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

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16. Abstract

State and local Departments of Transportation (DOTs) are interested in providing effective traffic management and operations strategies to mitigate the roadway mobility and safety problems due to adverse weather. Weather Responsive Traffic Management (WRTM) strategies such as variable speed limits, vehicle restrictions, signal timing, and traffic advisories are used today to provide travelers with advanced temporal and spatial notification of hazardous conditions that may be encountered as well as appropriate actions to take in response to the existing or forecast weather conditions.

Improved connectivity between the transportation infrastructure and vehicles and among vehicles themselves presents unique capabilities to enhance these WTRM strategies by: (1) enabling communication (i.e., 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.

Connected Vehicle-Enabled WRTM (CV-WRTM) is an approach that leverages this connectivity to develop and implement advanced capabilities for WRTM. Moving to this next generation of WRTM can take on different forms. This document identifies and describes three distinct, but related, pathways that could be taken.

1. Pathway 1- Intelligent Agency Fleets
2. Pathway 2- Connected Vehicles
3. Pathway 3- Connected Third Party Fleet Services and Connected Travelers

This document provides high-level guidelines on advancing connected vehicle enabled WRTM using these three implementation pathways. More detailed concepts and procedures for selected CV-WRTM Applications are provided to illustrate the pathways.

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Executive Summary

State and local departments of transportation (DOT) are interested in providing effective traffic management and operations strategies to mitigate roadway safety and mobility problems due to adverse weather. Weather responsive traffic management (WRTM) strategies such as variable speed limits, vehicle restrictions, signal timing, and traffic advisories are used today to provide travelers with advanced temporal and spatial notification of hazardous conditions that they may encounter as well as appropriate actions to take in response to the existing or forecast weather conditions. Effective deployment of these strategies depends upon the 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.

Improved connectivity between the transportation infrastructure and vehicles and among vehicles themselves presents unique capabilities to enhance these WTRM strategies by: (1) enabling communication (i.e., 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.

Connected vehicle-enabled weather responsive traffic management (CV-WRTM) is an approach that leverages this connectivity to develop and implement advanced capabilities for WRTM. Moving to this next generation of WRTM can take different forms.

- Pathway 1- Intelligent Agency Fleets: Arguably the starting point for many agencies, this pathway connects the fleets that an agency owns, or has access to, to support WRTM. The fleets could be snow plows, highway patrol vehicles, and other maintenance vehicles that are frequent users of the roadway, especially during adverse weather conditions. Many of these fleets have existing remote communication capabilities through either cellular links or agency-owned radio systems and can transmit both voice and data.
- Pathway 2- Connected Vehicles: The U.S. Department of Transportation (USDOT) defines a connected vehicle (CV) as one that can transmit and receive basic safety messages (BSMs) following the wireless access in vehicular environments (WAVE) protocol, established in 802.11p-2010, the Institute of Electrical and Electronics Engineers (IEEE) Standard for Information technology, which uses the intelligent transportation systems (ITS) band of 5.9 GHz (5.85 – 5.925 GHz)[1]. The second pathway relies on the possibility that regulation might require light vehicles to have dedicated short-range communications (DSRC) capabilities. DSRC is a networking technology that allows for fast, secure, and reliable communications for various vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-nomadic device (V2X) applications.
- Pathway 3- Connected Third Party Fleet Services and Connected Travelers: In parallel with State DOT fleet efforts, several private fleets have high levels of connectivity and potentially can send and receive information of value to WRTM. There are many private sector services and organizations that are looking at equipping fleets with data integration and communications

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[1] U.S DOT, Connected Vehicles Environment Fundamentals 101, available at http://stsmo.transportation.org/Documents/ConnectedVehiclesToInfrastructure101_PresentationRev7.pdf

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equipment or enabling data collection through an app on a nomadic device. Not reliant on DSRC adoption, data from these third party sources can provide information that is often difficult or costly for a public agency to collect. The difference between Pathway 1 and Pathway 3 is the reliance on third-party providers to provide and receive data from the public agency.

Note that these pathways are not mutually exclusive, and all lead to the same end. In fact, 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.

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 ES-1). Each phase consists of steps that detail the activities within its scope.

1. **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.
2. **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.
3. **Phase III** develops specific information needed to design the CV-WRTM system, including partnerships, procurement, and deployment plans.
4. **Phase IV** describes what will be required to manage and maintain the new system in order to achieve expected and desired performance levels.

There are three priority CV-WRTM applications, as follows:

1. **Connected Vehicle-enabled Variable Speed Limits (CV-WRTM-VSL) –** Each pathway can be used to help an agency post advisory or enforceable speed limits that take into account the actual road weather conditions. Variable speed limits help reduce speed variation between vehicles, a contributing factor to crashes during adverse weather. Traditionally, variable speed limits are set based on field-reported conditions or traffic video camera streams into the traffic management center (TMC)). Concepts in this application can be extended to posting roadside advisories via dynamic message signs (DMS) or highway advisory radio (HAR), imposing vehicle restrictions (e.g., for high-profile vehicles), or even implementing a road closure.
2. **Infrastructure to Vehicle (I2V) Situational Awareness for WRTM (CV-WRTM-SA) –** Situational awareness messages are valuable to travelers. Those messages that are conveyed through motorist alerts and advisories pertain to vehicle restrictions, chain laws, and parking

Phase I - Planning for CV-WRTM
- Step 1 – Needs Assessment
- Step 2 – Current Capability Assessment
- Step 3 – Concept Exploration
- Step 4 – Feasibility Assesment

Phase II – Concept Development
- Step 5 – Concept of Operations Development
- Step 6 – Safety, Security, and Privacy Concept Development
- Step 7 – Performance Measurement Plan
- Step 8 – Human Factors Plan

Phase III – System Development and Design
- Step 9 – Systems Requirements
- Step 10 – Application Development Plan
- Step 11 – System Design
- Step 12 – Partnership Development
- Step 13 – System Deployment

Phase IV – Operations and Maintenance
- Step 14 – Operations and Maintenance

Figure ES-1. Recommended steps for implementing CV-WRTM strategies.

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notifications provided directly to vehicles via DSRC, cellular, or satellite communications (depending on the pathway). Concepts in this application can be extended to support spot-specific weather impact warning (SWIW).

3. **Vehicle to Vehicle (V2V) Situational Awareness for WRTM (CV-WRTM-V2V) –** Employs V2V communication for collision avoidance and for sharing and forwarding distress notification between vehicles. This application depends on DSRC communications, so it requires a critical mass of vehicles equipped with DSRC on-board equipment.

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 utilizing connected vehicle data for weather responsive traffic management. 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.

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Chapter 1. Introduction

1.1 Context

Managing safety and reliability of travel during adverse weather conditions is a mission-critical activity for State and local departments of transportation (DOT). By effective use of advisory, control and treatment strategies, DOTs can support timely decision making by travelers and improved agency responses prior, during and after weather events.

Today, under the umbrella of weather responsive traffic management (WRTM), strategies such as speed management, vehicle restrictions, signal timing, and traffic advisories are used to 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. Figure 1-1 provides examples of the application of a variable speed limit strategy in Washington and a road closure strategy in Wyoming.

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.

The breadth and depth of WRTM strategies continue to grow. In a recent survey that summarized levels of deployment of road weather management practices, advisory information on road conditions was widespread, with 511 systems (i.e., phone, web, app) and dynamic message signs (DMS) reported as the two most popular ways for State DOTs to communicate road weather information. Highway advisory radio (HAR) systems are also used by many State DOTs to disseminate traveler information. The most widely deployed control strategy, either partially or statewide, is related to responding to traffic incidents that occur on the roadway. Less commonly used strategies include ramp meter adjustments and signal timing (FHWA, 2015).

Agencies still face several challenges in deploying WRTM, including:

Source: Washington Department of Transportation

Source: Wyoming Department of Transportation

Figure 1-1. Examples of weather responsive traffic management strategies.
Top: variable speed limit system in Washington.
Bottom: road closure system in Wyoming.

- Limited coverage of road weather information systems (RWIS) on roadways, leading to gaps in road condition information. The cost of installing and maintaining an RWIS is significant. Constrained budgets make it difficult to greatly expand the agency RWIS network quickly.
- Difficulty in communicating with travelers on the roadways, especially about rapidly changing conditions. Adverse road conditions may be detected in areas where there is no DMS or HAR coverage.
- Evolving, though improving, operational integration 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 accomplish the goals of WRTM. Connectivity presents unique capabilities to enhance WTRM strategies by: 1) enabling communication (i.e., 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 needs to take advantage of the potential offered by connected vehicles (CV). As shown in

Figure 1-2, 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. While the arguments in favor of connected vehicles are compelling, details on how best to move forward may not be.
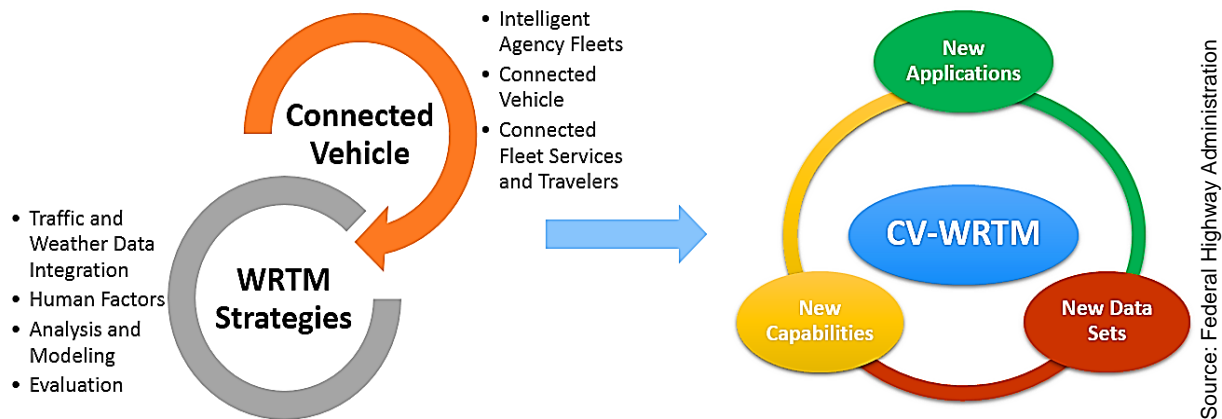
Figure 1-2. CV-WRTM: leveraging connected vehicles for weather responsive traffic management.

As illustrated in Figure 1-3, agency managers have a host of questions that need to be addressed before they commit to connected vehicle technology beyond research and pilot projects.

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Figure 1-3. Questions these guidelines address.

1.2 Pathways for Connected Vehicle-enabled Weather Responsive Traffic Management

Moving to the next generation of WRTM can take on different forms, and leveraging vehicle connectivity has multiple pathways. This document identifies three distinct but related pathways that can be taken by State and local DOTs. The pathways shown in Figure 1-4 are not mutually exclusive, and all lead to the same end. In fact, they build on each other, and each pathway provides unique value to the potential system deployments. It is also important to note that agencies could already employ some elements of each pathway, and the capabilities represented by each can overlap.
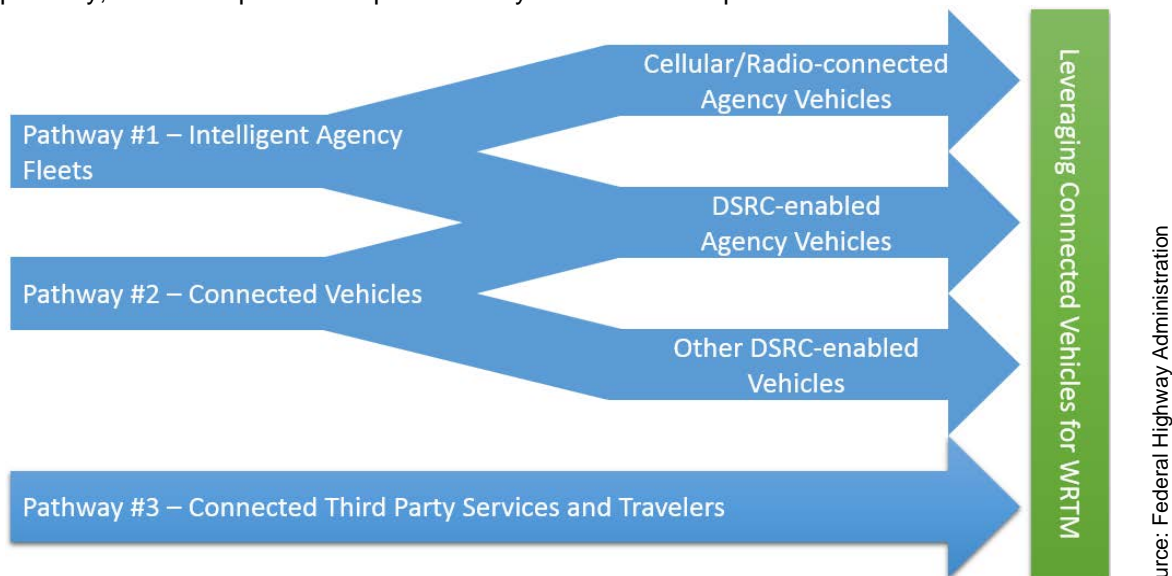
Note: DSRC = dedicated short-range communication. WRTM = weather responsive traffic management.

Figure 1-4. Supportive pathways for CV-WRTM.

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1.2.1 PATHWAY 1- INTELLIGENT AGENCY FLEETS

Arguably the starting point for many agencies, this pathway connects the fleets that an agency owns, or has access to, in order to support WRTM. The fleets could be snow plows, highway patrol vehicles, and other maintenance vehicles that are frequent users of the roadway, especially during adverse weather conditions, as illustrated in Figure 1-5. Note that, because fleet vehicles are publicly owned, agencies can easily set up communications among them through policy changes, precluding the possibility of drivers opting out of data sharing. Many of these fleets have existing remote communication capabilities through either cellular links or through agency-owned radio systems and can transmit both voice and data.

Figure 1-5. Examples of vehicles in agency fleets.

Traditionally, data and voice communications from fleets have served singular purposes. Data from snow plows has supported winter maintenance management. Similarly, data from the highway patrol has supported emergency response. However, there is a real opportunity to use data coming from these fleets for WRTM.

Increased use of mobile observations will support a wide variety of strategic and tactical decision-making for State DOT maintenance and traffic operations. In the 2015 State DOT survey conducted by FHWA (n=40), practitioners were asked whether their agencies collect real-time field data from maintenance vehicles and, if so, from what percentage of applicable fleets. The results indicate that 20 of the States surveyed collect real-time field data from maintenance vehicles; Figure 1-6 shows the type of data collected and from what percentage of the applicable vehicle fleets. The results of the survey show that collecting data fleet-wide is starting to become state of the practice. As many as three State DOTs reported using 100 percent of the fleet to collect data, compared to zero in 2013 (Gopalakrishna D., 2015).

For example, snow plows can improve the situational awareness of drivers during adverse weather events. From road condition reports, to vehicle location, to treatment information (materials used and treated routes), to data from installed weather sensors (and even from the vehicle itself), snow plows provide a plethora of information that can be used for traffic management. Figure 1-7 shows examples of the information that could be collected through Pathway 1. Today, equipped vehicles can collect and share a variety of information, including:

- Time.
- GPS location (e.g., coordinates, altitude, and compass heading).
- Speed.
- Photos (taken by the driver or when an autonomous event such as ABS or traction control activation occurs).
- Environmental condition (e.g., road surface temperature, dew point, ambient air temperature, humidity).
- Onboard diagnostic keys (e.g., tachometer, throttle, brake activation, anti-lock braking system activation, electronic stability control activation, traction control system activation, windshield wiper activation).
- Highway treatment activity; materials used, spread rate and locations.
- Road surface coefficient of friction (grip).

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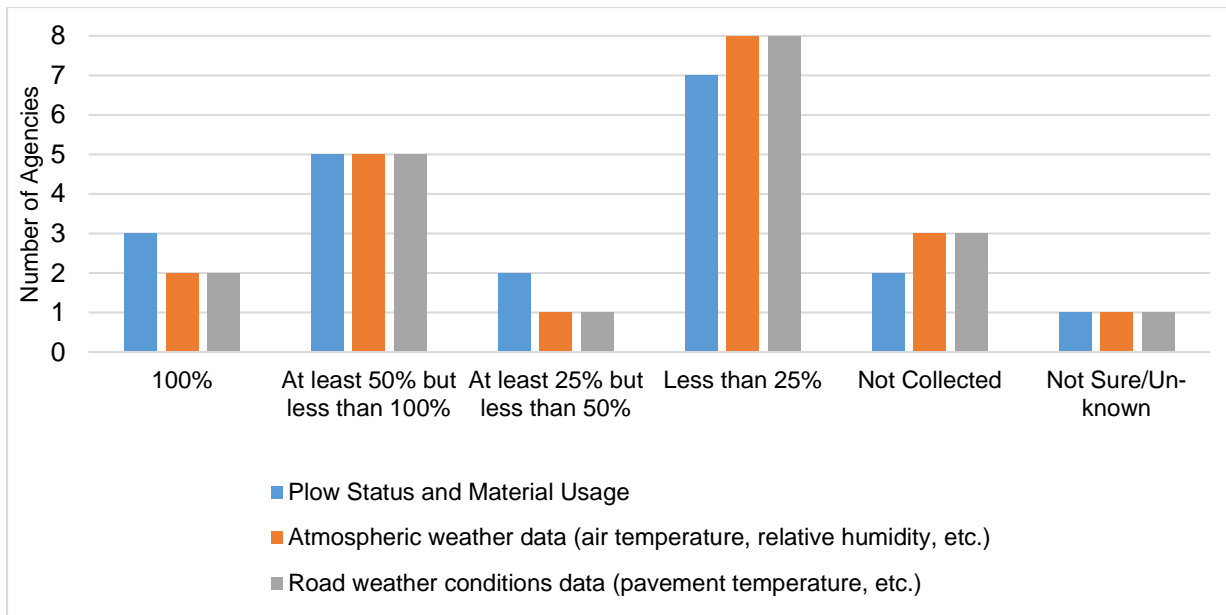
Figure 1-6. Use of mobile data from vehicle fleets by agencies.

From the information listed above, data files are then created at specific time intervals (e.g., 5 minutes), sent via cellular to a server, validated, and then shared with users. When this data is available to traffic managers, they can significantly affect how advisory and control strategies are implemented. For example, road condition data can be directly shared with the traveling public through existing traveler information systems (e.g., 511, web sites and DMS). Maintenance data and weather sensors can influence road closures and vehicle and speed restrictions. From an agency perspective, this pathway is appealing because the agency controls the fleets, in many cases with drivers being State employees. Data collected from these fleets is owned by the implementing agency and can serve multiple purposes, as illustrated in Figure 1-8. This data can support road weather forecasting and traffic management, traveler information systems, winter maintenance operations, and transportation asset management, along with other potential applications.

