Concept of Operations for Road Weather Connected Vehicle and Automated Vehicle Applications

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16. Abstract

Weather has a significant impact on the operations of the nation's roadway system year round. These weather events translate into changes in traffic conditions, roadway safety, travel reliability, operational effectiveness and productivity. It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance by mitigating the effects of weather on the roadways. Accurate, timely, route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. Connected vehicle technologies hold the promise to transform road weather management. Road weather connected vehicle applications will dramatically expand the amount of data that can be used to assess, forecast, and address the impacts that weather has on roads, vehicles, and travelers; fundamentally changing the manner in which weather-sensitive transportation system management and operations are conducted. Automated vehicle technologies have progressed in development and research phases. Weather conditions pose a threat to the safety and mobility of automated vehicles, and therefore road weather information must be considered when further developing automated vehicle applications. The U.S. Department of Transportation's Road Weather Management Program has developed this Concept of Operations (ConOps) to define the priorities for connected vehicle and automated-vehicle-enabled road weather applications.

17. Key Words
Road Weather, Meteorology, Connected Vehicle, Connected Vehicle Systems, Traffic Management, Traveler Information, Data Collection, Applications, Automated Vehicle

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TABLE OF CONTENTS

Table of Figures

Table of Tables

EXECUTIVE SUMMARY

Weather has a significant impact on the operations of the nation's roadway system year round. Rain reduces pavement friction; winter weather can leave pavements snow-covered or icy; fog, smoke, blowing dust, heavy precipitation, and vehicle spray can restrict visibility; strong winds can lead to vehicle instability; flooding, snow accumulation, and wind-blown debris can cause lane obstructions.

Weather events may prompt travelers to change departure times, cancel trips, choose an alternate route, or select a different mode. Slick pavements, low visibility and lane obstructions lead to driving at lower speeds or with increased following distances. These changes in driver behavior can impact the operation of signalized roadways, where traffic signals are timed for clear, dry conditions, resulting in reduced traffic throughputs, increased delays, and increased travel times. Travel reliability for motorists and commercial vehicle operators is also affected by a variety of weather conditions. Overall, weather impacts the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time.

It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance under such conditions by mitigating the effects of weather on the roadways. The operational approaches used by these personnel dictate their needs for weather and road condition information. Accurate, timely, route-specific weather information at high temporal and spatial resolutions allows traffic and maintenance managers to better operate and maintain roads under adverse conditions. Connected vehicle research is a multi-modal initiative that aims to enable interoperable, networked wireless communications among vehicles, infrastructure, and other wireless devices. These technologies hold the promise to transform road weather management. Road weather connected vehicle applications will dramatically expand the amount of data that can be used to assess, forecast, and address the impacts that weather has on roads, vehicles, and travelers; fundamentally changing the manner in which weather-sensitive transportation system management and operations are conducted. The broad availability of road weather data from an immense fleet of mobile sources will vastly improve the ability to detect and forecast road weather and pavement conditions, and will provide the capability to manage the effects of adverse weather on specific roadway links.

In addition, automated vehicle technologies offer tremendous possibilities for safety and mobility. By using the information about their surroundings, including data from nearby vehicles, infrastructure, and various other sources, automated vehicles will be able to control

specific vehicle functions (e.g., steering, braking) that motorists usually perform. Adverse weather affects driving conditions and poses safety challenges for automated vehicles. As such, weather must be considered when performing further research and development of automated vehicles. The U.S. Department of Transportation (USDOT) is providing national leadership in the connected vehicle and vehicle automation programs. Considering these programs, the USDOT through the Road Weather Management Program has developed this Concept of Operations (ConOps) to define the priorities for connected vehicle and automated-enabled road weather applications. Ten high-priority connected and automated vehicle road weather concepts are identified and described in this document.

CHAPTER 1. SCOPE

DOCUMENT SECURITY

This document is not restricted.

IDENTIFICATION

This document is identified as "Concept of Operations for Road Weather Connected Vehicle and Automated Vehicle Applications. Draft. June 10, 2015

DOCUMENT OVERVIEW

The format of this document is consistent with the outline of a concept of operations (ConOps) document defined in Institute of Electrical and Electronics Engineers Standard 1362-1998. Titles of major sections have, in some instances, been edited to reflect the focus of this document on identifying and describing a set of applications, rather than a single system development effort.

Chapter 2 describes the current situation from the perspectives of the Road Weather Management Program (RWMP), State DOTs, and weather enterprises with relationship to how road weather information is used to support the management, operations, and maintenance of the roadway network in the United States.

Chapter 3 identifies the need for changes from the current situation and includes descriptions of the impacts of weather events on transportation safety, mobility, and productivity. This section introduces the connected vehicle program and highlights the ITS strategic plan's relationship to the development of vehicle automation. Chapter 3 introduces desired changes for connected vehicle road weather alerts and warnings applications, performance management applications, state and local agency-based applications, freight-based applications, Emergency Medical Services (EMS)/first-responder applications, and Enabling Capability Systems for Connected Vehicle Road Weather Data.

Chapter 4 provides details of high-priority connected vehicle and automated vehicle road weather applications, while Chapter 5 presents operational scenarios for each application.

Chapter 6 summarizes operational and organizational impacts that may result from the development of the selected applications. Chapter 7 concludes with an analysis of the expected improvements and disadvantages or limitations that may occur following implementation of the applications.

CONCEPTS OVERVIEW

Ten High-priority concepts are described in the document; nine connected vehicle road weather applications, two connected vehicle enabling systems, and one road weather module for automated vehicle applications. The applications can be summarized as follows:

Connected Vehicle Applications

- **Enhanced Maintenance Decision Support System (EMDSS):** The EMDSS will provide the existing federal prototype MDSS with expanded data acquisition from connected vehicles. Snowplows, agency fleet vehicles, and other vehicles operated by the general public will provide road weather connected vehicle data to the EMDSS, which will use this data to generate improved plans and recommendations to maintenance personnel. In turn, enhanced treatment plans and recommendations will be provided to the snowplow operators and drivers of agency maintenance vehicles.
- **Information for Maintenance and Fleet Management Systems:** In this concept, connected vehicle information is more concerned with non-road weather data. The data collected may include powertrain diagnostic information from maintenance and specialty vehicles, the status of vehicle components, the current location of maintenance vehicles and other equipment, and the types and amounts of materials onboard maintenance vehicles and will be used to automate the inputs to Maintenance and Fleet Management Systems on a year-round basis. In addition, desirable synergies can be achieved if selected data relating to winter maintenance activities, such as the location and status of snowplows or the location and availability of deicing chemicals, can be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies.
- **Weather-Responsive Traffic Management:** Connected vehicle systems (CVS) provide opportunities to enhance several Weather-Responsive Traffic Management (W R T M) applications. Four WRTM strategies are discussed in this ConOps. First, CVS will have the potential to enhance the operation of variable speed limit (VSL) systems and dramatically improve work zone safety during severe weather events. Additional road weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed limits to reflect prevailing weather and road conditions. Second, CVSs can support the effective operation of signalized intersections when severe weather affects road conditions. Information from connected vehicles can be used to adjust timing intervals in a signal cycle or to select special signal timing plans that are most appropriate for the prevailing conditions. Third, CVS will enhance the performance of lane

restriction strategies during adverse weather. Connected vehicle road weather information will be incorporated in algorithms to better identify when lane restrictions will be most effective. Ramp metering is the fourth is WTRM application discussed in this ConOps. Connected vehicle weather information can be used to improve ramp metering timing parameters, which will increase safety and mobility during inclement weather.

- **Motorist Advisories and Warnings:** Information on segment-specific weather and road conditions is not broadly available, even though surveys suggest that this information is considered of significant importance to travelers. The ability to gather weather and road condition information from connected vehicles will dramatically change this situation. Information on current, deteriorating road and weather conditions on specific roadway segments can be pushed to travelers through a variety of means as alerts and advisories within a few minutes. In addition, combining these observations with forecasts from other sources and with additional processing, will enable the dissemination of medium-term advisories of the next 2–12 hours and long-term advisories for more than 12 hours into the future.
- **Information for Freight Carriers:** The ability to gather weather and road condition information from connected vehicles will significantly improve the ability of freight shippers to plan and respond to the impacts of severe weather events and poor road conditions. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to both truck drivers and their dispatchers. In combination with observations and forecasts from other sources and with additional processing, medium-to-long-term advisories can also be provided to dispatchers to support routing and scheduling decisions. Because these decisions involve a variety of other factors, such as highway and bridge restrictions, hours-of-service limitations, parking availability, delivery schedules, and—in some instances—the permits the vehicle holds, it is envisioned that the motor carrier firms or their commercial service providers will develop and operate the systems that use the road weather information generated through this concept.
- **Information and Routing Support for Emergency Responders:** Emergency responders, including ambulance operators, paramedics, and fire and rescue organizations, have a compelling need for the short, medium, and long time horizon road weather alerts and warnings. This information can help drivers safely operate their vehicles during severe weather events and under deteriorating road conditions. Emergency responders also have a particular need for information that affects their dispatching and routing decisions. Information on weather-affected travel routes, especially road or lane closures caused by snow, flooding, and wind-blown debris, is particularly important. Low latency road weather information from connected vehicles for specific roadway segments together with information from other surface weather observation systems, such as flooding and high winds, will be used to determine response routes, calculate response times, and influence decisions to hand off an emergency call from one responder to another responder in a different location.

- **Road Weather Performance Management Application:** A performance management tool takes advantage of connected vehicle data to enhance and transform road weather performance measurement and management processes in State Departments of Transportation (DOT). The tool will incorporate mobile traffic and weather observations in evaluating how well transportation agencies are performing weather-related traffic management and maintenance activities. Performance measures that are important to State DOTs can vary based on type and severity of weather events as well as the priorities and constraints faced by each State.

