of the table list common methods used to distribute weather related information to the public.

The rows headings of the table are a list of common weather conditions that are often the topic of weather-related alerts, warnings, and messages. In addition, the first row provides standards and guidance for generic weather-related messages.

Table 10. Taxonomy of commonly used messages for road weather.

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
Overall Message Guidelines	Per the Guidelines for the Operation of Permanent Variable Message Signs,(26) it is not possible to display messages regarding adverse weather conditions (high winds, icy conditions, etc.) everywhere or every time they occur. TMC Operations and District maintenance personnel are generally in the best position to determine the need for chain-up requirements or to post other messages related to adverse weather conditions. Agency-	Any available weather-related information that impacts motorist travel should be displayed and delivered in a consistent manner. The two keys to weather are relaying impacts and providing navigational references to aid the traveler. *Weather Related Impacts* - when current or predicted weather conditions might cause accidents, incidents	HAR messages should contain the minimum number of words needed to convey the roadway situation. Messages should follow a standard format with an introductory statement, attention statement, problem statement, location, effect statement, and action statement. Messages should	No specific message guidelines are available for this category. Some policies have been established by agencies but no standard messages exist in this area.	No specific message guidelines are available for this category. Some policies have been established by agencies but no standard messages exist in this area.

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
	specific guidelines for DMS usage have been developed by several DOTs. Messages related to icy conditions should only be posted if conditions are unusual on that section of roadway. Black ice and ice that develops rapidly are examples of unusual conditions. Previous ice-related incidents or crashes at the location could provide additional support for providing motorists information about the current situation. If needed, a VMS can be used to display ice-related message.	and delays. *Navigation Reference* - presentation of weather information with a navigation reference such as: road segment; cities/towns; milepost; exits; major intersection/ interchange to major intersection/ interchange; landmarks; and rest areas.	follow FCC requirements and identify the broadcasting agency.		
A: Rain	#1 PERIODIC RAIN REDUCE SPEED USE HEADLIGHTS #2: SEVERE THUNDERSTORM WARNING TUNE TO LOCAL MEDIA #3 WET ROAD USE CAUTION	No Data	Operator fills in specifics including agency Identification, day/time, update frequency, radio call sign, and additional regulations in effect (e.g., Chains): RAINING ON PASS, WET PAVEMENT and	No Data	No Data

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
			SLIPPERY ROADS AHEAD. TURN LIGHTS ON FOR SAFETY. USE CAUTION AROUND CURVES. EXPECT SLOWER TRAFFIC.		
B: Snow	#1: WINTER WEATHER ADVISORY WATCH FOR DRIFTING SNOW ON EXIT RAMPS #2: #SNOW STORM WARNING UNTIL 9 PM TODAY NORTH/ NE IOWA #3 HEAVY SNOW WARNING UNTIL 9 AM MONDAY NORTH/NE IOWA	. . . early spring snow continues today. . . . periods of snow. . . heavy at times will continue across much of southeast Idaho today. some of the heaviest snowfall will occur along the interstate 84 corridor from burley to the Utah border where combined with strong winds will create very hazardous travel conditions. periods of snow are likely today in all of… More Details Current as of: 3/29/2016 2:10:00 AM PDT	Operator fills in specifics including agency Identification, day/time, update frequency, radio call sign, and additional regulations in effect (e.g., chains). SNOWING ON PASS, 4-6 INCHES EXPECT SLOWER TRAFFIC, SLIPPERY ROAD USE CAUTION RECOMMEND MOTORISTS SLOW DOWN, USE HEADLIGHTS	#1 Snow is blanketing NE Ohio this AM! Ohgo. com showing significant slowdowns & reduced visibility #2 #Flagstaff is waking up to snow, very slippery roads and an I-40 EB closure at the east end of town. #azwx #3: Snow is building up on I-17 south of Flagstaff. Snowplows are out. Please adjust speed to conditions. #azwx #4: Travel is	#1 HEAVY SNOW .08 miles ahead