Ultimately, as the role of dedicated short-range communication (DSRC) grows, it is likely that agency fleets will begin to have such connectivity which will allow them to merge this pathway with the second pathway.

Figure 1-7. Potential information collected through Pathway 1.

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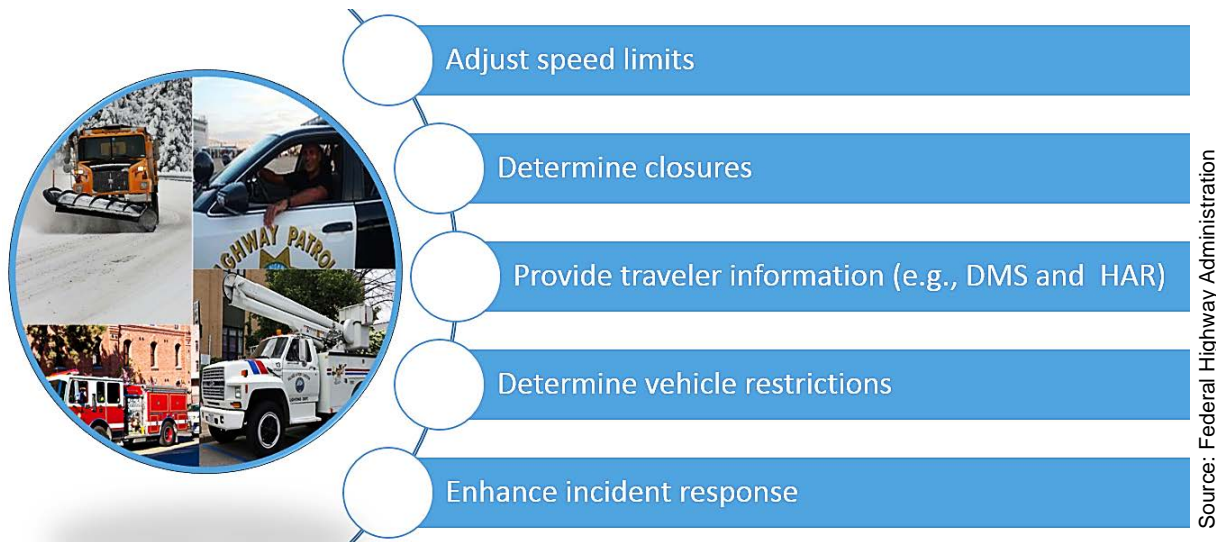
Figure 1-8. Uses of Pathway 1 for weather responsive traffic management.

1.2.2 PATHWAY 2- CONNECTED VEHICLES

The U.S. Department of Transportation (USDOT) defines a connected vehicle as one that can transmit and receive basic safety messages (BSM) following the wireless access in vehicular environments (WAVE) protocol, established in the Institute of Electrical and Electronics Engineers (IEEE) Standard IEEE 802.11p which uses the ITS band of 5.9 GHz (5.85 – 5.925 GHz).[2]

The second pathway relies on the possibility that regulation might require light vehicles to have DSRC capabilities. DSRC is a networking technology that allows fast, secure, and reliable communications for various vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-nomadic device (V2X)[3] applications. Vehicles could include:

1. Connected Fleet Vehicles (DSRC communication) – These consist of agency-owned vehicles with DSRC communication capabilities. The addition of DSRC provides more localized communication between roadside units (RSUs) and other DSRC-equipped vehicles based on the application.
2. Private Automobiles with DSRC – These automobiles have the ability to receive and transmit data via DSRC for short-range communication between vehicles and RSUs. These vehicles are able to broadcast basic or enhanced safety messages as part of the CV environment.
3. Specialty vehicles with DSRC – Similar to private automobiles, these are transit and freight vehicles that have the ability to receive and transmit data via DSRC for short-range communications with other vehicles and RSUs. These vehicles are able to broadcast basic or enhanced safety messages as part of the CV environment.

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[2] U.S DOT, Connected Vehicles Environment Fundamentals 101, available at
http://stsmo.transportation.org/Documents/ConnectedVehiclesToInfrastructure101_PresentationRev7.pdf
[3] Nomadic devices refer to other electronics that have connective capability that could interact with the vehicle, such as cellphones.

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The vehicles described above communicate not only with each other but also with DSRC-enabled roadside units which, in turn, communicate with back office data collection and management systems.

Information from connected vehicles takes the form of a BSM that is transmitted over DSRC. BSMs are based on standard *J2735: Dedicated Short Range Communications (DSRC) Message Set Dictionary* (SAE, 2016), which has two parts:

1. BSM Part I which contains the core data elements (vehicle size, position, speed, heading acceleration, brake system status) and is transmitted approximately 10 times per second;
2. BSM Part II, which is added to Part I depending upon events (e.g., activated when the automatic braking system (ABS) engages) and contains a variable set of data elements drawn from many optional data elements (availability by vehicle model varies) that are transmitted less frequently.

Other vehicle probe data and event logs may be transmitted over DSRC as well, including traveler information messages (TIM)[4]—as defined in J2735 (SAE, 2016) and yet-to-be-defined basic infrastructure messages (BIM).[5] Figure 1-9 shows examples of the information that could be collected through Pathway 2.

The DSRC-enabled CV environment enables a wide variety of new and modified strategies that provide advisory, control and treatment information to operations staff. The Connected Vehicle Reference

Basic Safety Message Part I

Basic Safety Message Part II

Other Vehicle Probe Data

Event Log

Source: Federal Highway Administration
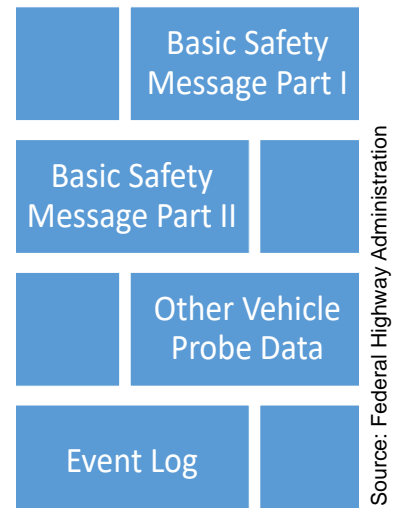
Figure 1-9. Potential information collected through Pathway 2.

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[4] The TIM is used to send various types of information (advisory and road sign types) to equipped devices. It makes heavy use of the International Traveler Information Systems (ITIS) encoding system to send well known phrases, but allows limited text for local place names. The supported message types specify several sub-dialects of ITIS phrase patterns to further reduce the number of octets to be sent. The expressed messages are active at a precise start and duration period, which can be specified to a resolution of a minute. The affected local area can be expressed using either a radius system or one of the systems of short defined regions, similar to the way roadway geometry is defined in mapdata (MAP) messages.

[5] While standards for the BIM are currently being developed, a clear description of its intended purpose is that BIMs will serve as supplementary information to the BSMs and TIMs, focusing on infrastructure-related information. While some of the infrastructure-related information (i.e. a Signal Phase and Timing (SPaT) message, and a MAP message (including intersection ID, reference point, orientation, lane width, type, etc.)) are already included in the current standards, there are other pieces of infrastructure information that may benefit connected vehicle applications, such as standard signage in the area, presence of school zones, work zones and lane closures, messages displayed on variable messages signs or highway advisory radios, and horizontal and vertical alignment of the infrastructure, amongst other. A BIM message would relay this information to the CV, which, when combined with BSM and TIM, would allow the system to perform more robust analyses and to yield more accurate advisories and alerts to the driver.

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Implementation Architecture (CVRIA)[6] includes 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 CVRIA 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.

From an agency standpoint, the potential of DSRC-enabled connected vehicles is just starting to emerge, and several important research initiatives are underway to move DSRC-based connected vehicle technology into operational use.

With the USDOT-funded CV Pilot Deployments and ongoing initiatives at other State DOTs, several road-weather-specific applications will be tested in the real world in 2017. From a traffic management standpoint, most of the applications have focused on advisories (alerts/advisories) rather than control. However, there are concepts that can utilize CV data for control strategies such as variable speed limits, signal timing, and road closures. The penetration rate of DSRC-equipped vehicles is dependent on both DOT rulemaking as well as adoption rates by vehicle manufacturers.

1.2.3 PATHWAY 3- CONNECTED THIRD PARTY FLEET SERVICES AND CONNECTED TRAVELERS

In parallel to State DOT fleet efforts, several private fleets are being extensively connected and potentially can send and receive information that is vital to WRTM. There are many private sector services and organizations that are looking at equipping fleets with their equipment or enabling data collection through an app on a nomadic device.

Not reliant on DSRC adoption, data from these third party sources can provide information that is often difficult or costly for a public agency to collect. Figure 1-10 illustrates the third pathway identified in this

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[6] CVRIA provides the basis for identifying the key interfaces across the connected vehicle environment, supporting the identification and prioritization of standards related to connected vehicles. More information can be found in http://www.iteris.com/cvria/index.html.

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document. The difference between Pathway 1 and Pathway 3 is the reliance on third-party providers to provide and receive data from the public agency.

Weather and Traffic Data   **Private Sector Data**

Third Party Services

State and Local Agencies

Traveler Information Messages   **Agency-owned data and information**
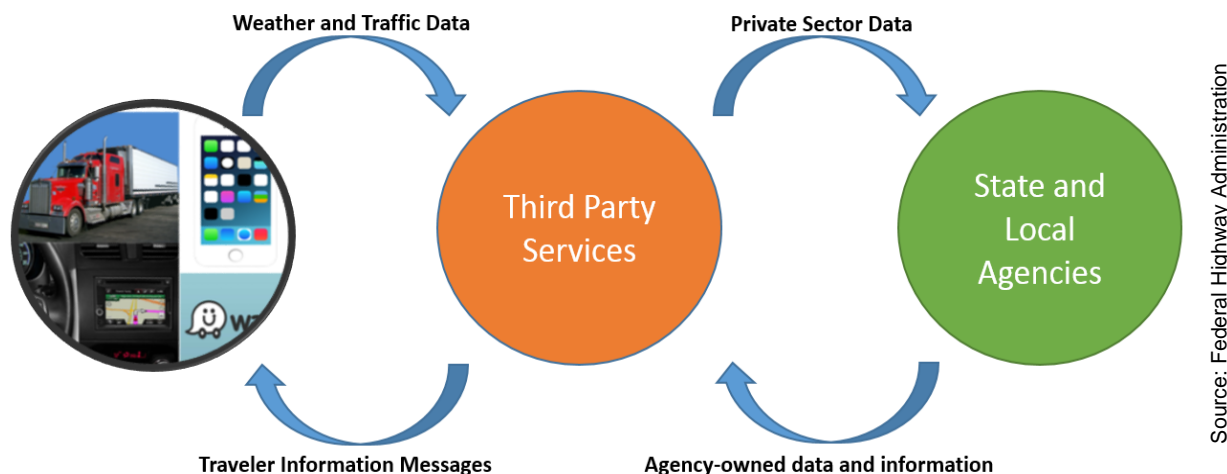
Figure 1-10. Pathway 3: Non-dedicated short range communications-based connected vehicles and travelers.

Figure 1-11 shows examples of the information that could be collected through Pathway 3. Note that data on speeds along various segments (both freeways and arterials) are increasingly being sourced from private vendors, who obtain data from connected fleets and travelers. Several of these vendors are moving toward additional value-added services such as origin/destination, truck parking, and road condition data. State DOTs have also developed mobile apps that both send and receive crowd-sourced weather and road condition information. Private companies have also unveiled road weather tools that reports road conditions based on crowdsourced information. Other companies use smartphone-based sensors to collect data on driving behavior and vehicles, and some are developing approaches for using this data to infer road conditions.

New initiatives like Mobile Platform Environmental Data (MoPED) rely on weather information obtained from equipped commercial vehicles, as they travel major transportation routes (not excluding state and local corridors), providing extensive coverage through urban, suburban and rural areas in between the origin and destination points. In this sense, MoPED acts as a supplement to fixed weather stations from airports and RWIS as it is able to detect small-scale phenomena (e.g., thunderstorm or flash flood) that occur between fixed station points.

Many of these fleets are also potential recipients of information available from the transportation agency. For example, some State DOTs are entering data-sharing partnerships with private navigation app providers that use information from millions of drivers to provide traffic conditions in real-time. These agreements entail a non-exclusive cross-licensure of each party's traffic data with the objective of enhancing each provider's individual ability to supply needed traffic information to the traveling public. Examples of States that have entered two-way data-sharing partnerships are Florida, Pennsylvania, Oregon, Kentucky, New York,

Speed Data

Truck Parking P

Weather Conditions

Incidents

Congestion Levels

Figure 1-11. Potential information collected through Pathway 3.

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California, Utah, Massachusetts, Maine, Vermont, New Hampshire, and Iowa. Most of these agreements took effect in 2015 (Florida DOT, 2015; Oregon DOT, 2015; New Hampshire DOT, 2015; Bereznak, 2014; Danielson, 2015).

Public agencies are increasingly procuring data from these private services for various reasons, including traffic management. Some of the cost of acquiring this data can be offset if what is purchased eliminates the need for fixed infrastructure devices. In addition, agencies are not responsible for the maintenance and update of equipment on fleets or for the data processing required to create useful information for the DOT.

Many of the applications identified for Pathway 1 can also use data provided by Pathway 3.

1.3 Intended Users and Uses of the Guidelines

The guidelines are primarily targeted at State and local DOT personnel in charge of either road weather maintenance or traffic operations.

Figure 1-12 illustrates the key users of the guidelines and their interests in this topic.

Traffic Managers
- How can I use CV technologies to support traffic management during weather events?
- What steps do I have to take and requrements do I need to meet in order to successfully implement CV-WRTM?

Maintenance Managers
- How can CV-WRTM improve maintenance operations in my agency?
- How can I make our maintenance vehicles support CV-WRTM?

ITS Program Managers
- How can I integrate various on-going connected vehicle technology deployments for WRTM?
- How can I create a roadmap for deploying sustainable CV technology for WRTM?

Source: Federal Highway Administration

Figure 1-12. Users of guidelines and their key questions.

The guidelines are intended to address specific questions and provide information on moving forward along each pathway for CV-WRTM. Agencies can go directly to specific chapters depending on whether they are looking for guidelines on planning, applications, and issues particular to each individual pathway.

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1.4 Structure of the Guidelines

The guidelines are organized around the three pathways identified for CV-WRTM. However, key elements that are common across the three pathways are provided as separate chapters. Figure 1-13 provides the outline of the guidelines identifying each chapter and its contents. In each chapter, resource and implementation tips are provided in text boxes. The appendix provides guidelines for three specific applications for CV-WRTM.

Chapter 1. Introduction	• Provides the context and the definition of the pathways
Chapter 2. Core Capabilities	• Defines the core capabilities that are needed to begin the evolution toward CV-WRTM including the role of the Transportation Management Center (TMC), ability to integrate mobile data, and provides key resources that are common across all pathways
Chapter 3. Pathway 1 – Intelligent Agency Fleets	• The following topics are discussed for Pathway 1: • Examples • Planning and Development Guidelines • Applications Supported • Institutional Issues • Constraints and Challenges • Performance measures • Key Resources
Chapter 4. Pathway 2 – Connected Vehicles	• The following topics are discussed for Pathway 2: • Examples • Planning and Development Guidelines • Applications Supported • Institutional Issues • Constraints and Challenges • Performance measures • Key Resources
Chapter 5. Pathway 3 – Connected Third Party Fleets and Travelers	• The following topics are discussed for Pathway 3: • Examples • Planning and Development Guidelines • Applications Supported • Institutional Issues • Constraints and Challenges • Performance measures • Key Resources
Chapter 6. Implementation Process	• Provides a sequence of steps that an agency could follow to implement CV-WRTM strategies.
Appendices	• Appendix A – Concept Development Of Selected CV-WRTM Applications • Appendix B – List of References and Resources • Appendix C – List of Acronyms and Terms

Source: Federal Highway Administration

Figure 1-13. Guidelines structure.

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Chapter 2. Core Capabilities for Connected Vehicle-Enabled Weather Responsive Traffic Management

Effectively using connected vehicle technology for weather responsive traffic management (WRTM) requires new capabilities, partnerships, and agreements regardless of which connected vehicle-enabled weather responsive traffic management (CV-WRTM) pathway is followed. WRTM and connected vehicles (CV) each include a variety of strategies and applications for which the current capabilities need to be assessed. The core capabilities listed in Figure 2-1 are likely to become important as the agency progresses towards greater use of connected vehicle data and applications for managing traffic during weather events. Each capability is explained in the following subsections. While the core capabilities are not listed in any particular order, it is recommended that an agency undertake a close examination of capabilities in all these areas before embarking on CV-WRTM.

- Role of traffic management centers in managing connected vehicle-enabled weather-responsive traffic management
- Collaboration between maintenance, weather enterprise and traffic operations
- Establishment of new partnerships
- Effective messaging for road weather
- Systems engineering capabilities
- Safety, security and privacy management
- Performance measurement and reporting
- Operation and maintenance of the connected vehicle environment
- Data capture and management

Source: Federal Highway Administration

Figure 2-1. Core agency capabilities for CV-WRTM.

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> **Resource Tip**: The Road Weather Capability Maturity Framework (CMF) is a good tool to assess capability of road weather management programs and identify specific actions. Through the use of the framework, agencies can quickly assess their relative strengths and weaknesses in key process areas for road weather management. Implementation actions to address the weaknesses allow for progression to advanced strategies like CV-WRTM. The CMF can be found in the following link:
>
> http://www.ops.fhwa.dot.gov/tsmoframeworktool/available_frameworks/road_weather.htm

> **Implementation Tip(s):** Conduct a road weather management capability assessment workshop prior to moving forward with CV-WRTM.

2.1 Role of Traffic Management Centers in Managing Connected Vehicle Technology for Weather Responsive Traffic Management

Traffic management centers (TMC) are often the nerve center of operations management during typical adverse weather events. While emergency operations centers (EOC) may be activated for larger scale or high-impact events, on a day-to-day basis, the TMC staff plays a vital role in activation and deactivation of available advisory, control, and treatment strategies. TMCs around the country have diverse functional responsibilities during weather events from managing signals, to responding to incidents, to adjusting speed limits, to managing closures and setting vehicle restrictions. Often these activities are closely coordinated with law enforcement and maintenance field personnel.

> **Resource Tip(s)**: A good summary of the role of TMCs can be found in the Connected Vehicle Pooled Fund Report *"Traffic Management Centers in a Connected Vehicle Environment, December 2013".* The report seeks to identify how a connected vehicle environment will shape the role and function of TMCs.
>
> http://www.cts.virginia.edu/wp-content/uploads/2014/05/Task3._Future_TMC_12232013_-_FINAL.pdf

CV-WRTM offers the potential to add new tools to the TMC operator's tool box. With CV-WRTM, an agency can:

- Enhance situational awareness of TMC operators along corridors where there are gaps in coverage.
  - Connected fleets and vehicles report road weather and atmospheric conditions back to the TMC as they traverse the facility.