Enabling Systems for Connected Vehicle Applications

- **Integrated Modeling for Road Weather Condition Prediction:** The performance of connected vehicle applications are predominantly based on the type and quality of information processed. The Integrated Modeling for Road Weather Condition Prediction increases the sophistication of connected vehicle applications by considering trends in unpredictable road conditions (e.g., accidents, road maintenance). Furthermore, the model combines this information with road and weather data, which allows applications that integrate the model to use predictive information. Overall this concept will help numerous applications mitigate adverse road and weather conditions.
- **Citizen Reporting of Weather and Road Conditions:** Citizen reporting (CR) is a form of crowdsourcing in which citizens (non-DOT personnel) are recruited and trained to use specific applications to report weather and road conditions as they travel. Compared to other forms of crowdsourcing (e.g., social media and third-party applications such as Waze), CR programs and software are built and managed by the DOT; therefore, they are able to give the DOT the information it needs to enhance situational awareness and decision making in operations. In most circumstances, DOTs can feed CR data directly into their operational software systems. Moreover, depending on the technology built by the DOT, reporters may have the functionality to submit reports from the field via smartphone applications while the conditions are being observed. The objective of CR programs is to increase weather and road condition data concentration beyond traditional forms of condition reporting (usually maintenance field crews). Thus, Citizen Reporting will create timelier, more concentrated data that connected vehicle road weather applications can use to increase accuracy in outputs.

Road Weather Module for Automated Vehicle Applications

- **Automated Vehicle (AV) Applications:** Adverse weather has major impacts on safety and operations of all roads, from two-lane rural roads to signalized arterials and Interstate highways. Weather mainly affects driver behavior, vehicle performance, pavement friction, and roadway infrastructure, thereby increasing the risk of crashes. Most literature on weather effects have focused on collision risk, traffic volume variations, signal control, travel patterns, and traffic flow parameters. However, there is limited literature that characterizes the vehicle performance in the different levels of automation under adverse weather conditions. It is thus important for AV application developers to understand how these factors/elements (driver behavior, roadway characteristics, vehicle characteristics, and communications) are affected by adverse weather. This will help develop applications that can perform without degraded accuracy in adverse weather conditions. Accurate real-time road weather data enables safe decision control processes for automated vehicles.

Road Weather Components for Connected Vehicle Safety and Mobility Applications

- **V2I Safety and Traffic Network Mobility Applications:** Safety and mobility applications are being developed elsewhere in the connected vehicle program, however the RWMP have identified several non-weather related applications that need weather components added to the application. Since these applications are being discussed elsewhere, this ConOps only address weather aspects and discuss how systems like the integrated modeling for road weather condition prediction, Citizen Reporting, the Meteorological Assimilation Data Ingest System (MADIS), and the VDT will benefit the performance of these applications during adverse weather events.

CHAPTER 2. CURRENT SITUATION

BACKGROUND AND OBJECTIVES

To better understand this document, weather and road weather must first be defined to show how the two differentiate. Weather is defined as the state of the atmosphere at a place and time with respect to wind, temperatures, cloudiness, precipitation, pressure, etc. Road weather is defined as the state of the roadways with respect to wind, temperature, precipitation type, pavement temperature, subsurface temperature, subsurface moisture, pavement conditions, visibility, relative humidity, etc. Road weather represents the conditions of the road as influenced by the combination of several factors, not only including the weather, but also traffic conditions and maintenance actions. Therefore, it is vital to differentiate weather from road weather to ensure that specific mitigation actions are taken.

Weather has a significant impact on the operations of the nation's roadway system year-round. Rain reduces pavement friction; winter weather can leave pavements snow covered or icy; fog, smoke, blowing dust, heavy precipitation, and vehicle spray can restrict visibility; flooding, snow accumulation, and wind-blown debris can cause lane obstructions. These weather events translate to changes in traffic conditions, roadway safety, travel reliability, operational effectiveness, and productivity.

Traffic conditions may change in a variety of ways. Weather events may prompt travelers to change departure times, cancel trips, choose an alternate routes, or select a different modes. Slick pavements, low visibility, and lane obstructions lead to driving at lower speeds or with increased following distances. These changes in driver behavior can affect the operation of signalized roadways, where traffic signals are timed for clear, dry conditions, resulting in reduced traffic throughputs, increased delays, and increased travel times.

Weather affects roadway safety by increasing exposure to hazards and crash risk. In addition, weather affects the operational effectiveness and productivity of traffic management agencies and road maintenance agencies through increased costs and lost time. Travel reliability for motorists and commercial vehicle operators is affected by a variety of weather conditions.

Moreover, climate change has and will continue to have major impacts to the nation's transportation system through increased incidences as well as increased severity of extreme weather[1] and increasing vulnerability to the weather's impacts[2]. The current climate situation has pushed the issue of weather preparedness and response to the forefront in recent years. With FHWA guidance, State DOTs are taking active measures to reduce the impacts of and increase their resilience to extreme weather events[3].

It is, therefore, an important responsibility of traffic managers and maintenance personnel to implement operational strategies that optimize system performance under such conditions by mitigating the effects of weather on the roadways. The operational approaches these personnel use dictate their needs for weather and road condition information. Accurate, timely, route-specific weather information allows traffic and maintenance managers to better operate and maintain roads under adverse conditions.

The U.S. Department of Transportation (USDOT) Federal Highway Administration (FHWA) has defined three types of road weather management strategies that can be employed in response to rain, snow, ice, fog, high winds, flooding, tornadoes, hurricanes, and avalanches:

- **Advisory Strategies:** These strategies provide information on prevailing and predicted conditions as well as impacts to motorists.
- **Control Strategies:** These strategies alter the state of infrastructure and roadway devices to permit or restrict traffic flow and regulate roadway capacity.
- **Treatment Strategies:** These strategies supply resources to roadways to minimize or eliminate weather impacts.

A variety of approaches are available to traffic managers to advise travelers of road weather conditions and weather-related travel restrictions (such as road closures resulting from fog or

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[1] Schwartz, H. G., M. Meyer, C. J. Burbank, M. Kuby, C. Oster, J. Posey, E. J. Russo, and A. Rypinski, 2014: Ch. 5: Transportation. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 130-149. doi:10.7930/J06Q1V53.

[2] FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework. Available: http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/vulnerability_assessment_framework/

[3] Summary of FHWA Climate Adaptation Work: Building Climate Resilient Transportation. Available: http://www.fhwa.dot.gov/environment/climate_change/adaptation/publications_and_tools/bcrt_brochure.cfm

flooding). Strategies include: posting warnings on dynamic message signs (DMS), broadcasting messages via highway advisory radio (HAR), providing road condition reports through interactive traveler information systems such as websites and 511 phone systems, and Public Information Officer interaction with media.

To control traffic flow during adverse weather, traffic managers may regulate lane use (such as lane reversals for evacuations), close hazardous roads and bridges, restrict access on particular roadways to designated vehicle types (e.g., tractor-trailers during high winds), implement variable speed limits, adjust freeway ramp metering rates, or modify traffic signal timings.

Maintenance managers use road weather information and decision support tools to assess the nature and magnitude of winter storms, determine the level of staffing required during a weather event, plan road treatment strategies (e.g., plowing, sanding, chemical applications), and activate anti-icing/deicing systems. Beyond winter weather, maintenance managers are also concerned about the impacts of other events such as sand storms and wildfires that may reduce visibility and create hazardous driving conditions.

Access to high-quality road weather information helps managers improve safety, enhance traffic flow and travel reliability, and increase agency productivity. Weather mitigation strategies enhance roadway safety by reducing crash frequency and severity, restricting access to hazardous roads and encouraging safer driver behavior. Road weather management strategies enhance traffic flow and mobility by allowing the public to make more informed travel decisions, promoting more uniform traffic flow, reducing traffic congestion and delay, and minimizing the time to clear roads of snow and ice.

Productivity is increased through better interagency communication and data sharing and by reduced labor, material, and equipment costs for snow and ice control operations.

OPERATIONAL POLICIES AND CONSTRAINTS

Operational policies for road weather management activities vary from state to state, both in terms of their detail and their formality. Many state transportation agencies have documented policies and procedures that describe strategies for conducting winter and non-winter maintenance activities under various adverse weather conditions. Similar guidelines for the management of traffic operations under adverse weather conditions appear to be less widespread but are gaining ground because of the efforts of the FHWA Weather-Responsive Traffic Management initiative, among other efforts. In many instances, the documented policies and procedures appear to be derived from personnel experience and informal rules of practice. It also appears that documented operational policies are supplemented with undocumented practices.

According to the American Association of State Highway and Transportation Officials, state transportation agencies are increasingly adopting the use of performance-based management approaches. All state departments of transportation (DOT) track asset condition and safety data. The majority of states provide comprehensive performance data to decision makers to both increase accountability to customers and achieve the best possible transportation system performance under current levels of investment. The definition of the performance measures and the formality of reporting again vary from state to state, but weather-related metrics, particularly relating to snow removal during winter storms, are not uncommon. Overall, no operational policies related to road weather management are common across the United States. In addition, no policies will specifically constrain the development of connected vehicle road weather applications.

DESCRIPTION OF CURRENT SITUATION

The Connected Vehicle Program

USDOT is providing the national leadership in the connected vehicle program. Connected vehicle research is a multi-modal initiative that aims to enable interoperable networked wireless communications among vehicles, the infrastructure, and other wireless devices.

- **Connected vehicle applications** provide real-time connectivity among vehicles, infrastructure, and wireless devices. The connectivity of applications gives the user (i.e., motorists, maintenance engineers/ personnel, operations managers, or other DOT professionals) transportation enhancements in areas pertaining to safety, mobility, and environmental benefits. Connected Vehicle Reference Implementation Architecture (CVRIA) is a tool that highlights the initial of physical, enterprise, and communications of connected vehicle technologies. The national architecture for connected vehicle deployment will encompass CVRIA, which has categorized connected vehicle applications into three types.

- **Safety applications** enable vehicles with 360-degree awareness to inform users of hazards and situations they may or may not be able to see. These safety applications have the potential to reduce crashes through advisories and warnings. Applications may advise users to reduce speeds in school zones, sharp ramp curves, or slippery patches of roadway ahead. Safety applications may also warn users in more imminent crash situations, such as during merging operations or if the vehicle ahead stops suddenly. Vehicles can also warn the user of bicycles and pedestrians through connected vehicle technology, enhancing the safety of these travel modes. CVRIA divides safety applications into three groups; Transit Safety, V2I Safety, and V2V Safety.