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
				extremely difficult and NOT recommended. Snow is still falling & blizzard conditions exist over much of the area. Please be safe! #5 Another cool feature of the Mi Drive pilot project showing snowplows in SW Michigan?Camera feeds on select plows	
C: Ice	#1WINTER WEATHER ADVISORY ICE & SNOW TAKE IT SLOW #2 ICY BRIDGE AHEAD USE CAUTION #3 WATCH FOR ICE NEXT XX MILES #4 EXTREME ICE COND	areas of black ice this morning. . . a late season winter storm that brought heavy snowfall to portions of western Nevada and northeastern California on Monday has resulted in many roads being slick and icy this morning. the only exception are the major highways such as i-80 and highway 50 which are generally dry. travelers and	Operator fills in specifics including agency Identification, day/time, update frequency, radio call sign, and additional regulations in effect. (e.g., chains). #1 ICE AND SNOW ON INTERSTATE 5	#1: #Rain on top of this snow & low temps are leaving bridges and roadways #ICED over @NCDOT_Triad is salting through the night #ncwx #SLOWDOWN #2: Mocosnow	No Data

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
	USE CAUTION #5 BLACK ICE REDUCE SPEED	commuters should allow for… More Details Current as of: 3/29/2016 2:25:00 AM PDT	FROM MPXX TO MPXX. SLIPPERY CONDITIONS EXIST. MOTORISTS SHOULD USE CAUTION, BE ALERT. #2 PATCHES OF BLACK ICE ON INTERSTATE 5 SLIPPERY CONDITIONS EXIST. MOTORISTS SHOULD USE CAUTION, BE ALERT, WATCH FOR PUDDLE-LIKE PATCHES ON ROADWAY.	February 15 Winter Storm WARNING now in effect for MoCo until 10:00am. A quarter inch of ice from freezing rain expected. #3 Pavement temperatures have remained above freezing today, but these will fall quickly tonight & icy conditions will result. Please be safe!	
D: Wind	#1 VEHICLES OVER 9 FEET HIGH USE CAUTION #2 BAY BRG WIND ADVISORY USE CAUTION #3 I-25 CLOSED TO LIGHT	I-77N at MM 1. 0 Description: On I-77 North at mile marker 1 in the County of Carroll, near Fancy Gap Mountain, motorists can expect potential delays due to high wind.	Operator fills in specifics; including agency identification, day/time, update frequency, radio call sign, and additional regulations in effect. (e.g., chains)	#1 Several weather alerts for potential severe t-storms and damaging winds. Please check your local weather for updates. #MDAlert #2 Weather Alert	No Data

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
	HIGH PROFILE VEHICLES WIND GUSTS 55+ MPH #4 CAMPERS AND TRALERS PROHIBITED	Last updated: Mon 03/28/2016 12:27 PM EDT	HIGH WINDS AHEAD AFFECTING TRUCKS AND RV'S, CROSS WINDS GUSTING FROM 0-90MPH ALL TRUCKS AND CAMPERS USE CAUTION. USE HEADLIGHTS FOR SAFETY.	Cont: SW wind gusts 45-55+ mph Southern UT Mon. Check UDOT Traf app b4 travel. @UtahTrucking http://www. udottraffic. utah. gov/RoadWeatherForecast #3 High wind warning on the #MightyMac this morning, and reduced visibility as well. http://mackinacbridge. org/conditions-25/	
E: Flooding	#1 CAUTION FLOODING AHEAD #2 FLASH FLOOD WARNING SANTA FE AREA (Panel 1) TUNE TO XXXX AM (Panel 2)	Flooded Road State Route 104 both directions in Dyer County - Between SR-181 (GREAT RIVER RD.) RT. & LT. and SR-182 (LENOX-NAUVOO RD.) LT., flooded road conditions were reported at 3/17/2016 7:45:00 AM with	THIS IS YOUR WASHINGTON HIGHWAY ADVISORY RADIO COMING TO YOU FROM TRAFFIC CONTROL HEADQUARTERS, 1660 KILOHERTZ ON	The NWS has extended the Flood Warning for Carroll and Frederick Co now in effect till 1PM today. #MdWx	#1 Road Closed RT FF BOTH PLATTE RIVER BUCHANAN Route is affected from .12 MILES