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- Allow TMC operators to improve the activation and deactivation of advisory, control, and treatment strategies.
  - Based on data from connected vehicles, spot-specific concerns can be identified early and control strategies like variable speed limits and vehicle restrictions can be set in place.
- Allow TMC operators to reach en-route travelers and freight operators beyond the DMS.
  - Through new applications, agencies can provide en-route warnings directly to travelers' vehicles that inform them about downstream driving conditions.

However, there are significant challenges to effectively integrating CV-WRTM into TMC operations. Challenges typically fall into three major categories:

- **Operator overload** – During weather events, operators in most TMCs are working in high-stress mode, dealing with multiple ongoing incidents and road condition reports. Connected vehicle data and information need to be seamlessly integrated into operational protocols without requiring a significant amount of manual intervention on the operator's part.
- **Trust in data** – As operators get comfortable with road weather data from RWIS and field-reported conditions, connected vehicle data require a new layer of understanding. Differences in vehicles, sensors, data quality, time intervals, and coverage all contribute to a mishmash of data arriving at the TMC. In some cases, data from connected vehicles may be in conflict with other reported sources.
- **Lack of tested business rules** – Agencies are still learning how to use CV data effectively to make decisions. Very few agencies to date have tested business rules that integrate CV data effectively into decision making.

Effective integration of CV-WRTM requires a careful consideration of legacy systems in use at TMCs today. Today's TMCs use advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), archived data systems, external data feeds such as weather and road conditions, and other operational center-to-center interfaces. A simplified example from the Wyoming Pilot Deployment of CV integration into the traditional TMC management systems is shown in Figure 2-2. The integration occurs when the operations from the new CV pilot elements (shown in blue) are linked to the operations of traditional TMC elements (shown in green). The Wyoming CV System ingests information collected from different sources (e.g., the onboard units (OBU) in the vehicles), analyzes it, and shares the results (e.g., advisories and alerts) with CV and non-CV users and operators.

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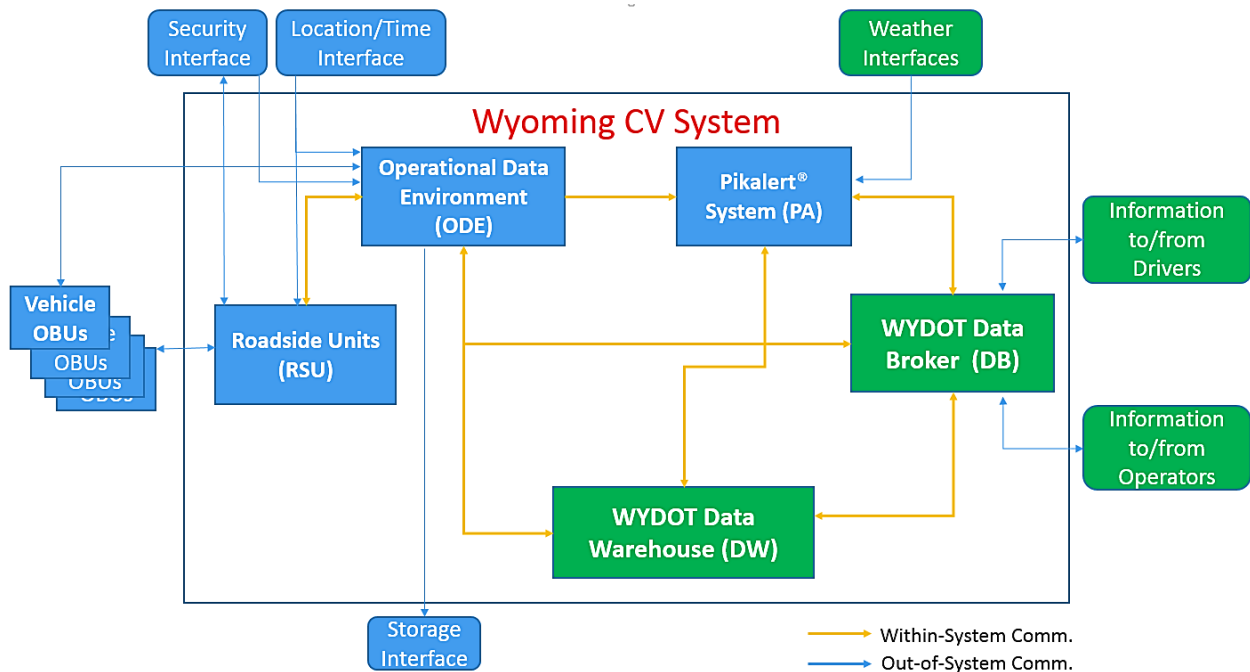
Source: Wyoming Department of Transportation

Figure 2-2**. Integration of connected vehicle systems with traffic management center systems for connected vehicle-enabled weather responsive traffic management in Wyoming.**

2.2 Collaboration between Maintenance, Weather Enterprise, and Traffic Operations

CV-WRTM requires a continued emphasis on the integration and collaboration between TMC Operation, Maintenance, and Weather Enterprise groups, as illustrated in Figure 2-3. CV-WRTM creates the following needs for collaboration between these groups.

1. TMC Operations and Maintenance

- As noted in Chapter 1, one of the pathways for CV-WRTM is to equip agency fleets. A majority of these fleets are likely maintenance vehicles.
- Road treatment status and field reported conditions from operation and maintenance personnel are essential to support several CV applications.

Source: Federal Highway Administration
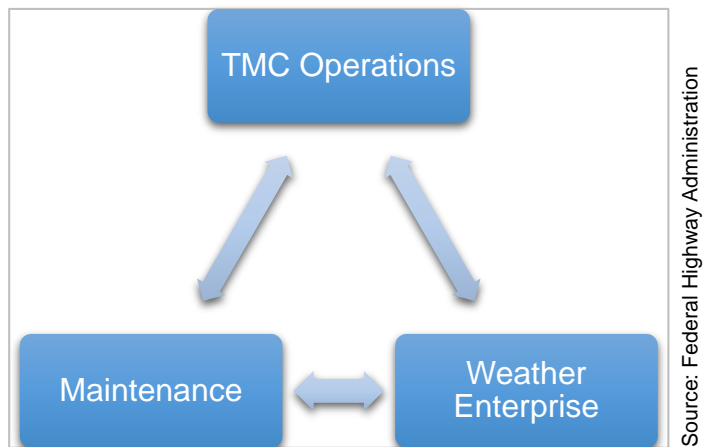
Figure 2-3. Collaboration framework for CV-WRTM.

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2. TMC Operations and Weather Enterprise

- Public and private sources are needed to supplement data collected from the CV environment to generate effective and accurate alerts and advisories from the TMC.
- Forecast data and consistent event messaging are also vital for several CV applications that seek to improve situational awareness for freight or general travelers.

3. Maintenance and Weather Enterprise

- Maintenance decision support process such as crew call-ups, treatment material selection, spread rates, timing, and pre-treatment strategies depend largely on road weather information.
- Spot-specific weather conditions and trouble spots may be better identified through mobile detection from connected vehicles and allow for targeted interventions.

> **Implementation Tip(s):** The National Weather Service (NWS) and the Federal Highway Administration have teamed up to build a framework that facilitates collaborative partnerships between NWS Weather Forecast Offices, State DOTs and, if applicable, the State DOT's private sector weather service provider. Called the "Pathfinder Initiative," the program has been implemented in four States and is now being deployed at the national level.
>
> Reference: http://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/

2.3 Establishment of New Partnerships

Transportation agencies at all levels (i.e., local, State, regional and national) engage in partnerships with both public and private sector entities, such as adjacent State agencies agreeing to integrate their corridor management efforts and other State agencies making agreements with data and service providers. In the case of connected vehicles, it is expected that the development and widespread deployment of this technology, specifically the on-board hardware, will be mainly driven by the private sector. In other cases, connected vehicle investments by a public agency need to be interoperable between jurisdictions and applicable to a wide variety of private fleets and automobiles. Further, business models around the use of CV technology are still evolving as the technology moves from research to deployment.

Specific partnership ideas for each pathway towards CV-WRTM are described in subsequent chapters, but broadly, the following partnerships are likely necessary as an agency moves forward in this area:

- Priority Internal Partnerships
  - Maintenance – New service-level agreements for maintenance and repair of CV equipment are likely necessary.
  - Telecommunications and Information Technology – Early discussions and agreement on use of agency telecommunications and information technology resources need to be in place. If DSRC-equipment is being considered, DSRC licensing related discussions are also likely to be managed by this partnerships.
- Priority External Partnerships
  - Original Equipment Manufacturers (OEM) – While direct partnerships may or may not be necessary, engaging with the OEM community and understanding the direction that they are heading toward is essential for the WRTM implementation agency.

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- o Fleet Partners – Partnerships with fleets (public and private) can have mutual benefits for the fleet partner as well as the State DOT. Equipping large fleets with on-board equipment may be an easier proposition than individual private vehicles. More details are provided under the Pathway 2 section.
- o Third Party Service Providers – As providers and users of data generated by CV technology, a WRTM implementation agency has to consider the role of third-party providers to amplify the impact of advisory information. More details are provided under the Pathway 3 section.
- o Research Institutions – In early implementations, access to research facilities and personnel is likely needed to test CV-WRTM implementations. From managing the use of human subjects to simulations, research partnerships can accelerate the deployment of CV-WRTM.
- o Adjacent States and Jurisdictions – Commonality in messaging across jurisdictions is important, and partnerships with adjacent States and jurisdictions are necessary to ensure that wide area messaging is appropriately communicated.

Implementation Tip(s): Develop a governance framework that identifies contractual relationships and Memoranda of Understanding necessary for CV-WRTM early in the implementation process. The partnership plan allows for a common understanding and evolution of roles and responsibilities as the project progresses.

2.4 Effective Messaging for Road Weather

With or without CV technology, WRTM requires effective communication with travelers that provides a clear sense of urgency, impact, and severity that enables a traveler to make an informed decision on when, where, and how to travel. Traditionally, WRTM has relied on technologies like 511 (phone and web) as well as roadside infrastructure (DMS and HAR) to communicate to travelers. In recent years, the use of smartphone-enabled apps to provide advisories has become a popular investment in both the public and private sectors. CV technology places additional requirements when enabling in-vehicle communications with the driver. Understanding the best ways to communicate with travelers about road weather before and during their trips is crucial to successful WRTM.

Resource Tip(s): For broad, non-CV specific guidelines on road weather messaging, the Federal Highway Administration (FHWA) produced human factors-based guidelines for road weather management titled *Guidelines for Disseminating Road Weather Advisory & Control Information (FHWA-JPO-12-046).* The guidelines provide recommended practices and principles for presenting road weather messages

Reference: http://ntl.bts.gov/lib/45000/45600/45623/FinalPackage_JPO-12-046_V1.pdf

CV is an emerging field, and while there are standards for CV technology design and performance, there is very little guidance that directly addresses the user interface for CV messages. The user interface is a critical issue because CV technology enables a vast number of potential messages to be presented to drivers, and it is important to ensure that these messages are easily accessed, understood, and responded to. Furthermore, these messages should not cause undue driver workload or distraction.

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There are numerous ways in which drivers can be presented with CV-WRTM information: on a fixed system built into the vehicle; on a portable device such as a smartphone or aftermarket CV device; or on external displays such as changeable message signs, variable speed limit signs, curve speed warnings, etc. Additionally, messages shown inside the vehicle can be presented using visual, auditory, haptic (e.g., seat vibration, gas pedal force feedback), or some combination of these modes. Human factors guidance can help practitioners develop interfaces that achieve their performance goals while minimizing potential negative outcomes such as driver distraction.

While human-machine interface (HMI) design guidance specifically for CV systems is limited, performance guidelines for in-vehicle systems currently exist that can be applied to CV systems. NHTSA's *Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices* (i.e., Phase I Distraction Guidelines) provides guidance for developers of OEM systems regarding device interface, location, and performance (National Highway Traffic Safety Administration, 2012).

The Alliance of Automobile Manufacturers (AAM) together with driver distraction experts developed *Driver Distraction Guidelines* in 2002. Their purpose was to offer solutions that limit driver distraction associated with the use of different types of telematics devices. The current working version was issued in 2006 (Driver Focus-Telematics Working Group, 2006).

2.5 Systems Engineering Capabilities

Projects related to CV, and communication/telematics in general, will depend heavily on systems engineering for their conceptualization, planning, development, and deployment phases. As such, the implementing agency should have strong systems engineering capabilities combined with a clear understanding of how these phases are linked and, to a great degree, interdependent. For any WRTM-CV-related projects, the agency should be capable of describing the proposed system as seen and understood by the stakeholders of interest and of documenting them in a concept of operation (ConOps) report. This will be the foundation of the system requirements for the desired physical objects and applications, leading toward the correct design and successful deployment of CV-WRTM strategies. Ideally, the agency should be able to manage the following CV-WRTM interfaces at its most basic capability level:

- TMC management systems (i.e., ATMS, ATIS, traffic signal management, data archives).
- External weather interfaces (i.e., NWS, NOAA, private sector).
- Private ISPs.
- Maintenance management systems (e.g., MDSS).

Given the complexity of CV-WRTM projects and their likely progression into a "system of systems," managing the interoperability of systems, while complying with a wide range of standards, is one of the most challenging aspects of such projects. Adding to this complexity is the constant evolution of the standards. As such, the agency needs to be able to modify and solidify its planning and development structure as warranted, in order to incorporate the necessary policy to successfully deploy CV-WRTM applications based on the newest standard possible. The following is a list of existing resources that the implementing agency could use to develop their system, some of which may be mandatory depending on the CV-WRTM application.

- Details of weather-related CV applications and technologies are provided in:
  - o Connected Vehicle Reference Implementation Architecture (CVRIA)
    http://www.iteris.com/cvria/html/applications/applications.html

- "Concept of Operations for Road Weather Connected Vehicle and Automated Vehicle Applications."
- Information on existing CV-WRTM application software, documentation, and gaps can be found in "Connected Vehicle Data Capture and Management (DCM) and Dynamic Mobility Applications (DMA) Assessment of Relevant Standards and Gaps for Candidate Applications," FHWA-JPP-13-019, October 2012. (http://www.its.dot.gov/dma/pdf/assessment_standards_applications.pdf)
- Guidance with respect to Open Source licensing and the OSADP is available at:
  - Apache 2.0 License: http://www.apache.org/licenses/LICENSE-2.0
  - OSADP release process: http://itsforge.net/applications/release-process
- General guidance on deployment of CV applications is provided in the "Draft 2015 FHWA Vehicle-to-Infrastructure Deployment Guidance and Products."
- Guidance on the contents and format for System Requirements Specifications as applied to CV-WRTM projects are described in:
  - "Systems Engineering for Intelligent Transportation Systems," USDOT/FHWA/FTA, January 2007.
  - "Systems Engineering Guidebook for Intelligent Transportation Systems," USDOT/FHWA/California Division, Version 3.0, November 2009.
  - "Systems and Software Engineering – Life Cycle Processes – Requirements Engineering," International Standard ISO/IEC/IEEE 29148 2011-12-01.
- Guidance on the architecture of CV applications is available through USDOT's CVRIA (http://www.iteris.com/cvria/) and Systems Engineering Tool for Intelligent Transportation (SET-IT – http://www.iteris.com/cvria/html/resources/tools.html).
- The Society of Automotive Engineers (SAE) provides a DSRC Data Dictionary (J2735) which defines messages, data frames, and data elements used to exchange CV-related data as well as the J2945 document suite, which provide recommended practices for using the data to support various CV applications.
- The Institute of Electrical and Electronic Engineers (IEEE) defines the over-the-air communication protocols used to exchange J2735 based messages in their wireless access for vehicular environments (WAVE) 1609 suite of standards.

Implementation Tip(s): The Connected Vehicle Reference Implementation Architecture (CVRIA) (http://www.iteris.com/cvria/) is a good starting point for more details on applications. CVRIA forms the basis for a common language definition and early deployment concepts. The CVRIA and its associated Systems Engineering Tool for Intelligent Transportation (SET-IT) tool support initial deployment and integration activities by taking different developments and research projects and illustrating how they all fit together. The CVRIA will form the basis for material to be integrated into the U.S. National Intelligent Transportation Systems Architecture and provide the interface information needed for standardization planning.

2.6 Safety, Security, and Privacy Management

CV technology is fundamentally driven by the exchange of information between vehicles and infrastructure, which makes it possible to know the locations of those vehicles. As such, the safety, security, and privacy of all elements interacting in the CV Environment need to be an inherent consideration throughout the concept, development, deployment, and management of CV-WRTM strategies. In order to ensure safety, the agency needs to be able to:

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- Document the system safety approach.
- Identify and document hazards.
- Assess and document risk.
- Identify and document risk mitigation measures.
- Reduce risk.
- Verify, validate, and document risk reduction.
- Accept and document risk.
- Manage life-cycle risk.

Similarly, the agency needs to be able to ensure that all components of the system comply with confidentiality, integrity, and availability criteria of security. Security assessments for CV systems need to include the security of the systems' components and of information flows between those components.[7] For CV-WRTM applications, these processes should be incorporated into system development, deployment, and operations through the systems engineering process and appropriate operational procedures—potentially using the "privacy by design" approach.

Resource Tip(s):

The process for addressing system safety considerations is described in the U.S. Department of Defense's *Department of Defense Standard Practice – System Safety* (MIL-STD-882E), May 2012 http://www.system-safety.org/Documents/MIL-STD-882E.pdf.

The National Institute of Standards and Technology (NIST) identifies seventeen impact categories and threats to consider in developing security schemes and mechanisms in *Minimum Security Requirements for Federal Information and Information Systems*, FIPS PUBS 200, March 2006, http://csrc.nist.gov/publications/fips/fips200/FIPS-200-final-march.pdf

Documentation of the security certificate management system and its interfaces for use in CV application deployments are still in development. However, various resources point to the fundamentals of planning for security in systems development and deployment in a series of NIST documents:

- *Standards for Security Categorization of Federal Information and Information Systems*, FIPS PUBS 199, February 2004, http://csrc.nist.gov/publications/fips/fips199/FIPS-PUB-199-final.pdf
- *Minimum Security Requirements for Federal Information and Information Systems*, FIPS PUBS 200, March 2006, http://csrc.nist.gov/publications/fips/fips200/FIPS-200-final-march.pdf
- *Security and Privacy Controls for Federal Information Systems and Organizations*, NIST Special Publication 800-53 Revision 4, April 2013 (includes updates as of 01-22-2015), http://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-53r4.pdf

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[7] Much of the potential assessment complexity is, however, addressed by the inclusion of the security certificate management system (SCMS) as part of the CV deployment. The SCMS provides and manages certificates for exchange of information between components of a CV system deployment to address confidentiality and integrity of the available system interactions.