- **Mobility applications** are intended to provide a connected, data-rich travel environment. The connected vehicle network will capture real-time data based on information transmitted anonymously from other vehicles. This information could help transportation managers monitor and manage transportation system performance – by adjusting traffic signals, transit operations, or dispatching maintenance crews or emergency services. The information for these applications could also help transportation agencies and fleet operators to manage crews and use resources as efficiently as possible. CVRIA divides mobility applications into eleven groups; Border, Commercial Vehicle Fleet Operations, Commercial Vehicle Roadside Operations, Electronic Payment, Freight Advanced Traveler Information Systems, Planning and Performance Monitoring, Public Safety, Traffic Network, Traffic Signals, Transit, Traveler Information.

- **Environmental applications** will provide travelers with real-time information about traffic congestion and other travel conditions that will help travelers make more informed decisions that can reduce the environmental impact of their trip. Informed travelers may decide to avoid congestion by taking alternate routes or public transit, or by rescheduling their trip, resulting in a more fuel-efficient and eco-friendly trip. Environmental applications will use connected vehicle data to assist the DOT in reducing emissions from its own fleet, as well as managing traffic to encourage fuel-efficiency. Another example of an environmental application is the Vehicles to Infrastructure (V2I) interactions, which could allow motorists to drive through traffic signal networks at optimum speeds, which would reduce stopping. CVRIA divides environmental applications into two groups; AERIS/Sustainable Travel, and Road Weather.

- **Connected vehicle systems (CVS)** enhance applications by providing the functionality needed to enable trust relationships and data exchanges between and among mobile and fixed transportation users. Connected vehicle systems do not directly interact with the users, but instead help application areas that improve their overall outcome. Systems are integral by being an intermediary between the data and the output of an application. Connected vehicle systems facilitate data transactions from multiple sources to applications including data requests and exchanges. In addition they can also interact with other systems to support and provide secure communications.

The Automated Vehicle Program

The USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) has established an automation research program within the overall ITS program. Automation is also a key component of the ITS JPO's ITS Strategic Plan 2015-2019. The program's goal is to enable safe, efficient, and equitable integration of automation into the transportation system. To achieve this goal, the USDOT will conduct research; assess impacts; communicate results; convene and coordinate with stakeholders; provide guidance, education, and assistance; develop or encourage appropriate standards and policies; and continue to provide oversight and enforcement. Automated vehicles have at least some aspects of a safety-critical control function (e.g., steering, throttle, or braking) that occur without direct driver input. These vehicles may use on-board sensors, cameras, GPS, and telecommunications to obtain information in order to make their own judgments regarding safety-critical situations and act appropriately by effectuating control at some level.[4] Levels of automation range from level 0 (no automation) to level 4 (full automation).

Table 1. Definitions – Levels of Automation.

Level 0 – No Automation	The driver is in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls. Vehicles that have certain driver support/convenience systems but do not have control authority over steering, braking, or throttle would still be considered level 0 vehicles. Examples include systems that provide only warnings (e.g., forward collision warning, lane departure warning, blind spot monitoring) as well as systems providing automated secondary controls such as wipers, headlights, turn signals, hazard lights, etc. Although a vehicle with V2V warning technology alone would be at this level, that technology could significantly augment, and could be necessary to fully implement, many of the technologies described below, and is capable of providing warnings in several scenarios where sensors and cameras cannot (e.g., vehicles approaching each other at intersections).

[4] U.S Department of Transportation, National Highway Traffic Safety Administration, "Preliminary Statement of Policy Concerning Automated Vehicles," May 2013

Level 1 – Function-Specific Automation	Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently from each other. The driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (as in adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (as in electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies). The vehicle may have multiple capabilities combining individual driver support and crash avoidance technologies, but does not replace driver vigilance and does not assume driving responsibility from the driver. The vehicle's automated system may assist or augment the driver in operating one of the primary controls – either steering or braking/throttle controls (but not both). As a result, there is no combination of vehicle control systems working in unison that enables the driver to be disengaged from physically operating the vehicle by having his or her hands off the steering wheel and feet off the pedals at the same time. Examples of function-specific automation systems include: cruise control, automatic braking, and lane keeping.
Level 2 - Combined Function Automation	This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. Vehicles at this level of automation can utilize shared authority when the driver cedes active primary control in certain limited driving situations. The driver is still responsible for monitoring the roadway and safe operation and is expected to be available for control at all times and on short notice. The system can relinquish control with no advance warning and the driver must be ready to control the vehicle safely. An example of combined functions enabling a level 2 system is adaptive cruise control in combination with lane centering. The major distinction between level 1 and level 2 is that, at level 2 in the specific operating conditions for which the system is designed, an automated operating mode is enabled such that the driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel and foot off pedal at the same time.

Level 3 - Limited Self-Driving Automation	Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The vehicle is designed to ensure safe operation during the automated driving mode. An example would be an automated or self-driving car that can determine when the system is no longer able to support automation, such as from an oncoming construction area, and then signals to the driver to reengage in the driving task, providing the driver with an appropriate amount of transition time to safely regain manual control. The major distinction between level 2 and level 3 is that at level 3, the vehicle is designed so that the driver is not expected to constantly monitor the roadway while driving.
Level 4 - Full Self-Driving Automation (Level 4)	The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. By design, safe operation rests solely on the automated vehicle system.

At this time, NHTSA is leading the automated vehicle safety research for the public sector. They have identified three key areas of research for the higher levels of automated vehicle systems.

- **Human Factor Research** focuses on developing requirements for the driver-vehicle interface (DVI) such that drivers can safely transition between automated and non-automated vehicle operation and that any additional information relevant to the safe operation of the vehicle is effectively communicated to the driver.
- **Electronic Control Systems Safety** has the potential need to be regulated to ensure reliability and security. NHTSA will focus on developing functional safety requirements as well as potential reliability requirements in the areas of diagnostics, prognostics, and failure response (fail safe) mechanisms.
- **Develop System Performance Requirements** to ensure a minimum safe level of performance. Research will be performed to support the development of any potential technical requirements for automated vehicle systems. An analysis of the levels described above to develop functional descriptions for automation systems. Based on

these functional descriptions, research to develop requirements will focus on identifying applicable scenarios for the automated system levels 2-4. Based on a detailed analysis of the use cases, appropriate safety performance requirements would be developed to ensure a minimum safe level of performance.

The USDOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) has developed the ITS 2015-2019 Strategic Plan. The Strategic plan was designed to help create interoperability among different areas of ITS research and development, such as automated vehicles. The automation program will focus on automated road-vehicle systems research and related technologies that transfer some amount of vehicle control from the driver to the vehicle.

USDOT Road Weather Management Program (RWMP)

The USDOT Road Weather Management Program (RWMP) performs road weather research and development on data, applications, and weather-responsive traffic management strategies with the intention of enhancing public agencies' implementation of strategies to improve transportation system performance through the mitigation of weather impacts on roadways. Research results are then pushed out to the implementing agencies in the form of software (e.g., prototype applications), guidance documents and other outreach products. The RWMP has sponsored a number of key activities that relate to the Connected Vehicle program. These activities are described in the following sections.

Pikalert® Vehicle Data Translator

The RWMP has partnered with the University Corporation for Atmospheric Research (UCAR) to develop the Vehicle Data Translator (VDT). The VDT ingests and processes mobile data available from connected vehicle devices and combines it with ancillary weather data sources. The complied data is then quality checked. The VDT creates near real-time and forecasted weather and road conditions information for a specific segment, which can be used by connected vehicle applications. The VDT has been updated from version 3.0 to the Pikalert Vehicle Data Translator (VDT Pikalert), which has recently received improvements to the science of its algorithms resulting in version 4.1.

Clarus, MADIS, and the Weather Data Environment

The *Clarus* System was a nationwide system that integrated, quality checked and disseminated the nation's road weather observations. It was originally built to conduct a variety of quality checks on data and makes the data available to public and private-sector users and researchers. The *Clarus* System was the precursor to the Weather Data Environment

(WxDE), and integrated with the Meteorological Assimilation Data Ingest System (MADIS), which will be described later in the section.

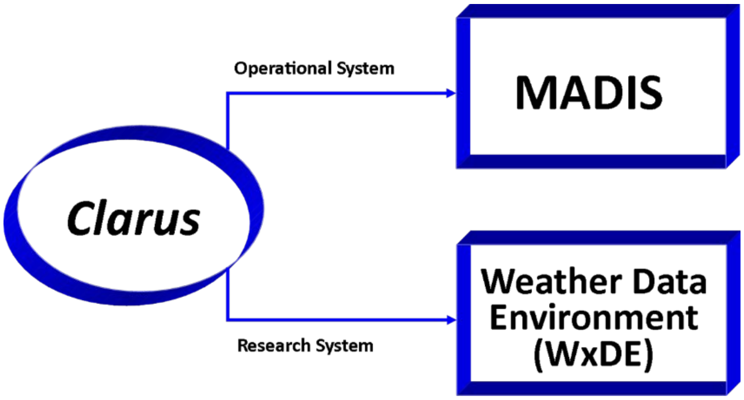

Figure 1. *Clarus*, MADIS, and WxDE.

The WxDE builds on the *Clarus* System's ability to assimilate and provide access to road weather data from networks of fixed stations across the nation, and to perform road weather data quality checks. The WxDE provides data on an interoperable platform to meet weather-related research needs focused towards Intelligent Transportation Systems (ITS). The WxDE incorporates the Vehicle Data Translator 4.1 (VDT) so that input files containing weather data for mobile and Road Weather Information System (RWIS) sources, road segment definitions, and contextual data (e.g., radar, RTMA, METAR) can be included in the system. With the VDT 4.1, the WxDE can compute value-added forms of collected data and preform quality checks on mobile data, thereby increasing the amount of weather-related data available. Furthermore, the WxDE has the ability to be integrated with the Research Data Exchange (RDE), which allows weather-related data to be readily accessible for the research and development of connected vehicle applications.

MDSS, EMDSS, and MAW

USDOT has sponsored the development of decision support tools for use by the transportation community. These tools are specifically directed toward the needs of both transportation agency managers and road users. The goals of the RWMP in this area acknowledge that decisions affecting the operation and maintenance of the transportation system require decision support tools that directly address the impacts of weather on the roadway system by placing weather and road condition information in a transportation system context.