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
	#3 MUTCD Signage ROAD MAY FLOOD (W8-18)	the roadway is closed to thru traffic.	YOUR DIAL. ATTENTION ALL TRAFFIC HEADED SOUTH ON INTERSTATE 5. YOU ARE ADVISED THAT THERE IS FLOODING BETWEEN WASHINGTON STATE ROUTE 599 AND WASHINGTON STATE ROUTE 518 JUST NORTH OF THE SEATTLE-TACOMA INTERNATIONAL AIRPORT. THIS FLOODING IS CAUSING TRAFFIC CONGESTION AND WILL RESULT IN SOME DELAY IN YOUR TRAVEL TIME ON INTERSTATE 5. BE ALERT FOR SLOWING VEHICLES. PLEASE DRIVE		BEFORE RT H W to AT RT H W

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
			SAFELY AND THANK YOU FOR LISTENING TO THE WASHINGTON HIGHWAY ADVISORY RADIO SYSTEM FOR TIMELY TRAFFIC REPORTS.		
F: Fog	#1 DENSE FOG AHEAD #2 “DENSE FOG” (panel 1) “ADVISE 50 MPH” (panel 2)	A fog advisory is in effect for Santa Rosa County. Motorists are asked to use caution.	ATTENTION ALL DRIVERS FOGGY CONDITIONS VISIBILITY IS LIMITED 0-15 FEET REDUCE SPEED USE HEADLIGHTS	No Data	No Data
G: Other Low Visibility	#1 REDUCED VISIBILITY AHEAD DRIVE SLOWLY	No Data	No Data	No Data	No Data
H: Other Weather Events/Weather Notices	#1 DUST STORM AHEAD USE CAUTION	Passenger vehicles are required to have snow or mud/snow tires, use chains/alternative traction devices, or a 4WD/AWD vehicle. Restriction began March 29th, 2016 at 7:04pm.	No Data	#1 Tornado Watch: Charles, Frederick, Harford, Howard, Kent, Montgomery Counties, as well as Baltimore City until 11PM. #MdWx #2 RAIN = wipers	No Data

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
				on. SNOW = wipers on. MIST = wipers on. WIPERS ON = LIGHTS ON!	
I: Other weather related notices	#1 SNOW REMOVAL EQUIPMENT IN USE USE CAUTION #2 SNOW ZONE CHAINS REQUIRED NEXT XX Miles OR ROAD NAME #2 SNOW ZONE CHAIN OR TRACTION TIRES VEH TOWING OR OVER 10000 GVW	No Data	No Data	No Data	No Data
J: CLOSURES	#1 CLOSED TO OVERSIZED DUE TO FOG USE EXIT x (OR) Roadway	No Data	No Data	No Data	No Data

	1: Dynamic Message Signs	2: 511 Website/Phone	3: Highway Advisory Radio	4: Social Media*	5: Apps
K: Heat Advisories	No Data	No Data	No Data	511 TRAVEL UPDATE: As the heat index pushes 100-degrees in some parts of Wisconsin, there's the possibility for pavement buckling or "blow outs" to occur. Stay alert and be on the lookout for damaged patches of road. Also, remember to move over, when safely possible, or at least slow down for highway crews making repairs. If this hot and humid stretch leads to major traffic delays or backups, you'll find them on www.511wi.gov or @511wi.	No Data

***** Social media refers to Twitter and Facebook.

Sources (organized by column number and row letter):

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