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2.7 Performance Measurement and Reporting

Connected vehicle technologies are still in their infancy, making the use of information gathering and dissemination techniques to support WRTM activities a completely new concept. Nonetheless, an agency should be able to provide core performance information obtained from a variety of sources, such as:

- System data – Data collected from the CV-WRTM system, including alerts/advisories issued, road weather condition reports, mobile weather, roadside unit logs, vehicle onboard unit logs, communication system logs, basic safety messages from connected vehicles, TMC logs, traveler information system logs, crash notification records, or other identified data.
- Non-System data – Data collected from external systems and databases necessary to support performance measurement. These data elements could include traffic data (speeds, volumes, and other traffic conditions), crash database records, road closures, road weather information system logs, automated sign logs, construction and maintenance event logs, environmental conditions or system logs, stakeholder operational logs, and other identified data.
- Survey data – Data collected through surveys of travelers and other stakeholders. These surveys could obtain perceptions of technology effectiveness and assessment of system performance during baseline and post-deployment conditions.
- Modeling and Simulation data (if used) – Data collected or generated by modeling/simulation activities that may be used to supplement other evaluation efforts.
- Interview data – Qualitative data collected at various points to support performance measure analysis. This also includes lessons learned and institutional issues gathered through interviews with involved personnel.

Overall, data collection and analysis processes need to be considered and integrated throughout the development and deployments phases of the project. The agency should have access to the resources needed to implement a vigorous data management approach documented in a *Performance Measurement Plan*. The precise CV-WRTM performance measures that will be applicable to the project will, of course, be highly dependent on the selected technology application(s). The measures should include system performance, as well as overall project impacts/benefits. Potential categories of CV-WRTM performance measures include:

- Road weather data collection – measures CV-WRTM strategies to collect more accurate, frequent, or extensive road weather conditions.
- Generation of advisories/alerts – measuring new procedures and/or systems to ingest/ process new/enhanced road weather condition data and generate advisories/alerts to transportation users via CV-WRTM technologies.
- Dissemination of traveler information – measure efficiency gains of disseminating CV-WRTM broad area traveler information and benefits to users of the information
- Implementation of traffic management strategies – measure efficiency gains of implementing traffic management strategies and benefits to users of the information.
- Effectiveness of I2V, V2I, V2V, and V2X technologies – measure system performance to transmit and communicate WRTM-based alerts/advisories via I2V, V2I, V2V, and V2X technologies.
- Driver behavior due to CV-WRTM information – measure impacts of alerts/advisories in terms of driver behavior following receipt of CV-WRTM information.
- Project outcomes (safety, mobility, environmental impacts, public agency efficiency, and productivity of transportation users) – measure impacts of CV-WRTM strategy implementations.

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Implementation Tip(s): The agency should develop a vigorous data management approach documented in a *Performance Measurement Plan* during a CV-WRTM project planning stage to capture and document the scope and approach to evaluating the project. The plan will define what data will be collected, how it will be processed (where applicable), where it will be stored (such as a warehouse) for later evaluation analysis, and the conditions under which it will be shared with others. In general, the plan should include the following elements:

- Project definition.
- Specific performance measures that focus on the primary expected project benefits.
- Data requirements to support the evaluation of the performance measures, including the establishment of baseline conditions.
- Evaluation designs and analysis approaches to define how the performance measures will be evaluated (before-after, with-without, system performance, behavior assessments, qualitative assessments, etc.).
- Data management planning.
- Confounding factors and mitigation approaches.
- Roles and responsibilities of project stakeholders and evaluation participants.
- Schedule of performance measurement activities.

The challenge for the agency lies in establishing evidence of CV-WRTM system performance and benefits and conveying its evaluation findings to validate the impact of the system. Furthermore, weather-related projects have unique characteristics that tend to challenge performance measurement activities. Regardless of the application, a CV-WRTM project will likely face some of the following challenges:

- Weather condition variability – The variability of weather events and entire winter weather seasons presents challenges in analyzing pre- and post- system implementation data. Ideally, the evaluation would compare data during similar weather events, although this is not always possible.
- Limited duration of evaluation activities – Typically, following full CV-WRTM implementation, an agency would define 1 or 2 years to evaluate the system. Often times this is not enough time to fully evaluate all aspects of the system.
- CV-WRTM technology adoption – New technology involving a change in the way people do things is always challenging. For a CV-WRTM system, there may be a myriad of agency personnel 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 now be available is unknown—the lack of technology adoption and information use may affect the evaluation outcomes.
- Reliability of roadside and in-vehicle systems – The reliability of roadside and in-vehicle systems is not known; however, reliable systems are critical to data collection to support performance measurement. This includes DSRC equipment to transmit and receive information to and from vehicles—from the roadside to vehicle, from vehicle to roadside, and from vehicle to vehicle.
- CV technology penetration rate – It is possible that a relatively few numbers of vehicles in the project will be capable of receiving direct information from the infrastructure or from other vehicles—especially in comparison to the number of total vehicles on a particular roadway. The technology can be shown to work; however, measuring the benefits with potentially a small sample size may be limiting.
- Availability of desired data – Data needed for performance measurement is not always available and can limit the success of the evaluation. These data can include baseline data, TMC

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operational data, road weather condition data, crash data, travel delay, commercial vehicle productivity, general mobility data, environmental factors, and others.

- Ability to interview or survey general travelers – Obtaining insights from general travelers is important, especially if one aspect of the project is better traveler information, and can be very challenging. The lack of this information can limit the success of the performance measurement efforts.
- Lack of training for system users – It is critical that the users of the CV-WRTM systems are ready to operate the system at the time evaluation activities begin. Time needed to "learn" how to use the system early in a project can skew the evaluation results.
- Liability issue (for with/without studies) – Agencies can be concerned about safety risks associated with evaluation techniques that are needed to properly test technology systems on the roadway.
- Underfunded performance measurement efforts – This could lead to a lack of performance data collection and analysis needed to properly evaluate a CV-WRTM project.

2.8 Operations and Maintenance of Connected Vehicle Environment

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 needs in this regard and securing the required dedicated resources early in the project are essential to a successful CV-WRTM project implementation.

This core capability is closely linked to Performance Measurement and Reporting as 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 operated and maintained, it is unlikely that data will be available to measure the performance of the system. As such, CV-WRTM systems will require attention to the equipment and software maintenance. Maintaining technical information systems is often overlooked in the project planning phases, which can result in system failures. Some items to consider when making system management decisions include the following:

- Where organizationally should system management reside? This is likely decided based on what part of your organization is planning to use the data and potentially make decisions based on the CV-WRTM information.
- What level of existing infrastructure is available to support the CV-WRTM operation and/or maintenance? If much of the infrastructure exists and your CV-WRTM project is a modest enhancement to a mature ITS device control and traveler information system, then system management may be fairly straightforward. However, if your CV-WRTM implementation also includes development and deployment of several new systems and processes, then your system management approach will require more significant consideration and the outcome may require organizational changes.
- What level of existing and relevant procedures are available? The extent of your CV-WRTM project will dictate the need for and use of operating procedures: the more extensive the project, the more attention to improving/enhancing procedures. Your system management approach should reflect these issues.
- What level of automation is incorporated in your CV-WRTM system design? The more system automation is included, the more likely that fewer personnel resources and management will be

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required. However, even the most highly automated system will still need a management structure to ensure consistent operation, maintenance, and manual override procedures.

- What level of vendor/contractor involvement is included in your project? Management of vendors/contractors needs to be considered in your system management approach. In some cases, the system owner could require some of the system management be performed by the vendor/contractor. In other cases, it could require more owner management to ensure the vendor/contractor is meeting their obligations.
- Where are database servers housed? Database servers' location, hosting, and maintenance could be provided in-house (in the DOT or project owner) or provided by contracted services off-site. Your overall system management approach will need to reflect your decision in this regard.

Implementation Tip(s): Consider preparing a plan that defines how the CV-WRTM systems will be maintained and what resources are necessary. High level DOT management (or system owner) commitment to the resources necessary to maintain the implemented systems is essential for project success. Some considerations include:

- Define all the equipment and systems involved that need to be maintained.
- Understand the failure points, frequency, and effort required to maintain each system component. Learning from other DOT's may help gather the information needed.
- Identify the staffing and special equipment resources needed to maintain the system. Translate this into a cost.
- Identify the actual staff that will be responsible for maintaining the system and gain their support and commitment to accomplish these tasks.
- During procurement of the CV-WRTM systems, order enough spare parts and components to quickly swap failed equipment to keep the system operational.
- Consider ongoing contractual relationship with vendors and support contractors to assist in advising or actually maintaining the systems.

2.9 Data Capture and Management

CV-WRTM applications will entail one or more of the following activities: data collection, processing, decision support of traffic management actions, and logging of all activities. Additionally, the data may have other uses by other organizations so an approach to share it may be needed.

Many, if not all, of these data collection efforts could be automated and designed into the CV-WRTM system. The premise behind data capture and management is that data is collected and stored in a manner that it can be used for multiple purposes. These data could be presented to system managers in summary dashboards or key information and the corresponding details of system performance. The frequency of data collection should be determined based on the level of system complication and technical sophistication. The level of automation should also be decided during the system design phase.

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Resource Tip(s): The data use analysis and processing (DUAP) system developed by Michigan DOT enables the use of data from connected vehicles throughout the road network. 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. This 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 analyses. Figure 2-5 provides a flowchart of how the DUAP system could be applied to process information.
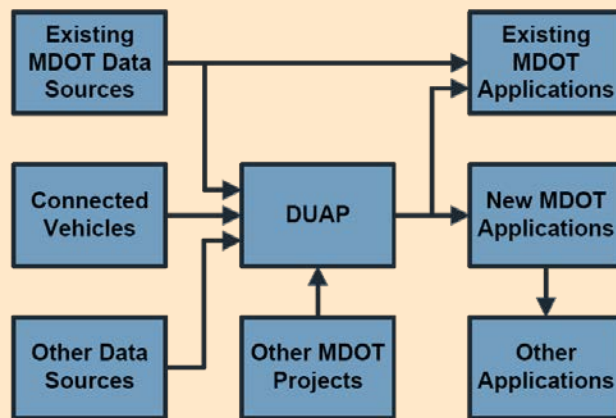
Figure 2-4. Michigan Department of Transportation's data use analysis and processing data flows.

Source: Mixon, Garrett, and Krueger (2012). *Vehicle Infrastructure Integration (VII) Data Use Analysis and Processing – Project Summary Report.* Michigan Department of Transportation.

Implementation Tip(s): Consider preparing a *data collection and management plan* during the project planning phase in conjunction with the development of a *performance measurement plan*. This effort needs to be comprehensive in its treatment of all aspects of data management, such as the approaches for data collection, processing, warehousing and sharing, as well as the decision support approach.

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Chapter 3. Pathway 1 – Intelligent Agency Fleets

3.1 Overview

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

Table 3-1 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 is introduced, dedicated short range communication (DSRC), which enables short-range communication between equipped vehicles as well as appropriate roadside equipment (which can then back-haul the data back to the management center). At this level, this pathway merges with Pathway 2 (refer to next chapter) for agency vehicles. Note that Pathway 2 may include non-agency vehicles.

Table 3-1. 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 (CV-WRTM): • Automatic vehicle location. • Remote communication through cellular links and/or through agency-owned radio channels. • Able to share both voice and data. • Snow plows can report some basic and aggregated core maintenance data some in real time, others not. Core maintenance data include: o Plow up or down, material usage tracked at high-level corridor segments, general material usage status information (e.g., full/empty), etc. • Operator reports subjective information on both road weather and vehicle condition to the agency through radio/cellular.

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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 communication (DSRC) communications in fleets enables communication not only with 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

3.2 Selected Examples

The Michigan, Minnesota, and Nevada Departments of Transportation (DOT) 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 (Belzowski & Cook, 2014). Figure 3-1 illustrates the architecture of Michigan DOT's system. The information was shared with different analysts, including the National Center for Atmospheric Research (NCAR), Mixon-Hill (Data Use and Analysis Processing (DUAP)), Atkins (Regional Integrated Transportation Information System (RITIS)), Iteris (Maintenance Decision Support System (MDSS)), and Leidos & Synesis Partners (FHWA Weather Data Environment (WxDE)).

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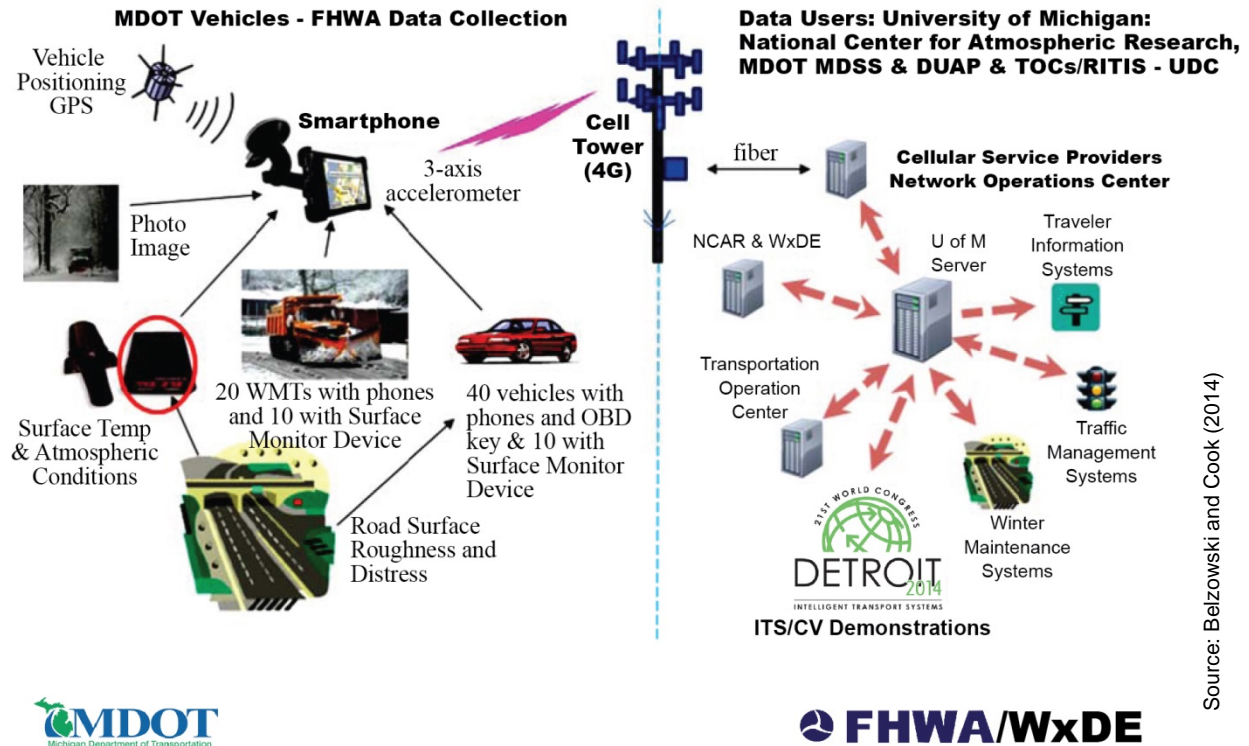
Figure 3-1. Michigan Department of Transportation's Integrated Mobile Observations 2.0 System Architecture Overview.

Similarly, Nevada DOT equipped 36 vehicles (21 snowplows and 15 passenger and light duty vehicles) that traversed along segments of Interstate 80 (Nevada DOT, 2014). The objective was to share real-time atmospheric and vehicle data between NCAR and Nevada DOT to support implementation of the State's maintenance management system (MMS) and enhanced maintenance and decision support system (E-MDSS).

Minnesota DOT equipped snow plows with automatic 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 controller area network (CAN) bus interfaces using both J1939 and J1979 protocols. As part of the second phase of the Integrated Mobile Observations (IMO) Project, MnDOT plans to expand use of AVL in light-duty fleets, provide mechanics with remote diagnostic support capabilities, and test V2I communications (Pape, 2013).

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. Figure 3-2 shows a tablet mounted on a snow plow and the App user interface. TMC operator actions taken based on input from the field maintenance staff included updating the traveler information system, changing variable speed limits, changing message signs, and 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.

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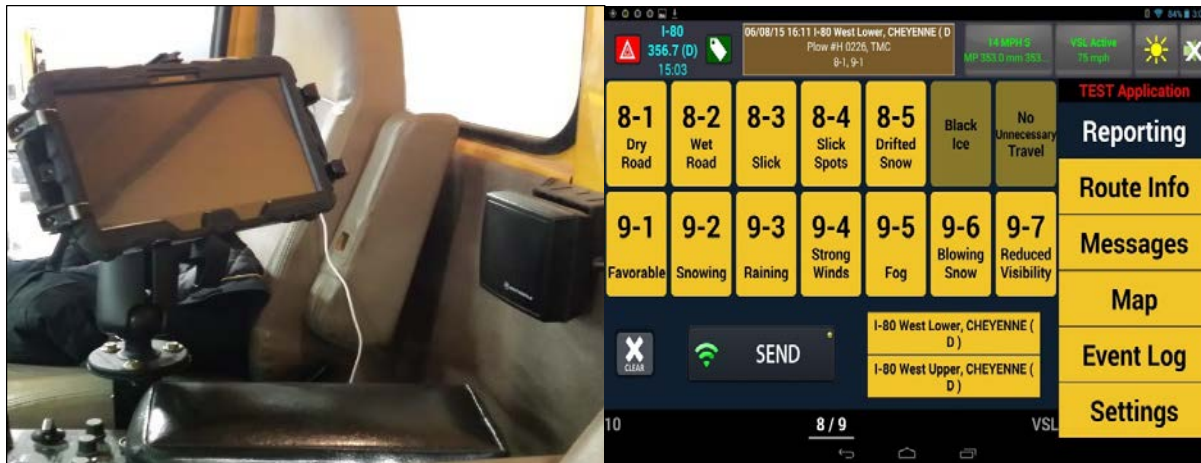
Figure 3-2. Weather responsive road condition reporting application.

The implementations described above illustrate examples of basic and intermediate Pathway 1 CV-WRTM strategies.

For the advanced level, the Connected Vehicle Pooled Fund Study funded a project by New York State DOT (NYSDOT) 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 onboard units (OBU), three DSRC roadside units (RSU), and two mobile road weather sensor units providing additional onboard road weather data gathering. The software developed in the project for the OBU can be configured to collect data from the vehicle's controller area network (CAN) bus, the aftermarket device, and road treatment equipment (if present), in addition to the Global Positioning System (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 NYSDOT to support operation of snow plow trucks and Highway Emergency Local Patrol (HELP service vehicles along and near the Long Island Expressway with monitoring and data retrieval through NYSDOT's INformation FOR Motorists (INFORM) system (Synesis Partners, 2015).