The Maintenance Decision Support System (MDSS) aids state and local transportation agencies with snow and ice control. MDSS uses weather forecasts, current weather observations, and customized rules of practice to produce road-specific forecasts and recommendations for treatments. Recommendations include a treatment plan (such as plow only, chemical use, or pre-wetting); recommended chemical application amount; timing of initial and subsequent treatments; and indication of the need to pre-treat or post-treat the roads.

Shifting out of the concept phase is the Enhanced Maintenance and Decision Support System (EMDSS). The EMDSS builds upon the MDSS, improving road weather treatment strategies. The EMDSS application enables more effective snow and ice control through a heightened ability to assess the nature and magnitude of storms. This then helps agencies determine staffing needs, plan road treatment strategies, and decide on pre-treatment and post-treatment actions. The EMDSS uses connected vehicle data from snowplows, agency fleet vehicles, and general public vehicles (when available) to create improved plans and recommendations for maintenance personnel. As the use of connected vehicle technologies increases, more vehicles will transmit road weather data to the VDT 4.1, making the system even more useful.

Another application that has moved out the concept phase is the Motorist Advisory and Warning System (MAW). The MAW application provides current readings for visibility, road conditions, and road precipitation. MAW uses connected vehicle data from both public vehicles (snowplows, maintenance trucks, and other agency pool or fleet vehicles) and private vehicles (private cars and trucks). The data is used to develop inclement weather or road conditions warnings or advisories for the traveling public. These warnings increase awareness of impending weather and pavement conditions allowing drivers to take appropriate actions.

Integrated Mobile Observations

MAW and EMDSS were selected for development, testing and evaluation under the Integrated Mobile Observations (IMO) project. The IMO project examines how road weather data can be collected from vehicles and then used to enhance decision-making for traffic operators, maintenance managers, and travelers. The National Center for Atmospheric Research (NCAR) has partnered with Minnesota Department of Transportation (MnDOT), Michigan Department of Transportation (MDOT), and Nevada Department of Transportation (NDOT) to obtain data from fleet vehicles. The three State DOTs have improved their vehicle data by adding external weather sensors, and creating software and hardware to read vehicle information and other external sensors. The new hardware and software also establish communication systems to send the data to servers, and incorporate the data into new and existing systems. Below is additional information on the IMO projects by state.

Minnesota Department of Transportation (MnDOT) has instrumented and deployed 478 heavy duty trucks, 20 light duty trucks, and 5 mowers. MnDOT is collecting the data from the vehicle, external sensors using customized software, and equipment then transmitting the data to servers via cellular communications, which is then streamed to other systems for use.

Michigan Department of Transportation (MDOT) has instrumented and deployed 20 snowplows and 50 light duty vehicles with connected vehicle technologies. They also have created a smartphone application to capture the vehicle and external sensor data via Bluetooth which will then transmit the data via cellular communications.

Nevada Department of Transportation (NDOT) has instrumented and deployed a mix of 40 heavy and light duty vehicles. They additionally created hardware and software that collects and transmits vehicle data using their statewide radio system and cellular communications.

The RWMP will continue to explore the use of data intrinsic to vehicles and from external weather sensors for safety and mobility. These efforts will include additional research for traveler information, road weather forecasts, decision support, and performance management. Also, the RWMP will continue to explore ways to address the weather-related aspects of other ITS program areas.

State DOTs and Local Agencies

State DOTs manage traffic operations and maintenance with the objective of mitigating weather impacts on the roadways. They also are responsible for disseminating travel information and road conditions to motorists, and working with emergency managers when severe weather events significantly affect the transportation system. Traffic and maintenance managers use a variety of environmental monitoring systems and other data sources to gather information on weather and related road conditions to make decisions on how to best mitigate weather impacts. These managers typically use four types of road weather information: atmospheric data (e.g., precipitation type and rate, wind speed and direction), roadway surface data (e.g., surface status and temperature), roadway subsurface data (e.g., subsurface temperature and moisture content), and hydrologic data (e.g., stream levels near roads). This data is generally obtained from various observing system technologies, including fixed sensor stations, transportable sensor stations, mobile sensing devices, and remote sensors.

An environmental sensor station (ESS) is the field component of an overall RWIS. An ESS is comprised of one or more sensors measuring atmospheric, surface, subsurface, and water level conditions, while centralized RWIS hardware and software are used to collect and process observation data from numerous ESSs. Traffic and maintenance managers then use environmental observation data from the field to develop route-specific forecasts and provide decision support for various operational actions. State transportation agencies own more than 2,400 ESSs. Most of these stations—more than 2,000—are part of an RWIS used to support winter road maintenance activities. The other stations are deployed for various applications, including traffic management, flood monitoring, and aviation.

Atmospheric data from ESSs include air temperature and humidity, visibility distance, wind speed and direction, precipitation type and rate, and air quality. Roadway surface data includes pavement temperature, pavement freeze point, pavement condition (e.g., wet, icy, flooded), pavement chemical concentration, and subsurface conditions (e.g., soil temperature). Water level data include tide levels (e.g., hurricane storm surge); stream, river, and lake levels near roads; and the conditions in areas known to flood during heavy rains or as a result of runoff. The remote processing units associated with RWIS-ESS can be programmed to alert DOT personnel when pre-defined thresholds of any of these parameters are met. This is a useful feature of RWIS for extreme weather applications. For example, an alert can be communicated from the RWIS to maintenance crews when the snow rate reaches a preset intensity threshold.

Mobile sensing involves the integration of sensors and other systems onto vehicle platforms. In combination with vehicle location and data communication technology, mobile sensor systems can be used to sense both pavement conditions (e.g., temperature, friction) and atmospheric conditions (e.g., air temperature). Although less widespread than fixed sensors, several state transportation agencies have deployed maintenance vehicles equipped with mobile environmental sensors. These environmental sensors complement other data collected on vehicles for maintenance purposes, such as snowplow status and material usage. In addition to these efforts by state agencies, a Connected Vehicle Program that could be widely deployed on light and heavy vehicles has the potential to dramatically increase the number of mobile sensor systems across the United States.

State DOTs have been working with the RWMP to enhance their weather-responsive traffic management (WRTM) strategies. The WRTM framework incorporates:

- Traffic and weather data collection and integration.
- Safety, mobility, and performance evaluation.
- Traffic analysis, modeling, and prediction.
- Behavioral and human factors analysis.

Below are descriptions of the leading weather-responsive traffic management (WRTM) strategies that states are implementing. State WRTM strategies are incorporating these factors to best to mitigate weather conditions for traffic management.

Utah DOT: Citizen Reporting and Weather-Responsive Traffic Signal Timing

The FHWA RWMP has partnered with Utah Department of Transportation (UDOT) to develop the Citizen Reporting Program for road weather information. The primary objective of the program is to provide both Traffic Operations Centers (TOC) and travelers with more accurate and timely road weather and travel impact condition information and forecasts. The program uses a smartphone application that allow citizens to report to DOTs on the roadway conditions. Citizen reporters help fill in gaps for existing road condition reports. The citizen reports are not expected to replace existing infrastructure sources or information from the maintenance field personnel, but instead provide an important complementary dataset to DOT forecasts, operations, and maintenance staff.

UDOT has also implemented and evaluated an advanced traffic signal timing strategy. The advanced traffic signal timing strategy's objective is to make traffic signal systems more responsive to changes in traffic demands and travel speeds during severe weather conditions. UDOT has integrated a RWIS station directly into a corridor to provide meteorologists and TMC operators with information on road temperature; road surface condition; precipitation type and rate; snow accumulation on the road; wind speed; and air temperature. The RWIS station gives meteorologists an additional data point to customize forecasts for a specific corridor, and allows signal engineers to view current weather and road weather conditions before implementing signal plans. UDOT has also installed an advanced traffic sensors that monitor individual vehicles as they approach the intersection. The sensors are able to provide increased dilemma zone protection and increased intersection efficiency. Additionally, a signal Performance Metrics System has been developed that uses a high-resolution detector and controller timing data to automatically generate performance metrics. Operators at the Traffic Signal Operations Desks can use the metrics to assess in real-time and post-event the effectiveness of different traffic signal timing plans, as well as identify necessary changes or future events.

South Dakota DOT: Weather-Responsive Regional Traveler Information System

The Weather-Responsive Regional Traveler Information (WRTMI) System was created by the South Dakota DOT (SDDOT) to help disseminate more accurate travel information in a more effective manner. The WRTMI uses the 511 phone system, websites, and mobile applications to relay information to motorists. Motorists receive comprehensive information that covers current road conditions, weather condition forecasts, camera images of the roads, road closure and adverse weather alerts, weather overlays, commercial vehicle restrictions, traffic incidents, and congestion.

Michigan DOT: Weather-Response Traffic Information System

The FHWA RWMP has partnered with MDOT to create the Weather Response Traffic Information System (WxTINFO). The purpose of the WxTINFO project is to bring together near-time environmental and weather-related data collected from fixed data sources (RWIS stations, NWS station, radar, warnings) and mobile data sources (IMO project fleet and Safety Pilot Deployment Project Fleet). This information will be made available to motorists through MDOT's ATMS, roadside dynamic message signs (DMS), and the MI Drive website.

Wyoming DOT: Mobile Data for Weather-Responsive Traffic Information and Management

WYDOT uses The Road Condition Reporting mobile application to help Traffic Maintenance Centers (TMC) more efficiently receive and log road weather reports from maintenance and citizen reports, update road side systems (DMS, VSLs, and HAR) and travel information systems (Web, Phone, Text/Email). The project improves situational awareness for maintenance and highway patrol employees by allowing them to easily access and report information when in the field. This then allows the reports from the field to be created faster, resulting in quicker updates to information sharing systems.

Oregon DOT: Weather-Responsive Active Traffic Management

The goal of the Weather-Responsive Active Traffic Management (WRATM) is to notify drivers of adverse weather conditions by providing advised speeds for different weather events and by providing applicable messages on VMS during adverse weather events. WRATM is in the process of adding the following methodologies:

- Traveler information system: During peak travel time, travel time sensors can be integrated by combining data from vehicle induction loops, radar, and Bluetooth sensors to adjust road notifications.
- Queue warning system.
- Variable advisory speeds: measures downstream speeds and automatically adjusts the advisory speeds to slow traffic down prior to encountering the slow traffic.
- Curve warning systems activate based on grip factor and by using sensors that detect temperature, moisture, and visibility.
- Updated adaptive ramp metering.
- Targeted shoulder widening.