Figure 3-3 shows the conceptual deployment for a DSRC system for road weather applications.

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INFORM
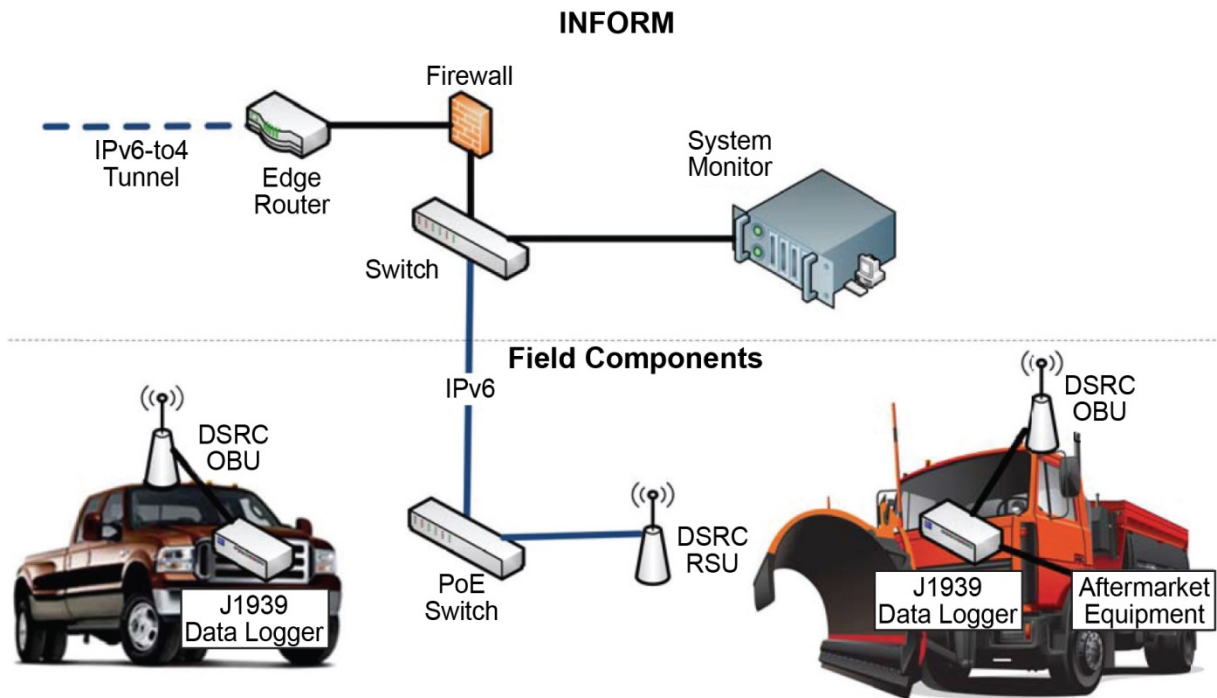
Source: Synesis Partners LLC (2015).

Figure 3-3. Conceptual DSRC system deployment.

3.3 Weather Responsive Traffic Management Applications Supported

Pathway 1 supports a wide variety of weather responsive traffic management strategies in use today. Table 3-2 summarizes the nature of applications enabled by this pathway.

Table 3-2. Application supported by Pathway 1.

Basic	Basic Data from connected agency fleets can support: • Weather-Responsive Traveler Information (Wx-TINFO)-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 (Wx-ATM) – 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 (E-MDSS)

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Table 3-2. Application supported by Pathway 1 (continued).

Advanced (merges with Pathway 2)	In addition to the applications listed above, advanced data from connected agency fleets can support: • Spot Weather Impact Warnings • V2V Applications (such as Forward Collision Warning, Electronic Emergency Brake Light)

3.4 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 need to be addressed as the agency proceeds in this pathway.

- **Ensuring an effective data sharing arrangement between various groups within the agency.** Institutionally, the data coming from the vehicles need to be managed in such a manner that it can support the needs of both maintenance and traffic operations.
- **Ensuring driver support and buy-in of technology**. Snow plow and other fleet vehicle 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.

Implementation Tip(s): Have the end-users (agency fleet drivers) participate in designing the human-machine interface for on-board equipment. Agile software development allows for quick iterations and updates of interface designs.

- **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 CV adopters (USDOT CV Pilot grantees, other State DOTs pursuing CV technology) will provide this business case.

Resource Tip(s): Documents relating to the USDOT CV Pilot deployment can be found at http://www.its.dot.gov/pilots/. In the next 2-3 years, additional documentation regarding independent evaluation of early CV deployments is expected to be posted to this site.

3.5 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,

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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 V2V and V2I interactions. More vehicles on the roadway reporting data also improves situational awareness of conditions.

3.6 Performance Measures

Performance for this pathway can be measured by the improvements of traditional WRTM advisory, control, and treatment strategies by using data collected from fleets. Table 3-3 lists 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 3-3. Potential performance measures for Pathway 1.

CV-WRTM PM 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)
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 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

Note: CV-WRTM = connected vehicle-enabled weather responsive traffic management. PM = performance measure.

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3.7 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.

> **Resource Tip(s):** Various foundational documents on the Integrated Mobile Observations (IMO) project are useful as an agency starts implementing Pathway 1. The following documents are identified as useful resources for this task:
>
> FHWA Road Weather Management Program web page, "Connected Vehicle and Dynamic Mobility Application Resources," available at:
> http://www.ops.fhwa.dot.gov/weather/resources/publications.htm#cv

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 the 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.

> **Resource Tip(s):** Two key references describe data management activities for Pathway 1.
>
> The Data Use Analysis and Processing (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. (Mixon et. al., 2012; MDOT, 2016)
>
> The Vehicle Data Translator (VDT) project showcased how connected vehicle data received in the management center can be effectively used for generating motorist alerts and advisories and supporting enhanced Maintenance Decision Support Systems. The current version of VDT (now called PikAlert) is Version 4.0. Details on the VDT can be found at:
> http://www.itsforge.net/index.php/pikalert-announced

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# Chapter 4. Pathway 2 – Connected Vehicles

4.1 Pathway Overview

As defined earlier, a connected vehicle (CV) can transmit and receive basic safety messages (BSM) using the intelligent transportation systems (ITS) band of 5.9 GHz (5.85 – 5.925 GHz). In addition to fleets that are connected in Pathway 1, this section focuses on the role of private connected vehicles that are anticipated in the near future for supporting weather responsive traffic management (WRTM).

The following sections from the U.S. Department of Transportation's (USDOT) "Connected Vehicle Basics" web page[8] provide the context for the pathway:

- The USDOT notes that "NHTSA [the National Highway Transportation Safety Administration] aims to deliver a Notice of Proposed Rulemaking on vehicle-to-vehicle (V2V) communications technology for light vehicles by 2016. 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 other vehicles' 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 helps V2V-equipped vehicles perceive some threats sooner than sensors, cameras, or radar can and warn their drivers accordingly.
- Connected vehicle technology also enables vehicles to exchange information with infrastructure, such as traffic signals, through vehicle-to-infrastructure (V2I) communications. V2I communications help to extend the benefits of connected vehicles beyond safety, to include mobility and the environment.

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[8] Research and Innovative Technologies Administration, ITS-JPO website, "Connected Vehicle Basics" web page, available at: http://its.dot.gov/cv_basics/index.htm .

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V2I deployment is not mandated and is not part of the NHTSA advanced notice of proposed rulemaking, which focuses on 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 (GAO) projected the long-term horizon for V2I and V2V deployment as shown in Figure 4-1.
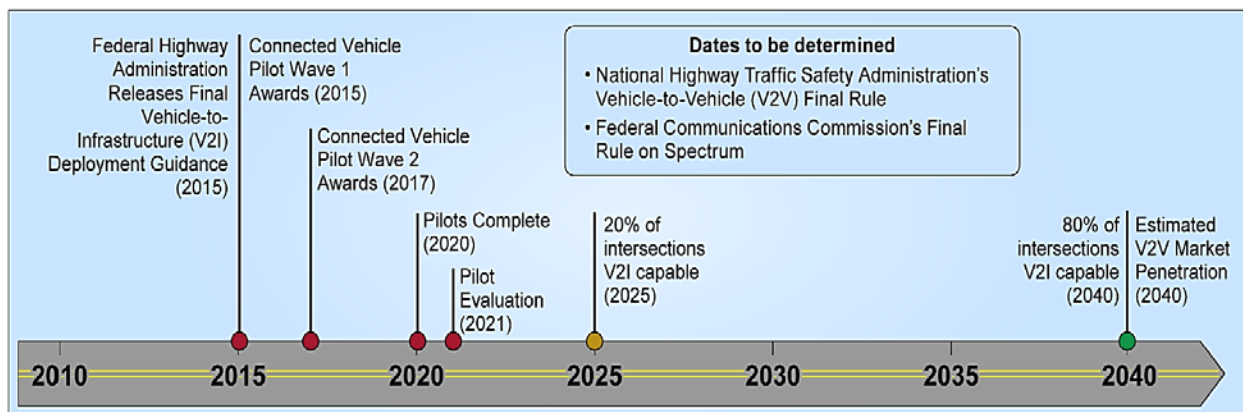
Figure 4-1. Deployment horizon for V2I technologies.

Table 4-1 identifies a potential implementation roadmap for leveraging the anticipated dedicated short-range communication (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 listed in the table below.

Table 4-1. Implementation pathways for V2I deployment for weather-responsive traffic management.

Basic	Agency installs dedicated short-range communication (DSRC)-enabled roadside equipment (RSE) along key interstate hotspots for spot-specific active warning on road conditions. RSEs will support communications of localized alerts (curve speed warnings, situational awareness messages for visibility, road conditions, etc.).
Intermediate	In addition to the basic development, 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.

4.2 Selected Examples

With the CV Pilot and other projects described in Chapter 3, several road-weather-specific applications will be tested in the real world in next few years. From a traffic management standpoint, most of the applications have focused on advisories (alerts/advisories) rather than control. However, there are concepts that can utilize CV data for control strategies such as variable speed limits, signal timing, and

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road closures. The ability of enhanced maintenance decision support system (E-MDSS) to provide treatment recommendations is still in testing phases but the value of CV data for road weather treatment has been investigated in the Integrated Mobile Observations (IMO) project positively.
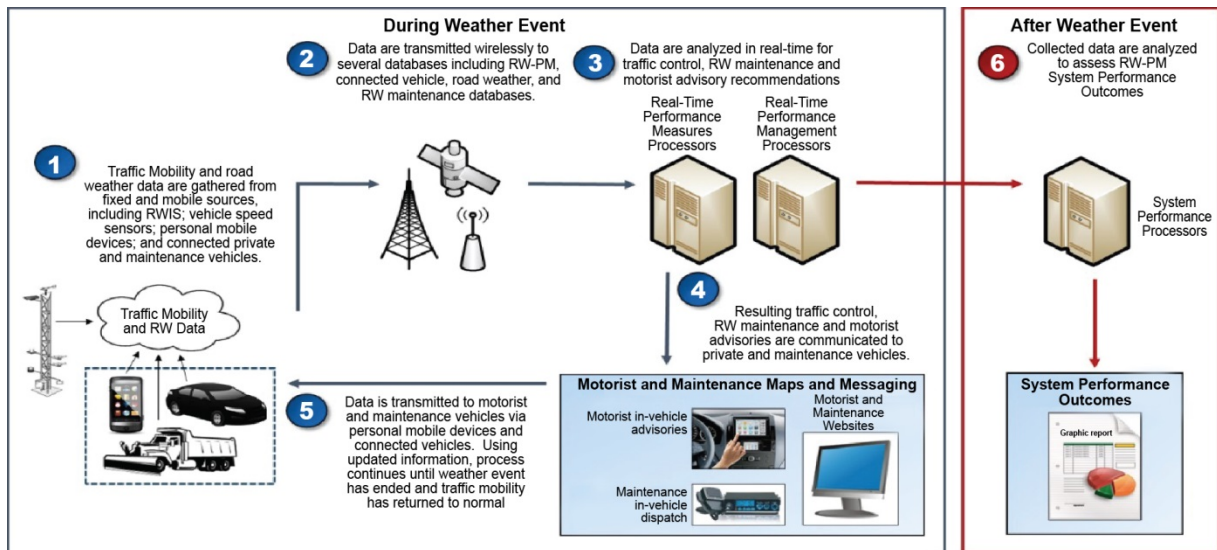
To date, very limited operational examples of road weather management using DSRC communications exist. While this is not surprising, as noted earlier, the advantage of connected vehicle data is not just to recreate existing WRTM applications but to develop new scenarios that best utilize the hyperlocal nature of the data and the alerts required. DSRC communication capabilities between vehicles and infrastructure unlock new tools in the connected vehicle-enabled weather responsive traffic management (CV-WRTM) toolbox. Of particular interest are the V2V applications that are enabled by DSRC.

However, for a public agency considering the role for WRTM, there are still several unknowns:

- Changes in regulatory landscape may influence adoption of DSRC greatly. As such, the level of penetration of DSRC equipped vehicles is uncertain.
- Ultimately, adoption of in-vehicle technology is going to be driven by automobile and truck manufacturers. There are still unknowns in the ability of car or truck manufacturers to support applications and data collection for CV-WRTM use-cases.
- Rapidly evolving standards and technology may render early deployments obsolete.
- Message lexicons for advisories are still uncertain, and traveler behavior in response to these messages needs to be ascertained.
- Liability issues with respect to in-vehicle data collection and management are still an unknown.

The Federal Highway Administration (FHWA) is currently developing 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 (see Figure 4-2). 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 utilize different types of data (e.g., road weather, traffic mobility, connected vehicle, and mobile device) from many sources, 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:

1. Develop more informed traffic and RW maintenance management responses.
2. Collect more robust, higher resolution, and higher density traffic mobility and road weather data.
3. Allocate staff, equipment, and material resources more effectively.
4. Provide more timely and targeted deployment to dynamic variations in weather.
5. Improve traffic mobility during an adverse weather event.
6. Return mobility to normal more quickly following an event.
7. Promote more informed and safer travel route and behavior decisions by drivers, among many other potential enhancements.

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Figure 4-2. Prototype road weather performance management tool.

The Wyoming Department of Transportation (WYDOT) is currently developing systems that support the use of CV technology along the 402 miles of Interstate 80 (I-80). At a very high level, the pilot scope includes the following implementation elements:

- **Deployment of about 75 roadside units (RSU)** that can receive and broadcast messages using DSRC along various sections on I-80.

- **Equip around 400 vehicles, a combination of fleet vehicles and commercial trucks, with on-board units (OBU).** Of the 400 vehicles, at least 150 would be heavy trucks. All vehicles are expected to be regular users of I-80. Several types of OBU are being procured as part of the pilot and differ based on their communication capabilities, ability to integrate with the in-vehicle network, and connectivity to ancillary devices and sensors. All OBUs will have the functionality to broadcast BSM Part I and will include a human-machine interface (HMI) to share alerts and advisories to drivers of these vehicles. A portion of the equipped vehicles will have additional capabilities, such as transmitting BSM Part II and collecting environmental data through mobile weather sensors.

- **Develop several V2V and V2I applications** that will enable communication with drivers for alerts and advisories regarding various road conditions. These applications include support for in-vehicle dissemination of advisories for collision avoidance, speed management, detours, parking, and presence of work zones and maintenance and emergency vehicles downstream of their current location.

- **Enable overall improvements in WYDOT's traffic management and traveler information practices** by using data collected from connected vehicles. Targeted improvements include better activation of variable speed limits (VSL) and improved road condition dissemination via 511, DMS and other WYDOT sources.

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4.3 Weather Responsive Traffic Management Applications Supported

A 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 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 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, through the Road Weather Management Program, the USDOT developed a concept of operations (ConOps) that defines the priorities for road-weather applications that are enabled by CVs. Two connected vehicle systems ConOps are developed to enhance WRTM for: (1) 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 timings to include connected vehicle data. (Figure 4-3).

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Source: Hill **(2013)**.

1. Connected vehicles gather road-weather data and transmit to roadside equipment.

2A Roadside equipment sends connected road-weather data local roadside processor to VDT.

2B Roadside equipment send connected vehicle road-weather data to remote processor VDT

3A Local processor acquires road-weather data, aggregates, quality checks, and applies algorithms to determine safe speed for display on mobile trailer.

3B Remote program acquires, aggregates, quality checks, and applies algorithms to determine safe speed to display DMS, mobile trailers or update signs.

Source: Hill **(2013)**.

1. Connected vehicles gather road-weather data and transmit to roadside equipment.

2A Roadside equipment sends connected vehicle road-weather data to a remote processor at a graffic management facility.

2B Roadside equipment sends connected vehicle road-weather data to a local processor associated with a traffic signal controller.

3A Remote traffic management processor applies algorithms to select appropriate special signal timing plan and communicates change to signal controller.

4. Traffic signal controller implements changes.

3B Local processor applies algorithms to determine changes to intervals in signal cycle and communicates changes to signal controller.

Figure 4-3. Schematic of weather-responsive VSL system (top) and signalized intersection system (bottom).

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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 4-4 shows how connected vehicle data can improve both spot-specific warnings as well as wide-area advisories.

1. Connected vehicles gather road-weather data and transmit to roadside equipment.

2. Roadside equipment sends disconnected vehicle road-weather data to VDT.

3. VDT quality checks data and applies motorist alert algorithm to determine short time horizon warning.

4A. Short time horizon warnings are provided to participating motorists.

4B. Data from VDT are provided to a secondary processing system for assimilation with other data to determine medium and long time horizon alerts.

5. Medium and long time horizon alerts are provided to various participating users.

Source: Hill **(2013)**.

Figure 4-4. Schematic of road weather motorist advisory and warning system.

4.4 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 states 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*

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warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I…[9]

As early deployers begin to transition to daily operations, additional issues may emerge. The following list is provided as a start. The AASHTO V2I Deployment Coalition (see Implementation Tip) below is a valuable resource and forum for the consideration of institutional and technical issues around V2I deployment.

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 when it comes to the business case for investing in roadside equipment and application development. Costs for V2I deployment are still vague and based only on a few testbeds, and the benefits of these applications are not yet fully proven.

Evolution of V2I Standards – While standards development for CV technology is in full swing, early stable standards are focused on V2V applications. V2I standards are still in the development stages, as are the certification approaches for associated equipment. These make procuring V2I systems a challenge.

Understanding original equipment manufacturers' (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 (TIM) 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 to the DSRC messaging standards and the 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 either to need PII to assure its effectiveness or to require that users be uniquely identified.

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[9] Government Accountability Office (GAO). (2015). *Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist.* GAO-15-775.