Additionally, WRATM uses a performance evaluation plan that measures the impacts on mean speeds, speed distribution, incident rates, and reliability. The evaluation plan also measures driver compliance and compares weather based speeds to congestion based recommended speeds. The data collected from the plan is then recorded to track patterns and analyze best practices.

The Weather Enterprise

The weather enterprise is comprised of public-sector weather services, private-sector weather services, and academia to perform weather related research and development to advance weather forecasting ability and the dissemination of weather information and associated watches, warnings and advisories. The National Weather Service (NWS), the National Hurricane/Tropical Prediction Center, the National Centers for Environmental Prediction, and private meteorological service providers are sources from which maintenance managers can obtain predictions of environmental conditions. Environmental data may also be obtained from mesoscale environmental monitoring networks, or mesonets, which integrate and disseminate data from many observing systems (including agricultural, flood monitoring, and aviation networks).

In addition, NWS has sponsored the private sector's development of the Mobile Platform Environmental Data (MoPED) system, a mobile sensing system deployed on buses and commercial trucks. Current MoPED data elements comprise road and air temperature, rain intensity, light level, relative humidity, and atmospheric pressure, plus derived values of dew point and sea level pressure.

Remote sensors are located at a significant distance from their target. Examples are satellites and radar systems that can be used for surveillance of meteorological conditions. Images and observations from remote sensors are used for weather monitoring and forecasting from local to global scales. Remote sensing is used to quantitatively measure atmospheric temperature and wind patterns; monitor advancing fronts and storms; and image water in all three of its states (i.e., vapor in the air, clouds, and snow cover).

MADIS is a data-management system that collects data from surface surveillance systems, hydrologic monitoring networks, balloon-borne instruments, Doppler radar, aircraft sensors, and other sources. MADIS leverages partnerships with international agencies; federal, state, and local agencies (including state DOTs); universities; volunteer networks; and the private sector (such as airlines and railroads) to integrate observations from their stations with observations from the National Oceanic and Atmospheric Administration (NOAA) to provide a finer-density, higher-frequency observational database for use by the meteorological community.

Like the *Clarus* System, MADIS has been reformatted and the FHWA, NWS, and NOAA Office of Oceanic and Atmospheric Research (OAR) are working towards enhancing MADIS to include some of the road weather quality checks that were developed in the *Clarus* System. MADIS will transition from Initial Operating Capability (IOC) to Final Operating Capability (FOC) in the first half of 2016. At FOC, MADIS operational and integration test systems will be hosted at the NWS's National Centers for Environmental Prediction (NCEP) Central Operations (NCO) with data archive capabilities provided by the National Environmental Satellite, Data, and Information Services (NESDIS) National Climatic Data Center (NCDC). The objective of the *Clarus* Transition effort is to functionally incorporate *Clarus* quality checking algorithms into the MADIS system so that *Clarus* users do not lose the *Clarus* capabilities that help road weather decision support.

OTHER INVOLVED PERSONNEL

Use of Road Weather Information in Maintenance Operations

Road Weather Information can be used to support and enhance a plethora of maintenance operations (e.g. treatment strategies, closures, etc.) before, during and after adverse weather conditions. Treatment strategies like plowing snow, spreading abrasives to improve vehicle traction, and dispensing anti-icing/deicing chemicals to lower the freezing point of precipitation on the pavement are used to mitigate snow and ice conditions. In regions with heavy snowfall, snow fences may be built adjacent to roads to reduce blowing and drifting snow. Another mitigation strategy involves the use of slope sensors and avalanche forecasts to minimize landslide and avalanche risks. When a slope becomes unstable because of snow accumulation or soil saturation, roads in the slide path may be closed to allow the controlled release of an avalanche or landslide. After snow, mud and debris are cleared and damaged infrastructure repaired the affected route can be reopened to traffic. In mountainous areas during the winter, super-cooled fog can persist in valleys for extended periods. To improve roadway visibility and reduce crash risk, a fog-dispersal strategy is implemented. Small amounts of liquid carbon dioxide are sprayed behind maintenance vehicles to encourage precipitation of water droplets in the fog. This strategy includes the application of anti-icing chemicals as fog is dispersed to prevent the precipitation from freezing on road surfaces.

Many non-winter maintenance activities are also affected by weather conditions. Mowing is conducted on a cycle throughout the summer months but will be suspended during heavy rain and thunderstorms. The spraying of herbicides is not conducted during rainstorms or high winds. Striping requires a dry roadway, no high winds, a minimum ambient air temperature, and no immediate likelihood of rain. Surface repairs (such as pothole and seam repairs) using hot mix asphalt need dry pavement with a minimum ambient air temperature and no risk of rain in the short term. Many maintenance activities will also be suspended for lightning storms, tornado forecasts, and periods of low visibility to protect the safety of both maintenance personnel and travelers who may unexpectedly encounter maintenance equipment on or near the roadway.

Use of Road Weather Information in Traffic Operations

Access to more accurate road weather information has helped traffic operation strategies become more advanced when mitigating the impacts of adverse weather on operations. Weather-Responsive Traffic Management (WRTM) strategies, previously mentioned in this chapter, are being used by state and local transportation agencies, making them more proactive in the way they manage traffic operations during weather events. WRTM strategies involve traffic advisory, control, and traffic mitigation strategy in direct response to or in anticipation of developing roadway and visibility issues that result from forecasted or deteriorating weather conditions.

Traffic operations personnel use road weather information when making operational decisions. They analyze road weather information to appropriately change speed limits on specific roadways or to adjust signal timing plans under certain conditions. Work zone personnel are responsible for the correct placement of speed limit sign trailers and processing systems where speed limit information is displayed in active work zones. The information from roadside units, Citizen Reporting, weather services, and other sources has helped the following WTRM strategies:

- Motorist advisories, alerts, and warnings intended to increase the awareness of the traveler to current and impending weather and pavement conditions. Approaches include active warning systems that warn drivers of unsafe travel conditions through a particular section of roadway, often in remote or isolated locations; pre-trip road condition information and forecast systems; and en-route weather alerts and pavement condition information.
- Speed-management strategies designed to manage drivers' speed during inclement weather events. This includes both advisory strategies, which usually involves posting an advisory travel speed deemed safe by the operating agency for the current travel conditions, and regulatory speed management techniques, which include speed limits that change based on road, traffic, or weather conditions.
- Vehicle restriction strategies involve placing restrictions on the types or characteristics of vehicles allowed to use facility during inclement weather events. These strategies might include size, height, weight, or profile restrictions.
- Road restriction strategies restrict the use of a facility during inclement weather to help travelers avoid sections of roadway that are dangerous or being treated. Approaches include lane-use restrictions, such as requiring trucks to use a specific lane during inclement weather conditions; parking restrictions, including special parking rules that

are implemented during significant snow events that restrict when and where on-street parking is permitted; access control and facility closures; and reversible lane operations, particularly during evacuations.

- Traffic signal control strategies involve making modifications or influencing the way traffic signals operate during inclement weather. Approaches in this category include changes to vehicle detector configuration, vehicle clearance intervals, interval and phase duration settings, and implementation of special signal coordination plans designed for inclement weather.

USE OF ROAD WEATHER INFORMATION BY EMERGENCY MANAGERS AND EMERGENCY RESPONDERS

Emergency managers, who are responsible the safe movement or evacuation of people during natural or man-made disasters, rely on comprehensive weather and road condition data. Current and predicted weather and road condition information is obtained through RWIS (often through collaboration with transportation agencies or airport operators); water level monitoring systems; and Federal Government sources, such as the National Hurricane/Tropical Prediction Center, commercial weather information providers, and the media. Emergency managers use DSSs that present weather data integrated with population data, topographic data, road and bridge locations, and traffic flow data.

Emergency managers gather weather observations and forecasts to identify hazards and their associated threatened areas and select a response or mitigation strategy. In response to flooding, tornadoes, hurricanes, wild fires, or hazardous material incidents, emergency managers can evacuate vulnerable residents, close threatened roadways and bridges, operate outflow devices to lower water levels, and disseminate information to the public. Many emergency management practices require coordination with traffic managers. Emergency managers may use several control strategies to manage traffic on designated evacuation routes. These strategies include opening shoulder lanes to traffic, contraflow operations to reverse traffic flow in selected freeway lanes, and modified traffic signal timing on arterial routes.

Emergency responders (including fire fighters, ambulance personnel, and paramedics, and police and law enforcement) must routinely operate on roadways affected by adverse weather events. With no option to defer their trips, emergency responders must reach their destinations irrespective of conditions or road closures.

Emergency responders rely on routing systems or must make dispatching decisions to hand off an emergency call to another responder, often in the absence of accurate, up-to-date road weather information.

Use of Road Weather Information by Motorists and Commercial Vehicle Operators.

Motorists make more informed travel decisions by using traveler information via roadway infrastructure, telephone systems, websites, broadcast media, and interactive smart phone applications that have road weather information both pre-trip and en route. Road weather traveler information applications are being tailored to different road users allowing them to make informed travel decisions regarding travel mode, departure time, route selection, vehicle type and equipment, and driving behavior. In the event of a road closure, recreational travelers may need alternate route information, while commuters familiar with their route may not. Commercial vehicle operators will also use this information as well as information from their truck dispatchers for travel decisions. Commercial vehicle operators are especially sensitive to time delays and may need additional information about road restrictions caused by high winds, height and weight limits, or subsurface freeze/thaw conditions. These applications use detailed information for dissemination of road weather information in a standard, unambiguous form. While different types of road users have varying information needs, it is important to have consistent information when disseminated from different sources.

CHAPTER 3. JUSTIFICATION FOR AND NATURE OF CHANGES

This chapter describes the existing situation and opportunities for improvement that address the need to develop connected vehicle and automated vehicle road weather applications.

JUSTIFICATION FOR CHANGES

The impacts of weather events on the transportation system have been well analyzed[5]. Adverse weather conditions have been shown to significantly impact the safety, mobility, and productivity of transportation system users and roadway operators. The increasing incidence of severe weather events associated with global climate change and the vulnerability of the nation's transportation system to these events have the potential to dramatically increase the negative impacts on safety, mobility, and productivity.

WEATHER IMPACTS ON SAFETY

On average, more than 5,870,303 vehicle crashes occur in the United States each year[3][6]. Twenty-three percent of these crashes, or approximately 1,311,970, are identified as weather related. Weather-related crashes are defined as those crashes that occur in adverse weather (such as, rain, sleet, snow, high winds, or fog) or on slick pavement (i.e., wet, snowy/slushy, or icy). On average, 6,241 people are killed and more than 480,333 people are injured in weather-related crashes each year.

Although these numbers show a downward trend from previous years, this data is consistent with overall trends for all traffic fatalities and injuries. Table 2 presents an analysis of weather-related crash statistics.

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[5] http://ops.fhwa.dot.gov/weather/q1_roadimpact.htm. Retrieved March 31, 2012.

[6] Ten-year averages from 2002to 2012 analyzed by Noblis, based on NHTSA data.

Table 2. Weather-Related Crash Statistics.

Road Weather Conditions	***Weather-Related Crash Statistics***		
	Annual Rates (Approximately)	***Percentages***	
Wet pavement	959,760 crashes	17% of vehicle crashes	74% of weather-related crashes
	384,032 people injured	16% of crash injuries	80% of weather-related crash injuries
	4,7900 people killed	13% of crash fatalities	77% of weather-related crash fatalities
Rain	595,000 crashes	11% of vehicle crashes	46% of weather-related crashes
	245,446 people injured	10% of crash injuries	52% of weather-related crash injuries
	2,866 people killed	8% of crash fatalities	46% of weather-related crash fatalities
Snow/sleet	211,188 crashes	4% of vehicle crashes	17% of weather-related crashes
	58,011,900 people injured	3% of crash injuries	13% of weather-related crash injuries
	8768 people killed	2% of crash fatalities	13% of weather-related crash fatalities
Icy pavement	154,580 crashes	3% of vehicle crashes	12% of weather-related crashes

	45,133,700 people injured	2% of crash injuries	10% of weather-related crash injuries
	602 people killed	2% of crash fatalities	10% of weather-related crash fatalities
Snow/slushy pavement	175,233 crashes	3% of vehicle crashes	14% of weather-related crashes
	43,503 people injured	2% of crash injuries	10% of weather-related crash injuries

Road Weather Conditions	***Weather-Related Crash Statistics***		
	Annual Rates (Approximately)	***Percentages***	
Fog	549 people killed	1% of crash fatalities	8% of weather-related crash fatalities
	31,385 crashes	1% of vehicle crashes	3% of weather-related crashes
	11,812 people injured	1% of crash injuries	3% of weather-related crash injuries
	473 people killed	2% of crash fatalities	8% of weather-related crash fatalities

WEATHER IMPACTS ON MOBILITY

Significant roadway capacity reductions can be due to flooding or lane obstruction caused by snow accumulation and wind-blown debris. Road closures and access restrictions resulting from hazardous conditions (such as large trucks in high winds) can also decrease roadway capacity.

Weather events can reduce mobility and the effectiveness of traffic signal timing plans on arterials. On signalized arterial routes, speed reductions can range from 10 to 25 percent on wet pavement and from 30 to 40 percent on snow-covered or slushy pavement. Weather events on the roadway significantly impact travel reliability. Depending on the severity of the weather impact, travel time delay on arterials can increase by 11 to 50 percent, and start-up delay can increase by 5 to 50 percent.

On freeways, light rain or snow can reduce the average speed by 3 to 13 percent. Heavy rain can decrease average speed by 3 to 16 percent. In heavy snow, average freeway speeds can decline by 5 to 40 percent. Low visibility can cause speed reductions of 10 to 12 percent. Freeway capacity reductions can also be significant— 4–11 percent in light rain, 10– 30 percent in heavy rain, 12–27 percent in heavy snow, and by 12 percent in low visibility.

Overall, it has been estimated that 23 percent of nonrecurring delay on highways across the nation is because of the impacts associated with snow, ice, and fog. This amounts to an estimated 544 million vehicle-hours of delay per year.

A common scenario of weather hindering mobility occurred during the winter of 2015 in the Washington, D.C., metro area. A weather forecast made by local reporters predicted, "an accumulation of snow between the hours of 4 a.m. to 6 a.m., which will coincide with the daily commuting time."[7] The broadcasted forecast was accurate. However, many motorists appeared to not consider the weather conditions during their daily commute. This resulted in accidents and major traffic delays. While there are multiple variables to consider for accidents that occur during adverse weather conditions, inconsistent information among disparate weather information sources does not help drivers make informed decisions. There was no differentiation between weather conditions and road weather conditions. Weather and road weather are closely related, however it is important to stress that weather forecasts are not intended for giving motorists detailed information on the road weather conditions. This

[7] Samenow, J. (2015, January 7). A forecast that should've been good enough, but just wasn't.The Washington Post.

scenario exemplifies that road weather and weather forecasts need to be differentiated form one another, and standardized so that road users can make appropriate decisions regarding travel. Furthermore, this scenario shows that motorists and commercial vehicle operators have an informational gap regarding current and predictive road weather conditions. If motorists had traveler information on snow fall that gave real-time and predictive information on the road conditions, better-informed decisions could have been made.

WEATHER IMPACTS ON PRODUCTIVITY

Adverse weather can also increase the operation and maintenance costs of road maintenance agencies, traffic management agencies, emergency management agencies, law enforcement agencies, and commercial vehicle operators. Winter road maintenance activities account for roughly 20 percent of state transportation agencies' maintenance budgets. Each year, state and local agencies spend more than $2.3 billion on snow and ice control operations.

The availability of accurate, up-to-date road weather observations that are tailored to the needs of roadway operators and decision support tools that place the observation data in a transportation system operations and management context can play a significant role in helping better prepare roadway operators and users of the transportation system for adverse weather conditions. In turn, this approach has the potential to improve safety, mobility, and productivity. The FHWA RWMP has already undertaken significant work to acquire, quality check, and make available road weather observations from fixed, mobile, and remote sensing systems.

Description of Opportunities and Desired Changes

It is difficult to imagine any transportation system activity that is unaffected by high-impact weather events and the resulting deterioration of road conditions. Therefore, road weather connected vehicle applications are uniquely cross-cutting, affecting the research efforts in many other connected vehicle program areas. Furthermore, this ConOps highlights road weather enabling systems that have the capacity to be used in a majority, if not all, of connected vehicle applications that are being developed.

The RWMP understands the effect weather has on all aspects of connected vehicle applications and has abridged access of road weather information through the development of the WxDE. The WxDE is a new data source that allows road weather information to be integrated when developing connected vehicle applications. The WxDE is able to provide connected vehicle road weather data on an interoperable platform, with the Research Data Exchange (RDE) permitting road weather connected vehicle data to integrate with other connected vehicle applications. The VDT, Citizen Reporting, and the other enabling systems discussed in this ConOps are key components that enhance road weather connected vehicle applications, and can be incorporated outside the road weather applications. Applications such as intersection collision avoidance, signalized intersection control, speed warnings, and traveler information dissemination can all be significantly enhanced when they take current and predictive road weather information into account. The availability of connected vehicle road weather information will benefit transportation professionals, including freight shippers, public safety agencies, and EMS. Information on current and predictive weather and pavement conditions on specific roadway links will open transformative applications for these constituents in areas of routing, scheduling, and response capabilities. Additionally, availability of connected vehicle road weather information will create new opportunities to provide applications to other stakeholders, including those outside the traditional surface transportation community.

Automated vehicles are those in which at least some aspect of a safety-critical control function (e.g., steering, throttle, or braking) occurs without direct driver input. Connected vehicles are those which use wireless technology to communicate between vehicles, roadside infrastructure, and other road users. While some automation technologies could be implemented without connectivity, higher levels of automation will likely need connected vehicle technology to achieve their full potential. Automation technologies offer tremendous possibilities for enhancing safety, mobility, and the environment; but also present new technical and policy challenges. The ITS program's focus in this area will be the advancement of technology and systems to enable smooth and safe introduction of automated features into the nation's vehicles and transportation systems. Weather information will play an important role in enhancing safety and mobility in automated vehicles. There is limited research on how weather/road weather affects automated vehicle technologies and there is a growing need to understand this relationship. Integrating road weather information/data into automated vehicle technologies will help vehicles take preventative action in adverse weather conditions thereby enhancing safety for not only the passengers of the automated vehicle, but other road users as well.

By making advancing automation a priority, the ITS Program will be able to delve into this innovative and cutting-edge field to research, develop, and adopt automation-related technologies as they emerge. Close collaboration with current industry and academic leaders in this field will be a cornerstone to this work. In many ways, automation technology builds on or leverages the technology and applications in the CV system, providing a close tie to the research activities associated with realizing CV Implementation.[8]

This section of the ConOps will describe how road weather information is used in new and modified connected vehicle systems, road weather connected vehicle applications, and road weather automated vehicle applications.

Enabling Systems for Road Weather Applications

The emergence of road weather information sources from connected vehicles opens opportunities to dramatically enhance existing systems, as well as create new ones. Connected vehicle systems have the ability to be integrated with one another, allowing applications to benefit from more than one system. However, significant amounts of data processing must occur to convert the prospective flow of large quantities of connected vehicle data into useful information. There are five systems described in this section that address some of the data processing needs between data collection and information dissemination. These systems are already or will be used by road weather connected vehicle applications. The connected vehicle basic safety message (BSM) and the updated vehicle data translator 4.1 (VDT) within the RWMP will improve the performance of road weather-related applications. Additionally, three new road weather connected vehicle systems have been developed and will improve road weather connected vehicle application performance.

The Connected Vehicle Basic Safety Message

Connected vehicle V2V safety applications heavily rely on the BSM, which is one of the messages defined in the Society of Automotive Engineers (SAE) Standard J2735, *Dedicated Short Range Communications (DSRC) Message Set Dictionary* (November 2009). The development of the BSM is ongoing and evolving. At the time of writing, the BSM consists of two parts, with the following characteristics:

[8] USDOT RITA ITS JPO, “ITS 2015-2019 Strategic Plan,”FHWA-JPO-14-145, December 2014.

BSM Part 1 contains core data elements, including vehicle position, heading, speed, acceleration, steering wheel angle, and vehicle size. It is transmitted at a rate of about 10 times per second.