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4.5 Constraints and Challenges

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

Added expense of maintaining CV equipment – RSUs represent field devices that need to be managed at a service level commensurate with the applications that are being deployed.

Limitations in the ability to build-out a roadside network – While RSUs can be easily installed along facilities where power and communications are present, these may not be the best locations for such applications. Some applications may require the installation of RSUs at strategic locations (such as ports of entry, parking lots, or key interchanges) where installations can be significantly more expensive.

Consistent messaging – Today, road weather information is communicated differently by different agencies. From different typology for road conditions to 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 on-board equipment must 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 the 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 seasons presents challenges to application development and testing.

Driver behavior and CV-WRTM technology adoption – New technology involving a change in the way people do things is always challenging. For a CV-WRTM system, there may be a myriad of agency personnel affected: transportation management center (TMC) staff, snowplow drivers, commercial vehicle drivers, dispatch center personnel at commercial companies, etc. How these stakeholders adopt the new

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technology and information that will now be available is unknown – the lack of technology adoption and information use may affect the evaluation outcomes.

4.6 Performance Measures

The performance of Pathway 2 could be measured through many of the indicators of performance from Pathway 1. However, given the added complexity of the system, other system performance and overall project impacts and benefits need to be included. Although this will generally be project-dependent, Table 4-2 presents some potential categories of CV-WRTM performance measures for Pathway 2 that could be considered in addition to those for Pathway 1.

Table 4-2. Potential performance measures for Pathway 2: connected vehicles.

CV WRTM PM Category	Description
Effectiveness of I2V, V2I, and V2V 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)

Note: CV-WRTM = connected vehicle-enabled weather responsive traffic management. I2V = infrastructure-to-vehicle. PM = performance measure. V2I = vehicle-to-infrastructure. V2V = vehicle-to-vehicle. WRTM = weather responsive traffic management.

4.7 System Development Guidelines

Guidance on effectively deploying roadside infrastructure that includes DSRC connectivity is emerging from FHWA. The following resources (upcoming) from FHWA are useful to ensure feasible, interoperable, and scalable infrastructure deployments to support CV technology:

1. **System Engineering Process for Vehicle to Infrastructure.** Guidance for professionals involved in developing systems engineering documents covering the evaluation, selection, and implementation of V2I technology.
2. **V2I Benefit Cost Analysis Tool.** Tool to assist adoption of an investment strategy that dedicates funding to the capital and ongoing operational costs for connected transportation.
3. **V2I Planning Guide.** Provide planning staff with an increased awareness of the benefits and opportunities for deploying these technologies by State DOTs and metropolitan planning organizations, and guidance on inclusion of the technology in long-range plans and project selection process.
4. **Guide to V2I Cyber-Security.** Provide deployers with analyses of:

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a) The extensibility of security and trust system to additional points of connection, including V2I, devices, backhaul, and others.
b) Additional risks from extensibility and cyber security.
c) The potential impacts to the existing transportation system/network. It will also provide definitions of the organizational functions and processes for operating the security function, along with cost models for operations and maintenance.

5. **Guide to Licensing DSRC Roadside Units**. A guide to requirements that a transportation owner/operator will use to navigate the process of licensing, be they in a position to develop or manage an outsourcing contract or understand / deal with private sector commercial deployments.

6. **Guide to V2I Communication Technology Selection.** A description of the technology options available and why certain options may be more appropriate for some applications than others.

7. **V2I Message Lexicon.** A list of allowable standard messages and formats for transmitted information for in-vehicle use. Although the OEMs will control the message/warning type provided to the user, the type of information and its form the RSU sends needs to be standardized.

8. **Guide to Initial Deployments.** A guide to transportation system owner/operators which are on a path from no V2I deployment to a build out of the various scenarios. This would include prioritization methodology, staged deployment applications, co-location with existing ITS infrastructure, legacy equipment, utility based on V2V market penetration, etc.

9. **Warrants for Deployment.** A set of criteria which can be used to define the relative need for and appropriateness of a particular V2I application.

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Chapter 5. Pathway 3 – Connected Third Party Fleet Services and Travelers

5.1 Overview

As connected vehicle (CV) technology develops, there is a growth in the number of third-party providers who collect and distribute data from vehicles. This pathway uses the connectivity provided by smart phones for road weather management, avoiding the necessity of dedicated short-range communication (DRSC) equipment on the vehicles. Not reliant on DSRC adoption, data from these third party sources can provide information that is often difficult or costly for a public agency to collect. Furthermore, new vehicles equipped with the Long Term Evolution (LTE) wireless standard for communications allow 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.[10] Table 5-1 shows the implementation roadmap for this pathway.

Table 5-1. Implementation roadmap for connected third party fleet services and travelers.

Basic	At its most basic level, agencies receive limited information from third parties and the information is limited to speed along traveled road segments.
Intermediate	Agencies receive rich sets 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 crowdsourced 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 and share all information collected through their internal systems. The end-result is a more balanced, comprehensive, and accurate dataset that both entities can use.

5.2 Selected Examples

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 range from traffic navigation providers who incorporate weather data collection (e.g., Waze, Inrix),

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[10] Audi announced its new traffic light information system, enabled by V2I communication between the on-board LTE data connection and Traffic Technology Services, Inc. servers (Audi, 2016).

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to mobile weather data collection providers (e.g., WeatherCloud), to freight telematics providers (e.g., Omnitracs, Telegois)—all of whom are capable of collecting useful data from mobile fleets to support weather responsive traffic management (WRTM).

From a strictly road weather-focused perspective, National Oceanic and Atmospheric Administration (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 in 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 one minute intervals. In this sense, the use of MoPED data supplements fixed weather stations from airports and road weather information systems (RWIS) as it could detect small-scale phenomenon (e.g., thunderstorm or flash flood) that could occur between fixed stations points, and helps 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, amongst others. State departments of transportation (DOT), including those in Utah, Wyoming, Idaho, Colorado and California, have also developed mobile apps that include weather and road conditions.

5.3 Weather Responsive Traffic Management Applications Supported

This pathway supports WRTM applications in ways similar to those of 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 could 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.

5.4 Institutional Issues

Institutionally, this pathway bypasses data safety, security, and management issues as agencies become consumers of data. Nonetheless, agencies still need to define clear policies regarding some of the "gray areas" of these applications, including:

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- **Laws banning the use of cellphones or texting while driving**. In order to promote and support private development of Information Service Providers (ISP), some agencies and States might need to review law(s) that may hinder driver's accessibility 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 the third parties need to be managed in such a manner that it can support both the needs of maintenance and traffic operations.

5.5 Constraints and Challenges

Through this pathway, agencies become data consumers, and, as such, bypass 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, including:

- **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 thus 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/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.

5.6 Performance Measures

Similar to Pathway 1, performance for this pathway can be measured by the improvements of advisory, control and treatment strategies by using data obtained from third parties. Table 5-2 lists some potential measures for this pathway.

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Table 5-2. Potential performance measures for Pathway 3.

CV-WRTM PM 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 ITS devices
	Qualitative improvements in traveler information
Project outcomes	Vehicle speeds compared to posted speed (third party users and all vehicles)
	Vehicle speed variation

Note: CV-WRTM = connected vehicle-enabled weather responsive traffic management. ITS = intelligent transportation systems. PM = performance measure.

5.7 System Development Guidelines

System development for this pathway is mainly centered 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 both 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.

> **Resource Tip(s):** The I-95 Corridor Coalition's Vehicle Probe Project (VPP) provides its members with the ability to acquire reliable travel time and speed data for their roadways without the need for sensors and other hardware. Additionally, the coalition provides real-time and historical tools for operations and planning. The VPP acquires data from mainly private vendors. Once processed, all data, regardless of vendor, is available to each of the participating agencies.
>
> Reference: http://i95coalition.org/projects/vehicle-probe-project/

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Chapter 6. Implementation Process for Connected Vehicle-enabled Weather Responsive Traffic Management

Chapters 1 through 5 provided the reader with an understanding of connected vehicle-enabled weather responsive traffic management (CV-WRTM) applications and how a State department of transportation (DOT) might approach implementing various applications in providing effective advisory, control and treatment strategies to mitigate mobility and safety challenges due to adverse weather. Reference and implementation tips were provided along the way. This chapter summarizes the steps an agency might take to plan, design, build, implement, and maintain a CV-WRTM system.

These steps are grouped into four phases necessary in developing a connected vehicle enabled weather responsive traffic management (WRTM) project - from project conceptualization through operation. The implementation process is presented in a concise manner with each phase (and step) briefly discussed.

Table 6-1 shows an overview of the suggested CV-WRTM implementation process, consisting of the following phases:

- Phase I introduces the 4 steps necessary to plan for CV-WRTM. Ideally, steps should be used during the conceptualization stage or at the beginning of the planning stage of any envisioned CV-WRTM strategy.
- Phase II provides guidance on how to build upon the findings in Steps 1 through 4 of Phase I in order to develop a cohesive and coherent concept of operations and the necessary safety, performance, and human factors documents.
- Phase III provides information on the steps needed to develop and design the CV-WRTM system, including the partnerships, procurement, and deployment plans.
- Phase IV describes what should be considered for the management and maintenance of the new system in order to achieve expected and desired performance levels.

Each phase includes questions that stakeholders should address at the different stages of the project (i.e., planning, conceptualization, development and deployment). It should be noted 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 related to CV-WRTM. For more general guidance on systems engineering (for example, specifics of concept of operations development), the reader should refer to FHWA systems engineering guidance.[11]

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[11] 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

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Table 6-1. Suggested CV-WRTM implementation process.

Phase I	Planning for Connected Vehicle enabled Weather Responsive Traffic Management (CV WRTM)	
This planning phase of a CV-WRTM project should seek to: • Understand what user needs can be identified 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 user 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 group of) to accomplish their objectives.		
Step 1 – Needs Assessment	The first step is to identify the needs of the different stakeholders that may be impacted by the desired CV-WRTM strategy(ies). The needs of road weather maintenance (RWM) managers are many. However, it is important to identify what needs of the traveler, agency, and the other stakeholders are unmet through current operations today that can be best addressed by CV-WRTM.	**Key Output**: Initial list of user needs of all stakeholders.
Step 2 – Current Capability Assessment	The second step of the process is to identify the existing capabilities and assets of the involved stakeholders along the geographical scope of the project (i.e., develop an inventory). Three main questions should be addressed: • What are your current capabilities for WRTM and connected vehicles (CV)? • What inventory of technology and assets can you leverage for CV-WRTM? • What institutional capabilities exist in your region?	**Key Output**: A report of available physical (e.g., infrastructure and fleets), technological (e.g., hardware and software) and human (e.g., staff and subcon-tractors) resources.

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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 what is the state-of-practice and the state-of-knowledge of the desired CV-WRTM strategy(ies).	**Key Output**: Initial report of the vision and goals of the desired CV-WRTM system.

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Table 6-1. Suggested CV-WRTM implementation process (continued).

Phase I Planning for Connected Vehicle enabled Weather Responsive Traffic Management (CV WRTM) continued		
Step 4 – Feasibility Assessment	Before moving onward 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, it should be noted that with limited results and effectiveness, feasibility assessment is more 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 Development	The concept of operations describes the proposed system as seen and understood by the stakeholders of interest. The concept of operations is based on information gathering efforts and a development workshop, which helps to identify user needs for the system. The concept of operations does not specify how but rather what should be achieved with a focus on the 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 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, 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).	**Key Output**: Two main conceptual documents should be developed during this step: 1. Safety management plan 2. Security management operational concept

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Table 6-1. Suggested CV-WRTM implementation process (continued).

	Phase II Concept Development continued	
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 to 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 everyday 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 development and design 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 and should be used as the basis for system design activities.	**Key Output**: A system requirements specification (SysRS)
Step 10 – Application Development Plan	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 application development plan 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

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Table 6-1. Suggested CV-WRTM implementation process (continued).

Phase III	System Requirements, Design, Development and Deployment continued	
Step 11 – System Design	This step to design the system, is the culmination of all previous thus far. At this step requirements are allocated to the system components, which the system architecture will continue to refine, especially where they interface to the external environment. The system development needs to be managed as a project unto itself, and, 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 fulfills its requirements and meets the intentions described in the concept of operations. Formal testing is completed 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 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

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Table 6-1. Suggested CV-WRTM implementation process (continued).

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, information technology and database operations and maintenance approaches, and equipment maintenance resources. Understanding your needs in this regard and securing the dedicated required resources early in your project is essential to a successful CV-WRTM project implementation. Step 14 is closely linked to performance measurement plan (step 7) 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

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Appendix A. Concept Development Of Selected Connected Vehicle-Enabled Weather Responsive Traffic Management Applications

This section describes three connected vehicle-enabled weather responsive traffic management (CV-WRTM) applications, providing guidelines for their implementation. Each one is dependent on vehicle connectivity, regardless of the pathway. As such, all three pathways can be used to implement them. Three applications are selected to show the possibilities associated with CV-WRTM. Each of the applications can be extended to support several operational scenarios as part of the concept development. This section will outline the following applications:

Connected Vehicle-enabled Variable Speed Limits (CV-WRTM-VSL)

This application demonstrates how different pathways can help an agency match posted advisory or enforceable speed limits to match road conditions. Variable speed limits help reduce speed variation between vehicles, a contributing factor to incidents during adverse weather. Traditionally, variable speed limits are set based on field reported conditions or on visual observations at the TMC. Concepts in this application can be extended to supporting roadside advisories via dynamic message signs (DMS) and highway advisory radio (HAR), imposing vehicle restrictions (e.g., for high-profile vehicles) or even implementing a road closure.

Infrastructure-to-Vehicle (I2V) Situational Awareness for WRTM (CV-WRTM-SA)

The application demonstrates the value of situational awareness messages to en-route vehicles. Situational awareness of conditions on the roadway includes motorist alerts and advisories such as vehicle restrictions, chain laws, parking notifications provided directly to vehicles via dedicated short-range communications (DSRC), cellular or satellite communications depending on the pathway. Concepts in this application can be extended to support spot specific weather impact warning (SWIW) and work zone impact warnings (WZIW) applications.

Vehicle-to-Vehicle (V2V) Situational Awareness for WRTM (CV-WRTM-V2V)

The last application illustrates the potential of V2V communication for collision avoidance but also sharing and forwarding of distress notification between vehicles. This application depends on DSRC, so it requires a critical mass of vehicles equipped with DSRC on-board equipment.

The next three sub-sections provide a starting point and a template for developing of a concept of operations around these applications. Not all required sections of a concept of operations are provided below. Additionally, information in these sections needs to be customized and expanded based on local conditions and agency needs prior to development. Applications may be combined in larger CV deployment concepts of operations as well.

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A.1 Connected Vehicle-enabled Variable Speed Limits (CV-WRTM-VSL)

1. Introduction

Variable speed limits are a well-accepted strategy for managing traffic during adverse weather. By reducing posted speed limits to match travel conditions, agencies try to manage the speed variation between vehicles in the traffic stream and improve speed adherence. Reduced speeds and a tighter speed distribution have positive impacts on reduction of crashes and crash rates especially when visibility is reduced, and safe stopping distance is increased due to slippery road conditions.

Assumption: The following application description provides a non-DSRC based approach relying on Pathway 1 (agency fleets) and Pathway 3 (third party services) to using mobile data for VSL management.

Requirement: A VSL system must be either in place or planned to be deployed in parallel with the CV-WRTM-VSL system. The system should have sufficient infrastructure along the roadway to reach drivers that are not connected (i.e., do not fit in any CV pathway).

2. Existing Approaches and State of Practice

Several agencies around the country use VSL, including Washington Department of Transportation (DOT), Oregon DOT, and Wyoming DOT. In some cases, VSL is applied across several zones along interstates (e.g., I-80 and I-25 in Wyoming). In others like Oregon, weather-responsive VSL is primarily used in a few corridors.

Activation of VSLs can be manual, semi-automated or automated. In manual mode, a traffic management center (TMC) operator (most likely) activates the VSL signage based on either field recommendations or visual observations. Typically, agencies have a protocol for activation and deactivation of these signs. In a semi-automated system, an algorithm uses data from speed sensors and road weather information systems (RWIS) to alert an operator with a recommendation. In a fully automated system, the system automatically adjusts speed limits to match conditions based on expert rules. Operators typically have the capability to override the system.

A good example of such a system with a weather-responsive component has been implemented by Oregon DOT on OR-217 as a part of a broader active traffic management (ATM) project. The purpose of the overall OR-217 ATM project is to develop systems that improve safety and travel time reliability along the OR-217
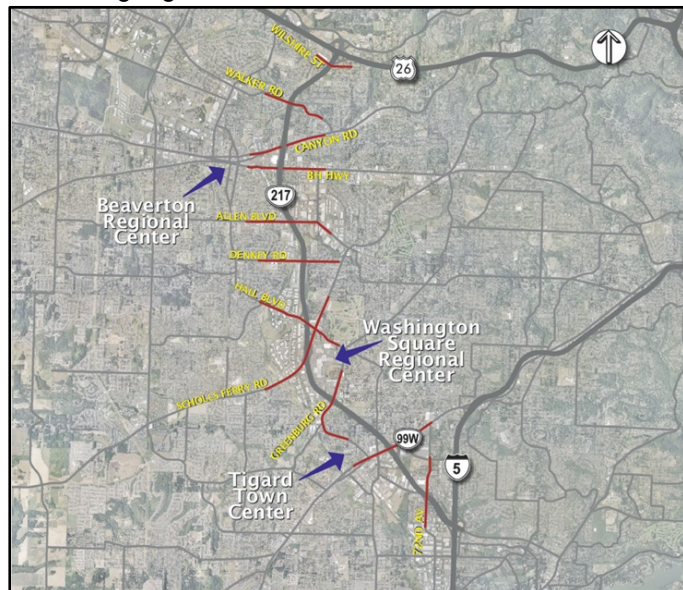
Source: Oregon Department of Transportation

Figure A-1. Oregon-217 ATM Deployment Site.

corridor in Washington County, Oregon. DMS on OR-217 and on key arterial approaches provide travelers with estimates of travel time and information about incidents, the end of queues, and congested traffic conditions. Variable advisory speed (VAS) 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.

OR217 (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, see Figure A-1. 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.

The OR217 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 OR217 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.

The purpose of the project was to assess the effectiveness of the system in supporting Oregon DOT to better manage traffic along the OR217 corridor during weather events. Evaluation activities focused on safety and mobility improvements. The system was fully operational July 2014 and the evaluation was based on data collected for the year following – 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.

Over the same period, traffic volumes in the Portland area increased by 6 percent. Additionally, during the evaluation time period, the number of days per month with rain increased by 23 percent.

The quantitative evaluation process has established a methodology to allow for objective measurement of the potential benefits of this and similar systems that may be deployed elsewhere in the future. It is also important to acknowledge that based on the success of this project and lessons learned, Oregon DOT has recently developed a statewide VSL system concept of operations document. The Oregon VSL system includes three major subsystems: congestion responsive, weather responsive, and operator control. The concept of operations (ConOps) defines both regulatory and advisory speed limit systems on rural and urban highways and interstates. The document identifies seven statewide VSL systems either in operation or under development; at least one in each of ODOT's five districts. The document further

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describes guidelines for establishing variable speed zones, operational needs, system description, operational and support environments, and operational scenarios.

3. Nature and Justification of Changes

Connected vehicles offer the potential to overcome the need for heavy instrumentation that is required for variable speed limit systems, a value proposition that becomes more critical when the concept is expanded to rural corridors.

Traditionally, VSLs have been responsive to traffic and are driven by speed sensors. However, as the Oregon example shows, it is possible and advantageous to reduce speeds prior to the traffic impact based on road condition and/or visibility. While RWIS has traditionally been the source for road condition data, other mobile sources of road condition are starting to emerge including:

- Mobile observations from agency fleets.
- Fleet driver's reported road conditions.
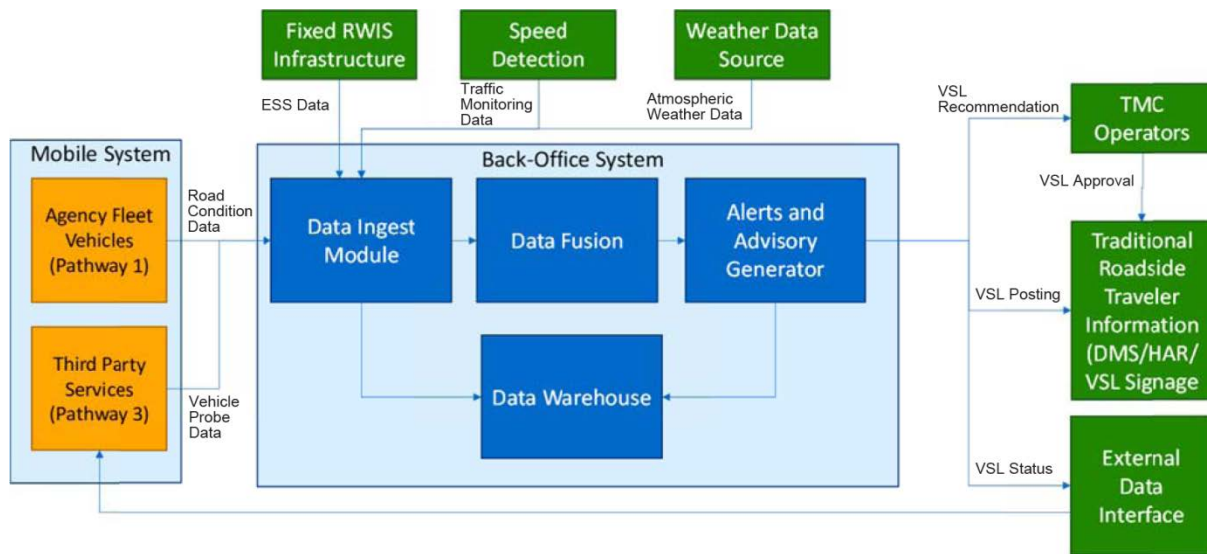- Private sector probe-based sources of road weather data.

In addition, weather forecasts and meteorological information can be another input to the variable speed limit algorithm. The following user needs are identified for this application:

- In addition to using fixed infrastructure, transportation agencies need to gather data from vehicles or infrastructure to increase the coverage of environmental monitoring of road conditions.
- Transportation agencies need to process current and historical data from multiple sources in order to provide recommended variable speed limits.

Changes considered but not included in this application include the use of DSRC for communicating VSLs back to the vehicles or obtaining vehicle probe information over DSRC. These are covered in the second application.

4. Proposed System

The proposed system diagram is shown in the following figure is comprised of two systems and several external interfaces. The system details are provided below.

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Source: Federal Highway Administration

Figure A-2. Concept diagram for connected vehicle-enabled VSL.

Mobile System – This system provides the mobile data sources for the CV-WRTM-VSL concept. Two sources of information are included here:

- Agency Fleets (Pathway 1) – Connected agency fleets provide road condition data. Road condition data can be collected using environmental sensors mounted on the fleets, vehicle network data (like wiper status, external lights), or reported by the driver through a human-machine interface (HMI). Communication from agency fleets to the back-office is likely through cellular or agency-owned radio network.
- Third Party Services (Pathway 3) – Third party services include mobile data providers who provide near real-time data services. Vehicle probe data services include: roadway speeds, mobile environmental sensing, and incident reporting.

Back Office System – This system provides the functionality to ingest, validate, and process multi-source data to generate a variable speed limit recommendation for a segment of the roadway. Four main sub-systems are envisioned for this system:

- Data Ingest sub-system – Data ingest module provides the ability to ingest multi-source data, validate the data and conduct established quality checks on the data
- Data Fusion sub-system – Quality-checked data is then fused and associated with pre-defined roadway segments in this module.
- Alerts and Advisories Generator sub-system – This module contains the algorithm that processes the fused data to generate a VSL recommendation. In addition to a VSL recommendation, additional alerts and advisories may be generated as well.
- Data Warehouse sub-system – This module stores the raw inputs as well as the alerts and advisories generated for performance measurement.

External Interfaces – The CV-WRTM-VSL system depends on several external interfaces that provide fixed infrastructure data as well as support the activation and dissemination of the VSLs.

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- RWIS – RWIS stations provide environmental sensing data to the VSL algorithm. Depending on the RWIS sensors, data elements may include atmospheric temperature, pavement temperature, visibility, wind speeds, precipitation levels, and road conditions
- Speed Detection – Speed sensors provide current reported speed on segments where VSL is being implemented.
- Weather – Atmospheric weather conditions like blowing snow, wind speeds, etc. might also be used to activate VSLs. Weather information can come from a variety of public (National Weather Service, etc.)
- TMC Operators – Depending on the nature of the VSL system, VSL recommendations may be provided to the TMC operators who would have to approve them before they get posted.
- Traditional ITS Traveler Information (e.g., website, DMS, HAR, and 511) – These represent the traditional traveler information systems to communicate the VSL with the traveler. For fully automated systems, the back-office system will automatically update these assets. In semi-automated systems, the TMC operator will initiate the activation and deactivation of these systems
- Third Party Interfaces – The agency might also provide the VSL status via a third party interface which can be used by various third party services to communicate data to their consumers.

5. Operational Scenario

Agency "X" has current advisory VSL system in place over a rural interstate corridor that spans about 100 miles. The corridor is heavily used by freight carriers and faces weather events such as blowing snow, high winds, and low visibility conditions on almost a weekly basis in the winter months. Agency X uses the VSL system to manage speeds in four segments where high-crash frequencies have been observed. To support the VSL deployment, Agency X has used a combination of RWIS and speed detection to inform them of road conditions. An algorithm that is based on sensor thresholds (speeds < 50 mph, measured reading of roadway friction less than a defined threshold) are used to activate VSL. Occasionally, the agency manually activates the VSL based on recommendations from their field personnel. Evaluations have proven that VSL zones have had a statistically significant impact on the speed distribution and VSL zones have seen a reduced severity in crashes compared to non-VSL zones.

Agency X has decided to equip its fleet vehicles (snow plows, salt-spreading vehicles, and other maintenance trucks) with an on-board unit that collects environmental sensor data (like precipitation, cross winds, visibility levels, and pavement temperature). In addition, an Android-based tablet installed on these vehicles allows the drivers to report on road condition using specific codes for different conditions.[12] The on-board equipment is not solely for VSL but supports maintenance operations and improves information sharing between the agency field personnel and dispatchers. In addition, the agency has procured real-time speed data from a third party vendor to support broader traffic management.

With these developments, Agency X feels that it can expand the VSL zones fairly efficiently. Agency X builds a data ingest system that takes in the various sources of data and performs specific quality checks to each data source. Once quality-tested, the information is associated with specific segments of the roadway. Based on expert rules defined in the system, alerts are generated for each segment.

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[12] This is the case for WyDOT's road condition reporting app (described in Chapter 3), which also provides VSL recommendations.

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Since this is a new system, the system provides these alerts as speed limit recommendations to the TMC operator. When a recommendation is generated, the operator console gets a notification. The TMC Operator is trained to respond to the alert within a few minutes of its arrival and either approve or reject the recommendation. When the recommendation is approved, the system changes the VSL signage on DMS. In addition, VSL status is constantly updated in the data feed that Agency X provides to private app developers and users.

6. Summary of Impacts

The CV-WRTM-VSL system enhances existing VSL systems by using additional probe-based data on weather, road condition, and speeds to make better decisions on the timing and the nature of the reduction in variable speed limits. The CV-WRTM-VSL system uses data collected by maintenance fleets as well externally available data (from other sources within the agency and private sources). Compared to existing VSL systems, the additional challenge is in the complexity of data ingest and fusion required to deal with different quality, temporal and spatial resolution of data streams.

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A.2 Infrastructure to Vehicle Situational Awareness (SA) for WRTM (CV-WRTM-SA)

1. Introduction

Infrastructure to vehicle (I2V) communication enables a variety of applications, ranging from safety, to mobility, to road weather management, amongst others. This particular application focuses on Situational Awareness, as applicable to WRTM. It enables relevant downstream road condition information including, but not limited to, weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking, and road closures to be broadcast from a roadside unit and received by the connected host vehicle. Such information is useful to connected host vehicles that are not fully equipped with weather sensors or to connected host vehicles moving towards or entering areas with hazardous conditions. For this application, this document provides insight into the application guidelines based on the description of "Situational Awareness (Field)" provided by J3067 August 2014 Section 2.9.3.6 and the Connected Vehicle Reference Implementation Architecture (CVRIA) requirements for I2V spot weather impact warning (SWIW).

Assumption: The following application provides situational awareness messages to en-route travelers via multiple mechanisms including DSRC, cellular and satellite.

Requirement: Vehicles and drivers pertaining to Pathway 1 (agency fleets), Pathway 2 (connected vehicles) and Pathway 3 (third party services) are all included in the applications.

2. Existing Approaches and State of Practice

Providing real-time advisories to an en-route traveler from a public agency perspective has traditionally relied on infrastructure-related elements such as DMS/HAR. In-car radio has been another important media for communication. However, in recent years, with the development of the smart phone, new apps (both private and public) are changing how traveler information is used on the road.

With Google Maps and Waze and other mapping services, real-time routing and wayfinding guidance is now commonly used relying mostly on ubiquitous cellular and data connectivity of smart phones. State DOTs are also seeing the value of smartphone based apps as a valuable addition to their situational awareness and have developed or are in agreement with private companies to share information.[13] Furthermore, existing and new applications (both private and public) are now including weather and road conditions. From a fleet standpoint, trucks and other freight carriers have long relied on communications with their dispatch centers and on-board equipment that provides traffic guidance and warnings. Freight telematics companies are continuing to support freight driver specific navigation guidance (such as truck routes, truck services, and size/weight/height restrictions).

Recent research efforts are underway to utilize DSRC for situational awareness and more information is provided under Pathway 2 (see Chapter 4).

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[13] See Section 1.2.3 for examples of States that have entered a two-way data-sharing partnership with Waze.

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3. Nature of and Justification of Changes

Despite the efforts to increase detection along roadways, there are still significant gaps in determining road weather conditions. The distances between the fixed detection sensors and the restricted ability to communicate actionable information to travelers already on the roadway are still limiting factors that reduce the effectiveness of many information-based capabilities identified in Section 2. From a private sector side, while the use of crowd-sourced information is increasing being used, information on work zone closures, lane impacts, vehicle restrictions are still a challenge to obtain without assistance from the public agency. There is a need for expanding the communication system and providing hyper-local alerts, that are, real-time geocoded and continuous in nature. DSRC communications and other wide area communication mechanisms offer the potential to provide new ways to reach travelers on the roadway. Travelers equipped with appropriate on-board equipment can receive traveler information messages that provide a heightened awareness of anticipated conditions downstream of their current location.

4. Proposed System

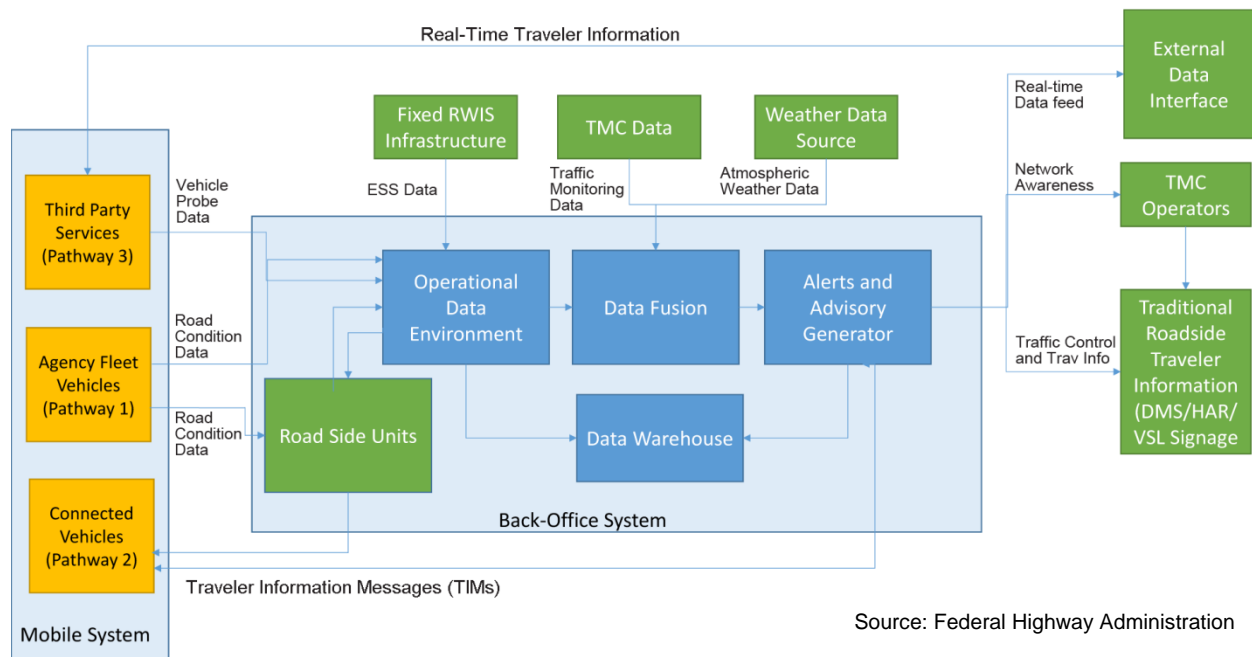Figure A-3 provides the context diagram for the application.

Source: Federal Highway Administration

Figure A-3. Concept diagram for I2V situational awareness.

Mobile System – This system provides the mobile data sources for the CV-WRTM-SA concept. Three subsystems are included here:

- Agency Fleets (Pathway 1 with DSRC connectivity) – Connected agency fleets provide road condition data. Road condition data can be collected using environmental sensors mounted on the fleets, vehicle network data (like wiper status, external lights), or reported by the driver through a human-machine interface (HMI). Communication from agency fleets to the back-office is both through cellular or agency-owned radio network and using DSRC communications with the roadside units for redundancies.
- Connected vehicles (Pathway 2) – These include private connected vehicles that are able to receive traveler information messages through DSRC communications via a roadside unit. They

are also able to receive traveler information messages through satellite or cellular communications directly from the back-office.

- Third Party Services (Pathway 3) – Third party services include mobile data providers who provide near real-time data services. Vehicle probe data services include: roadway speeds, mobile environmental sensing, and incident reporting.

Back Office System – This system provides the functionality to ingest, validate, and process multi-source data to generate an alert for a segment of the roadway. Five main sub-systems are envisioned for this system:

- Operational Data Environment sub-system – The Operational Data Environment provides the ability to ingest multi-source connected vehicle data, validate and verify the data, and conduct established quality checks on the data.
- Data Fusion sub-system – Quality-checked data is then fused and associated with pre-defined roadway segments in this module.
- Alerts and Advisories Generator sub-system – This module contains the algorithm that processes the fused data to generate alerts and advisories regarding road conditions.
- Data Warehouse sub-system – This module stores the raw inputs as well as the alerts and advisories generated for performance measurement.
- Roadside units – represents the CV roadside devices that are used to send messages to, and receive messages from, nearby vehicles using DSRC. Communications with adjacent field equipment and back office centers that monitor and control the unit are also supported. This device operates from a fixed position and may be permanently deployed or a portable device that is located temporarily in the vicinity of a traffic incident, road construction, or a special event. It includes a processor, data storage, and communications capabilities that support secure communications with passing vehicles, other field equipment, and centers.

External Interfaces – The CV-WRTM-SA system depends on several external interfaces that provide fixed infrastructure data as well as support the activation and dissemination of the VSLs.

- RWIS – RWIS stations provide environmental sensing data to the VSL algorithm. Depending on the RWIS sensors, data elements may include atmospheric temperature, pavement temperature, visibility, wind speeds, precipitation levels, and road conditions.
- TMC Data – Various traffic monitoring data feeds that support the TMC operations including speed sensing, incident reports, construction management, status of current ITS assets, and other infrastructure-related condition monitoring and management that is performed at the TMCs.
- Weather – Atmospheric weather conditions like blowing snow, wind speeds, etc. might also be used to activate VSLs. Weather information can come from a variety of public sources (e.g., National Weather Service).
- TMC Operators – Depending on the nature of the alert, recommendations may be provided to the TMC operators who would have to approve them before they get posted.
- Traditional ITS Traveler Information (e.g., DMS/HAR/511) – These represent the traditional traveler information systems to communicate the alert with the traveler. For fully automated systems, the back-office system will automatically update these assets. In semi-automated systems, the TMC operator will initiate the activation and deactivation of these systems.
- Third Party Interfaces – The agency might also provide the information via a third party interface which can be used by various third party services to communicate data to their consumers.

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5. Operational Scenarios

Agency X is piloting the deployment of V2I applications along a key corridor in the State. With the new Cadillacs coming on board with DSRC connectivity in the 2017 model year, Agency X feels like it is a good time to test out delivery of traveler information messages over DSRC. To that end, they have installed several road side units at key locations along the corridor. These locations include high-crash risk zones, decision-points prior to key freeway interchanges, port of entry locations and parking facilities. However, Agency X would like to amplify the ability to get the word out when dangerous conditions are present so multiple communication channels including delivery through satellite providers and through a third party interface that is used by private-sector information service providers.