BSM Part 2 contains a variable set of data elements drawn from an extensive list of optional elements. They are selected based on event triggers (such as when the antilock braking system [ABS] is activated). BSM Part 2 data elements are added to Part 1 and sent as part of the BSM message but are transmitted less frequently to conserve data communications bandwidth. It is important to note that even if a data element is defined in BSM Part 2 of the SAE J2735 standard, it does not necessarily mean that vehicle manufacturers will provide it. Most of the Part 2 data elements are defined as optional information in the standard. Some of the Part 2 data elements are currently available on the internal data bus of some vehicles; others are not.

For road weather connected vehicle applications to fully benefit from the BSM, the following core data sets must be provided by the BSM. The BSM part 1 needs to consider vehicle data from the following elements:

- Position (longitude, latitude, elevation).
- Motion (speed, Heading, angle of steering wheel).
- Control (brakes, traction control, antilock, stability control).
- Basic (vehicle size).

The BSM part 2 needs to consider vehicle data from the following elements:

- Wiper status and wiper rate.
- Air temperature.
- Rain data.
- Road friction.

Appendix B contains a table listing data elements found in BSM Part 1 or Part 2. The table also contains the results of an analysis[4] that identifies whether the element may be useful in determining road weather conditions. This shows that most desired Part 2 elements are weather related. It should be noted that USDOT has requested that certain weather data be incorporated into the SAE J2735 SE message set. The requested data elements, their ranges, and the resolution of the request are presented in Appendix C.

The Vehicle Data Translator

The VDT is a system that ingests and processes mobile data available from connected vehicle devices and combines them with ancillary weather data sources. Development and validation of VDT Version 4.1 is underway at the time of writing. A long-term view of the connected vehicle program includes the collection of data by millions of passenger and commercial vehicles. However, for this data to be useful to the broad community of stakeholders, it must be acquired, and then processed into meaningful, actionable information. The VDT inputs two types of data:

- Mobile data is all data originating from a vehicle, whether native to the Controller Access Network Bus (CANbus) or as an add-on sensor (e.g., pavement temperature sensor mounted to a vehicle).
- Ancillary data represents all other data, such as surface weather stations, model output, satellite data, and radar data.

The VDT 4.1 currently incorporates vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) from original equipment manufacturers' sensors and aftermarket sensors. The data received is then assigned to a road segment based on the latitude and longitude creating one mile road segments. The VDT 4.1 ingests data from weather sources like satellites and radar, which is used to perform quality tests on all mobile observations received. The list below is the quality test the VDT 4.1 performs.

- Data Filtering Test: allows the user to configure parameters to filter out suspicious data.
- Sensor Range Test: detects readings that fall outside the range of sensor hardware specifications or theoretical limits.
- Spatial Tests—Barnes and IQR: compares observation to other observations in the area based on configurable parameters.
- Model Analysis Test: compares the temperature and pressure observations from vehicles to those of a numerical weather model analysis field for the closest grid point.

- Neighboring Vehicle Test: compares the given vehicle observation to neighboring vehicles in the road segment.
- Climate Range Test: detects sensor readings that fall outside predetermined climate range values.
- Persistence Test: detects whether sensor readings remain constant for a predefined variable-specific period of time.
- Step Test: detects unreasonably large changes in sensor values over a user-defined time period.
- Combined Algorithm Test: assigns a confidence value to the observation based on the results of all quality checking tests.

The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments. The hazard datasets can then be used as a vital input into any other systems or applications.

Integrated Modeling for Road Weather Condition Prediction

The ability to access almost instant data is changing the way industries, companies, governments, and consumers use information. The RWMP is using real-time road weather information to promote safety, mobility, and productivity in their applications. Real-time data has been incorporated to processing systems, giving connected vehicle road weather applications the ability to use up-to-date information for more effective strategies. While real-time road weather information can dramatically benefit all applications, more is needed. Weather conditions can rapidly change over short periods of time. Furthermore, climate change can act as a catalyst, increasing the unpredictability of weather conditions, which poses more danger for motorists. There is a need for predictive information that will predict traffic conditions based on adverse weather as well as unpredictable variables (e.g., traffic accidents, work zones). This information has the capability to be used in multiple road weather connected vehicle applications. There is a need for a road weather connected vehicle system that will not only harness real-time data to channel real-time information, but will also use past weather and traffic data trends to create predictive information. This system would enhance all applications allowing users to proactively react to weather conditions.

Weather Data Environment

The WxDE is a system that allows new observation types, collection and dissemination of multiple file types, and additional quality checking algorithms. It collects data in near real-time from both fixed environmental sensor stations (ESS) and mobile sources, and incorporates the VDT to provide additional quality checks for mobile observations and weather conditions from vehicle data (e.g., inferring precipitation based on windshield wiper activation). The quality checked observations can then be used in applications that use road weather information.

The WxDE makes data available either through a map interface, or through queries and subscriptions. Metadata is also collected, stored, and sent about items such as platforms, sensors, observations, and contributors. The WxDE is a tool that is available to incorporate with all connected vehicle applications. Archived road weather observation from the WxDE is sent to the Research Data Exchange (RDE) allowing it to perform a query to determine if weather data can be used. The WxDE helps connected vehicle applications incorporate road weather information from the beginning of development.

Meteorological Assimilation Data Ingest System

As stated earlier in this document, MADIS is a data-management system that will fully incorporate the *Clarus* system during the third quarter of the 2016 fiscal year. The *Clarus* system provides the following data to MADIS.

Atmospheric data includes, but is not limited to:

- Air temperature.
- Humidity.
- Visibility.
- Wind speed.
- Wind direction.
- Precipitation type.
- Precipitation rate.
- Cloud cover.

Pavement data includes, but is not limited to:

- Pavement temperature.
- Pavement freezing point.
- Pavement condition.
- Pavement chemical concentration.
- Subsurface soil temperatures.

Water level data includes, but is not limited to:

- Streams.
- Rivers.
- Lake levels near roads.
- Storm surges.

In addition, data from NOAA; DOTs; international agencies; federal, state, and local agencies; universities; volunteer networks; and the private sector (e.g., airlines, railroads) will be integrated and quality checked in MADIS. Integrating MADIS connected vehicle applications will increase the accuracy and density of road weather information used in applications.

Citizen Reporting

Local agencies are responsible for providing motorists with up-to-date information on roadway conditions, especially during adverse weather. Traveler information is disseminated through outlets, including websites, smartphone applications, and 511 phone line information. Since weather and road condition information is usually updated manually by field crews, it is subject to gaps and delays that can render the information outdated and inaccurate.

To improve the quality of weather-related traveler information, a type of crowdsourcing called Citizen Reporting (CR) has been developed. CR provides an interface (either smartphone application or website) through which trained citizens are able to report weather and road conditions to local agencies. The information collected by citizen reporters supplements the usual field crew reports, helping to fill information gaps that exist in road condition reports, as well as support more timely and accurate road weather forecasts. CR data that is integrated with connected vehicle applications will increase the accuracy of weather and road conditions information within those applications. Furthermore, CR applications may be catered to gather additional information that connected vehicle technologies could not pick up (e.g., pot holes or emergency roadside incidents).

Application of Connected Vehicle Road Weather Data

The emergence of new sources of road weather information from connected vehicles opens opportunities to create transformative new applications for the data. Additionally, the use of connected vehicle road weather information can bring supplemental capabilities to other connected vehicle safety, mobility, and environmental applications. Within the connected vehicle research program at USDOT, additional definition and development work is underway on a variety of safety and dynamic mobility applications. In a number of instances, these activities acknowledge that road weather information might contribute to the effectiveness of the application. It is, therefore, suggested that connected vehicle road weather information, with its potentially dense, roadway segment-specific nature and short time horizon, would especially enhance these applications and should be considered a key component of their development.

Cross-cutting these categories, the following taxonomy of application areas has been developed:

- Road weather alerts and warnings.
- Performance management.
- State and local agency-based applications.
- Freight-based applications.
- EMS/first-responder applications.

This section of the ConOps introduces and briefly describes the applications that have been identified in each of these application areas. A number of these applications were introduced in the previous version of this ConOps and, through efforts undertaken by the RWMP, have advanced from the conceptual stage into prototype or pre-deployment solutions. Of the remaining applications, those with highest priority are selected in the following section, and are then explored in greater detail in Chapter 4.

Road Weather Alerts and Warnings

Motorist Advisories and Warnings

Although motorists now have access to multiple sources of travel information through roadway infrastructure, radio broadcasts, phone systems, and applications on their personal mobile devices, a recent analysis[9] suggests that this community is underserved with road weather information. The analysis further indicates that weather information for roadways of interest is an especially high priority for these users—more important than other forms of travel information, including incident and travel time reports.

A road weather connected vehicle application would push roadway link-specific information to users' in-vehicle equipment or personal wireless devices. As a minimum, users would receive road weather alerts and warnings within a short time horizon of adverse conditions being detected by mobile data sources. These conditions may include precipitation types and rates, road surface slickness, and low visibility.

Real-time mobile source data would also be combined and processed with forecast information and data from other fixed and remote sensors to provide medium- to longer-term alerts and warnings to users. Opportunities exist with this application for commercial service providers to use these road weather alerts and warnings through various onboard or off-board processing capabilities to deliver routing and other traveler information services to subscribers.

Enable Advanced Traveler Information Systems

The Enable Advanced Traveler Information Systems (EnableATIS) represents a bundle of connected vehicle applications currently being developed within the USDOT Dynamic Mobility Applications (DMA) program. This bundle of applications seeks to provide a framework for multisource, multimodal data to enable the development of new advanced traveler information applications and strategies.

EnableATIS envisions a traveler information services framework with a pool of real-time data through connected vehicles, public and private systems, and user-generated content. Current

[9] American Meteorological Society, *Realizing the Potential of Vehicle-Based Observations*, 2011

work on EnableATIS is not defining specific applications but is instead formalizing the framework to support diverse traveler information solutions. The existing work recognizes the importance of road weather information as a component of the real-time data pool. However, the current EnableATIS work does not emphasize the importance of road weather information at the level of timeliness, accuracy, and relevance that drivers request and that will be facilitated through focused road weather connected vehicle applications.