Using this application, the agency transmits relevant downstream road condition information including weather alerts, speed restrictions, vehicle restrictions, road conditions, incidents, parking, and road closures to be broadcast from a roadside unit and received by the connected host vehicle (see Figure A-4). Such information is useful to connected host vehicles that are not fully equipped with weather sensors or to connected host vehicles in paths toward or entering areas with hazardous conditions. Due to the limited deployment of RSUs, traveler information messages can also be provided with satellite communications.
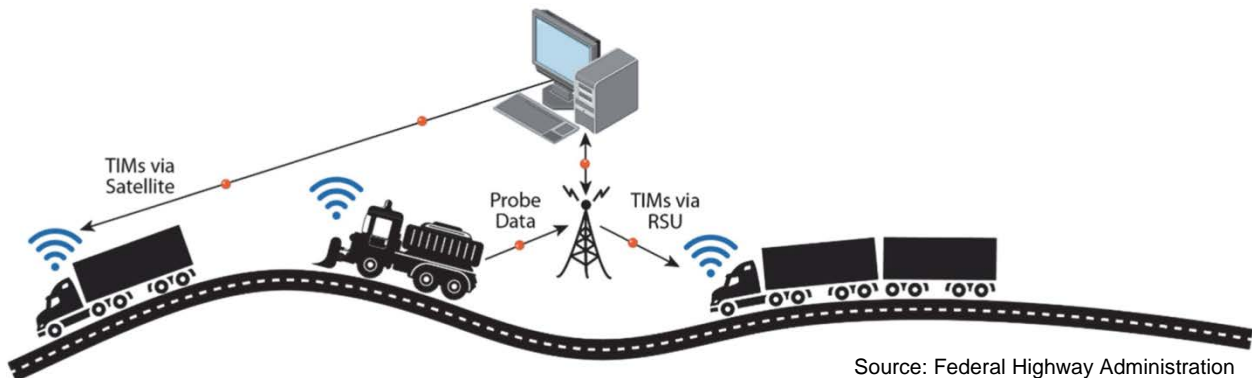
Source: Federal Highway Administration

Figure A-4. Illustration of the I2V situational awareness concept.

With this application, the agency is able to broadcast information about the conditions that exist around different locations that demand awareness of the driver (e.g., a spot-specific weather) toward which the vehicle is approaching (see
Figure A-5). This application supports work zone notifications as well.
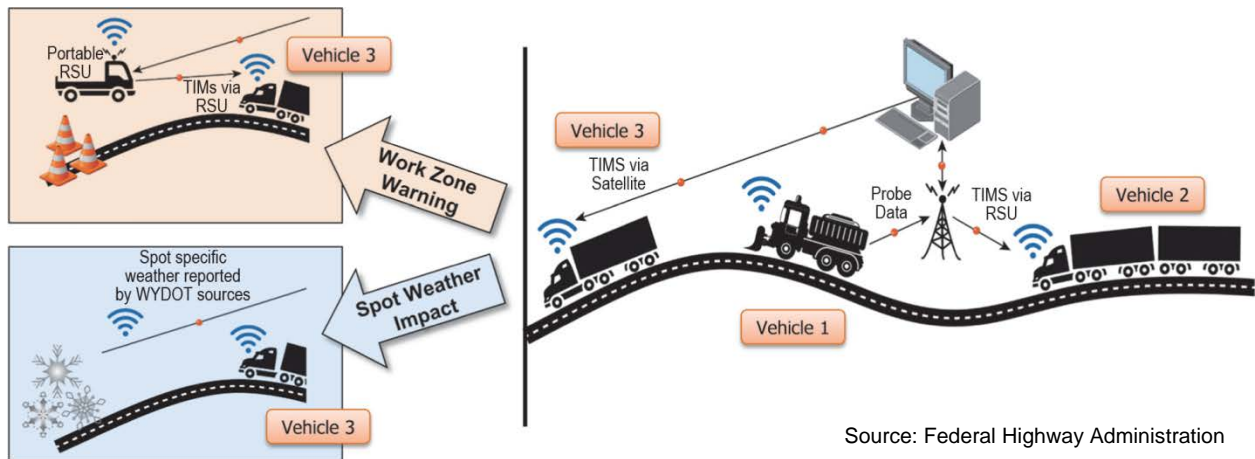
Source: Federal Highway Administration

Figure A-5. I2V situational awareness (spot-specific warning and work zone) concept diagram.

6. Summary of Impacts

Organizationally, this application requires the management of new data sets and new field infrastructure which may be a challenge for resource constrained agencies. However, multiple pathways are used so an agency can slowly move toward the full implementation of the application. Additional requirements for DSRC licensing are also needed for roadside units.

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A.3 V2V Situational Awareness for WRTM (CV-WRTM-V2V)

1.0 Introduction

The last application showcases the use of DSRC for enabling vehicle to vehicle communications of safety-critical conditions. The CV-WRTM-V2V Situational Awareness (SA) application determines if the road conditions measured by other vehicles represent a potential safety hazard for the vehicle containing the application. To enable this application other vehicles broadcast relevant road condition information, such as fog or icy roads. This application supports the capability for connected vehicles to share situational awareness information even in areas where no roadside communications infrastructure exists. This application can be useful to vehicles that are not fully equipped with sensors, or vehicles entering an area with hazardous conditions.

This use case includes slow moving maintenance vehicles broadcasting their location and heading to other following vehicles (which may be other agency vehicles or private vehicles) and supporting forward collision warning type applications. Another use case for this application could collect and relay notifications of distress to other vehicles that might be approaching the distress location.

Assumption: This application assumes a critical mass of DSRC-enabled vehicles that are able to broadcast and transmit BSMs with each other.

Requirement: This application is reliant on private vehicles, agency fleets (Pathway 1) and private vehicles (Pathway 2) communicating with each other using DSRC.

2. Existing Approaches and State of Practice

V2V communications have primarily been demonstrated in pilot settings with the Safety Pilot being a prime example. The U.S DOT Safety Pilot researched the effectiveness of V2V based safety applications. The Model Deployment Geographic Area (MDGA) for this project is Ann Arbor, Michigan and includes 73 lane-miles of equipped roadway with 29 roadside equipment boxes (RSEs) and 2,800 cars, trucks and transit buses. The Safety Pilot had limited weather related applications but did test Forward Collision Warning (FCW) and Enhanced Emergency Brake Light (EEBL) in both cars and trucks. For example, six applications were developed for commercial vehicles and demonstrated as part of the Safety Pilot project by U.S DOT to showcase V2V safety. (Battelle, 2014).

Additionally, collision avoidance systems are a commonly found feature in newer cars sold today. The Insurance Institute for Highway Safety (IIHS) reported that "Front crash prevention is reducing crashes. Vehicles equipped with the technology are less likely to rear-end other vehicles, IIHS research has shown. The Highway Loss Data Institute (HLDI) has found that vehicles with front crash prevention have fewer claims under property damage liability coverage, which pays for damage to vehicles that an at-fault driver hits."[14]

From an agency perspective, the ability to protect slow moving agency fleet vehicles from rear-end crashes is the primary motivation for the application. During winter maintenance activities, snow plows

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[14] Insurance Institute for Highway Safety and Highway Loss Data Institute. "Crash Avoidance Technologies." Accessible at http://www.iihs.org/iihs/topics/t/crash-avoidance-technologies/topicoverview.

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and patrol vehicles are at risk due to the challenging road conditions and their role on the roadway. In locations where "wing plows" are installed, vehicles trying to overtake them might be unaware of the extension (which might be obscured by snow). Highway patrol vehicles might have to make frequent stops.

3. Nature and Justification of Changes

In addition to emerging collision avoidance technologies, V2V communications using DSRC helps overcome line of sight issues and increases the detection zone for incidents including the ability to detect oncoming vehicles around corners at intersections. These will help augment existing collision avoidance technology by identifying scenarios which may have been missed by the forward-facing collision avoidance technology becoming available in cars.

4. Proposed System

Figure A-6 illustrates the context diagram for CV-WRTM-V2V applications. The primary elements are the vehicle systems that will exchange information with.
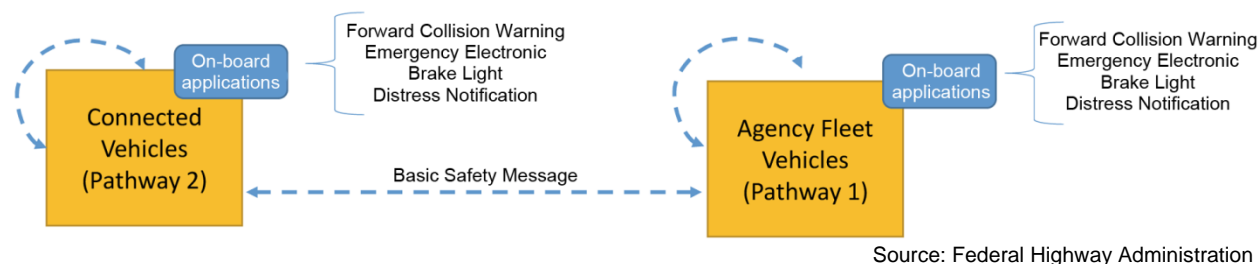

Source: Federal Highway Administration

Figure A-6. V2V situational awareness concept diagram.

The primary mechanism for sharing information is the BSM specified in SAE J2735. BSM includes Part I and Part II (optional). It is likely that Part I will be widely supported but weather and vehicle status related data are usually broadcast as part of the BSM Part II. Additional details on this application are available in CVRIA as part of the V2V Situational Awareness application.

The system typically includes an on-board unit which is able to process and use the received BSMs to support applications that warn the driver of impending danger. Three such applications are highlighted in the diagram – forward collision warning, emergency electronic brake light and distress notification since they are tightly coupled with weather conditions. But other V2V applications like intersection movement assist (IMA) may have included as well.

5. Operational Scenarios

Accidents with snow plows are on the rise, so Agency X has decided to try V2V communication as a potential long-term solution to this issue. Recognizing that widespread V2V adoption is still decades away, Agency X has identified some priority partners to support the initial roll-out of on-board equipment. These partners include agency fleets (like department of sanitation, construction), school district bus operations, freight operations, taxi fleets and transit buses that frequent the target roadways. While still far from critical mass, Agency X feels that this roll out should provide valuable feedback on how the technology works especially for different vehicle types (trucks, school buses, transit vehicles, etc.) since a majority of current work has been focused on light-duty vehicles.

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Agency X is primarily interested in two applications. First, a V2V communication-based safety feature that issues a warning to the driver of the connected host vehicle in case of an impending front-end collision with a connected vehicle ahead in traffic in the same lane and direction of travel on both straight and curved geometry roadways (see Figure A-7, Forward Collision Warning - FCW). FCW will help drivers avoid or mitigate front-to-rear vehicle collisions in the forward path of travel. The system does not attempt to control the host vehicle to avoid an impending collision.
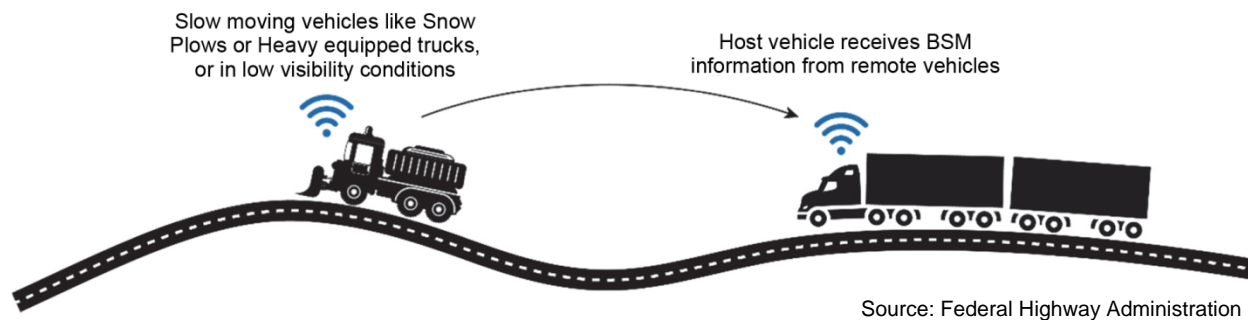

Source: Federal Highway Administration

Figure A-7. Illustration of the forward collision warning concept.

Second, with an aim to prevent secondary accidents, Agency X is interested in a distress notification application. In this application, connected vehicles communicate a distress status when the vehicle's sensors detect an event that might require assistance from others or the vehicle's operator manually initiates a distress status. The vehicle generates and broadcasts a distress message (e.g., Mayday). The message is received by connected vehicles that are in the vicinity and forwarded to notify oncoming vehicles that a distressed vehicle is ahead, or even to the TMC or 911 Center via DSRC or Cellular if the available infrastructure supports such communication.

Through these applications, Agency X is able to test the ability of V2V communication to alert drivers to conditions before they encounter them in their line of sight.

6. Summary of Impacts

With V2V communication elements in place, agencies are able to leverage the potential of DSRC to communicate between vehicles on the roadway. However, many uncertainties remain at this stage:

- Unknown levels of penetration of DSRC technology in light vehicles – With low levels of penetration, the utility of the V2V applications may be limited since a majority of the vehicles might not receive the alert
- Evolving standards and roadmaps for V2V deployment may affect how applications are designed. For example, if BSM Part II is consistently read by on-board equipment, applications that rely on vehicle status data may not work correctly.

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Appendix C. List of Acronyms and Terms

Tables C-1 and C-2 list and describe all the acronyms and terms used in this document, respectively.

Table C-1. List of Acronyms.

Acronym	Definition
AAM	Alliance of Automobile Manufacturers
AASHTO	American Association of State Highway and Transportation Officials
ATIS	advanced traveler information systems
ATMS	advanced traffic management systems
AVL	automatic vehicle location
BSM	basic safety messages
CAMP	Crash Avoidance Metrics Partnership
CAN	controller area network
CCTV	closed-circuit television
CMF	capability maturity framework
ConOps	concept of operation
CV	connected vehicle
CV-WRTM	vehicle-enabled WRTM
CV-WRTM-SA	infrastructure to vehicle (I2V) situational awareness for WRTM
CV-WRTM-V2V	V2V situational awareness for WRTM
CV-WRTM-VSL	connected vehicle enabled variable speed limits
CVRIA	Connected Vehicle Reference Implementation Architecture
DB	data broker
DCM	data capture and management
DMA	dynamic mobility applications
DMS	dynamic message signs
DOD	(U.S.) Department of Defense
DOT	departments of transportation
DSRC	dedicated short-range communication
DUAP	data use analysis and processing
DW	data warehouse
E-MDSS	enhanced maintenance and decision support system
EEBL	enhanced emergency brake light
EOC	emergency operations centers

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Acronym	Definition
ESS	environmental sensor stations
FCW	forward collision warning
FHWA	Federal Highway Administration
GAO	Government Accountability Office
HAR	highway advisory radio
HLDI	highway loss data institute
HMI	human-machine interface
IEEE	Institute of Electrical and Electronics Engineers
IIHS	Insurance Institute for Highway Safety
IMA	intersection movement assist
IMO	integrated mobile observations
INFORM	INformation FOR Motorists
ITE	Institute of Transportation Engineers
ITIS	international traveler information systems
ITS	intelligent transportation systems
ITSA	Intelligent Transportation Society of America
MDSS	maintenance decisions support system
MMS	maintenance management system
MnDOT	Minnesota DOT
MoPED	mobile platform environmental data
NCAR	National Center for Atmospheric Research
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OBU	onboard units
ODE	operational data environment
OEM	original equipment manufacturers
PA	Pikalert
PII	personal and identifiable information
QA/QC	quality assurance and quality control
RSU	roadside units
RWIS	road weather information systems
RW-PM	road weather performance management
SAE	Society of Automotive Engineers
SE	systems engineering

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Acronym	Definition
SyRS	system requirements specification
TIM	traveler information messages
TMC	transportation management center
TWG	technical working groups
V2I	vehicle to infrastructure
V2I-DC	Vehicle-to-Infrastructure Deployment Coalition
V2V	vehicle to vehicle
V2X	vehicle to nomadic device
VII	vehicle infrastructure integration
VMS	variable message sign
VPP	vehicle probe project
VSL	variable speed limit
WAVE	wireless access in vehicular environments
WRTM	weather responsive traffic management
Wx-ATM	weather-responsive active traffic management
WxDE	weather data environment
Wx-TINFO	weather-responsive traveler information

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Table C-2. List of Terms

Term	Description
Basic Safety Message (BSM)	The BSM is transmitted over DSRC (range ~300 meters) and is tailored for low latency, localized broadcast required by V2V safety applications. Connected V2V safety applications are built around the SAE J2735 BSM, which has two parts: BSM Part I: Contains the core data elements (vehicle size, position, speed, heading, acceleration). Transmitted approximately 10x per second BSM Part II: Added to Part I depending upon events (e.g., ABS activated). Contains a variable set of data elements drawn from many optional data elements (availability by vehicle model varies). It is also transmitted less frequently.
Broadcast	Sharing data with no specific destination. All broadcasted data is sent unencrypted but is signed with a certificate (based on 1609.2).
Connected Vehicle	A vehicle that can transmit and receive Basic Safety Messages (BSMs) following the Wireless Access in Vehicular Environments (WAVE) protocol, established in Standard IEEE 802.11p which uses the ITS band of 5.9 GHz (5.85 – 5.925 GHz).
Host Vehicle	A connected vehicle that receives messages from a remote vehicle. In this document, the host vehicle is also used to describe the originator of a vehicular transmission of information to the RSU.
International Traveler Information Systems (ITIS)	The term commonly associated with the SAE J2540-2 standard for incident phrases developed by the SAE ATIS Committee in conjunction with ITE TMDD and other standards. This work contains a wide variety of standard phrases to describe incidents (i.e., a traffic accident) and is used throughout the ITS industry. The codes found there can be used for sorting and classifying types of incident events, as well as creating uniform human-readable phrases. ITIS phrases can also be freely mixed with text and used to describe incidents, accidents, weather reports, roadway signage, and other content types.
Receive Data	A connected device accepts a data package broadcasted or transmitted by another connected device.
Remote Vehicle	A connected vehicle that periodically and dynamically broadcasts a message about its general situation to a host vehicle.
Transmit	Sharing data directed to a specific receiver. In the case of transmission between Systems, all transmitted data is signed and encrypted where required based on 2945/1.
Transportation Management Center (TMC)	Center that collects information and informs the public about changing travel conditions.

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Term	Description
Traveler Information Message (TIM)	The TIM is used to send various types of information (advisory and road sign types) to equipped devices. It makes heavy use of the International Traveler Information Systems (ITIS) encoding system to send well known phrases, but allows limited text for local place names. The supported message types specify several sub-dialects of ITIS phrase patterns to further reduce the number of octets to be sent. The expressed messages are active at a precise start and duration period, which can be specified to a resolution of a minute. The affected local area can be expressed using either a radius system or one of the systems of short defined regions, similar to the way roadway geometry is defined in the MAP messages.

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