Weather Performance Management Application

Performance measures can vary based on the type and severity of weather events as well as the priorities and constraints faced by each state DOT. This tool will consider the variables that states face and will be able to incorporate a variety of activities and performance measures as parameters for performance management. Outputs from the tool should help transportation agencies evaluate their performance and identify areas for improvement. For example, during winter operations, the Enhanced-MDSS tool can compare average traffic speeds and delays with historical data for similar weather events to help maintenance managers compare their performance. Based on real-time traffic and weather data, this tool can determine the need to improve performance or maintain current levels.

State DOTs and Local Agency-Based Applications

Enhanced Maintenance Decision Support System

MDSS is an existing decision support tool, described earlier in this report, which maintenance managers use to develop treatment and response plans to winter storms and other winter weather events. Available MDSS solutions typically acquire data from fixed and remote sensors for use in various weather and pavement temperature models. Although the federal MDSS prototype acquires data from mobile sources, it is exclusively automatic vehicle location data used to display current snowplow locations.

Mobile sensor data, both from the general vehicle fleet and from additional, specialized sensors on plows and other maintenance vehicles, can be used to expand the capabilities of MDSS. In particular, a denser, more comprehensive set of mobile observations will provide data for more accurate model runs and forecasts in complex terrain or in areas where sensor networks are particularly sparse. Data from specialized sensors on agency-controlled vehicles, such as real-time measures of salinity and freeze point on specific segments of roadway, will help MDSS optimize and communicate treatment strategies to plow operators.

Information for Maintenance and Fleet Management Systems

Maintenance and fleet management systems are typically software-based systems used to manage an agency's vehicle and material assets. These systems will monitor the status (e.g., vehicles in or out of service), locations, quantities, and usage of assets, as appropriate. The information is used for scheduling maintenance of vehicles, ordering materials, and deploying assets to the required locations. Certain non-weather-related connected vehicle data, such as maintenance diagnostics or vehicle location, could provide valuable real-time information to these systems.

In addition, integration between maintenance management systems and MDSS may provide some opportunities, especially when using real-time connected vehicle data. Vehicle status and location information can be used in MDSS to support the development of treatment plans, while outputs of treatment strategies, including the types and quantity of materials used, can be used to update information in maintenance management systems.

Weather-Responsive Traffic Management

Several weather-responsive traffic-management strategies were identified earlier in this document and are already well established. Several of these could benefit from the additional sources of mobile road weather data afforded by connected vehicles. The denser and more comprehensive network of observations will assist traffic managers in their decisions to implement restrictions.

Weather-responsive traffic-management strategies that include pre-trip and en-route advisories and warnings will be enhanced through the availability of connected vehicle road weather data. These applications focus on the needs of motorists and are described elsewhere.

Another category of weather-responsive traffic-management strategies involves signalized intersection controls. There is extensive work on this topic in other areas of the connected vehicle program that is discussed in a subsequent section of this chapter. However, this area is ripe for additional exploration of the impacts of road weather-specific connected vehicle data and is discussed in greater detail later in this document.

Lane-use restriction is also a common weather-responsive traffic-management strategy. This strategy involves requiring specific types of vehicle to use specific lanes during certain weather events (e.g., trucks use right lane). These restrictions could be posted on highway message signs and/or traveler information systems to provide travelers with end of queue warnings and lane closure information. Lane-use restrictions use information from weather and pavement conditions from road sensors; cameras; weather services; field personnel (including lane conditions for multi-lane roadways); time stamped and archived (by site locations, and before, during and after restriction periods); and road weather forecasts from weather services. Road weather connected vehicle information would enhance lane-use restrictions, more comprehensive data elements would give the application a holistic perspective of weather effects on roadways.

Ramp control signals and ramp metering is another strategy that will benefit from connected vehicle information. This strategy involves implementing special timing plans to account for lost freeway capacity, slow travel speeds, and increased start-up time at ramp control signals. Strategies could include limiting traffic flow entering the freeway or strategies to increase ramp capacities during inclement weather. With connected vehicle information, this strategy will be able to better identify traffic patterns and how they are affected by weather. This information will be incorporated into the signal timing of ramp metering.

The use of connected vehicle road weather information in certain ATDM applications is not addressed in other connected vehicle program areas and will be discussed in this section. In particular, connected vehicle road weather information would facilitate the development of weather-responsive speed advisories or VSLs. With appropriate state or local legislation, VSLs are enforceable by public safety agencies.

A VSL application would use data acquired from connected vehicle mobile sources to determine precipitation types and amounts, visibility, or road surface slickness for segments of the roadway network under VSL control. This data would be combined with other information on prevailing traffic volumes and speeds. Algorithms would be developed to determine appropriate travel speeds under the current traffic, weather, and road conditions. Speed limit information would be displayed on suitable roadway infrastructure and potentially could be provided directly to drivers of suitably equipped vehicles in the form of alerts or in-vehicle signage.

Intelligent Network Flow Optimization

The Intelligent Network Flow Optimization (INFLO) bundle of applications is under development within the DMA program area. This bundle consists of three applications: speed harmonization, queue warning, and cooperative adaptive cruise control. The objective of speed harmonization is to dynamically adjust and coordinate maximum appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions to maximize traffic throughput and reduce crashes. The objective of queue warning is to provide a vehicle operator sufficient warning of impending queue backup to brake safely, change lanes, or modify route, such that secondary collisions can be minimized. A queue backup can occur as a result of several conditions, including adverse weather. The objective of cooperative adaptive cruise control is to dynamically and automatically coordinate cruise control speeds among platooning vehicles to significantly increase traffic throughput.

INLFO has incorporated a road weather algorithm to provide recommended travel speed, road condition advisories, and alerts based on measured road weather conditions in the corridor. The INLFO algorithm will encompass road weather information from mobile and stationary ESSs, external weather information providers, and connected vehicle data. The need for road weather information from both fixed and mobile sources is acknowledged in the current concept development work for INFLO.

V2I Safety Applications

Red Light and Stop Sign Violation Warnings

Within the connected vehicle V2I safety application program, traffic signal and stop sign violation warning applications are under development and are intended to predict whether a driver approaching a signal or stop sign will be in violation, and then issue a warning to the driver. Adverse weather conditions (such as precipitation or a slick road surface) would affect when the warning should be issued. Furthermore, pavement friction and information on whether the road is asphalt or concrete could be significant for better understanding vehicle performance during adverse weather events. Connected vehicle road weather information could be integrated into the warning algorithm.

Curve Speed Warnings and Rollover Warnings

Also within the V2I safety application program, curve speed warning and rollover warning applications are being developed that will aid drivers in negotiating curves at appropriate speeds.

Weather-related curved warning systems have been implemented in select corridors. The system uses four RWIS grip factor sensors, as well as sensors that gather temperature, moisture, and visibility to help disseminate an accurate road condition warning. Road weather information from connected vehicles combined with the curved warning system would benefit the development of this application. Icy roads or high winds would influence the timing of the warning and the recommended speed. Road weather information from connected vehicles could support the development of this application.

Spot Weather Information Warning

Desired changes for the spot weather information weather (SWIW) are identified in the Vehicle-to-Infrastructure Safety Applications Concept of Operations. The ConOps recognizes that the limiting factor is the availability and coverage of ESS data. The application utilizes RWIS data to detect low visibility due to fog or smoke; surface conditions, such as wet or icy pavement; flooding; and high winds that would affect traffic, particularly commercial vehicles. The ConOps also identifies that other data might include detection of vehicle speeds to be used for suggestions of reduced advisory or enforceable speeds, and/or validation of weather impacts to current traffic conditions. Furthermore, there are potential reliability concerns with RWIS and there is a need for minimal false alarms. The availability of a back office TMC and/or traffic data for validation purposes is essential to determine when the application should transmit an advisory message, alert, or warning. Data available from equipped vehicles to be used by the application may include temperature and vehicle telematics data (e.g., speed, windshield wiper status, application of traction control). While different aspects of connected vehicle road weather information are brought up in the Vehicle-to-Infrastructure Safety Applications ConOps, it does not specify where or how connected vehicle road weather information is incorporated. A road weather connected vehicle system would collect and quality check weather and road data from mobile sources, roadside units, and other weather systems. This additional information would dramatically enhance the accuracy and performance of the SWIW application.

Freight-Based Applications

Information for Freight Shippers

Freight shippers' needs for road weather information are naturally different from other motorists. In certain instances, roadway restrictions, such as lane closures and seasonal road closures, apply uniquely to motor carriers. In other situations, certain adverse weather events, such has high winds, have a far greater impact on high-profile trucks than they do on passenger vehicles. Commercial freight shippers are also especially sensitive to travel delays, which translate directly into productivity losses and higher costs, and have a particular impact on just-in-time deliveries. Road closures also have special impacts where rerouting may not always be possible because of bridge height or highway weight restrictions or restrictions placed on special haulers such as hazardous material carriers.

The Freight Advanced Traveler Information System (FRATIS) project discusses these information needs together with the application of connected vehicle technologies. FRATIS optimizes intermodal drayage operations and acknowledges the importance of road weather information as a component of the freight industry's needs. However, the current FRATIS work does not emphasize the importance of road weather information at the level of timeliness, accuracy, and relevance that commercial vehicle operators are requesting and that will be facilitated through focused road weather connected vehicle applications. Road weather connected vehicle freight applications must therefore ensure that the identified needs in FRATIS are met, but also identify and support the deeper and broader road weather information needs of the freight community.

A road weather connected vehicle application for freight shippers must accommodate the different information needs of the driver and the dispatcher. Short-term alerts on precipitation type and rate; road surface slickness; high winds; low visibility; and the presence of thunderstorms, hail, and tornadoes are all of immediate concern to drivers, who must operate their vehicles safely under deteriorating conditions and make decisions about their hours of service. This information, together with longer-term regional forecasts and information about road closures and restrictions, is important to fleet managers and dispatchers, who will use it to make decisions about schedule and routing changes.

Opportunities in this application area exist for commercial service providers to integrate road weather data from connected vehicles with other fleet-management and decision support tools that motor carrier companies use.

EMS/First-Responder Applications

Information and Routing Support for Emergency Responders

Emergency responders, including fire and rescue organizations, paramedics, and ambulance operators, represent a unique community of stakeholders for connected vehicle road weather information. Unlike many other users of the transportation system, this group of constituents has no opportunity to cancel or defer trips. In fact, this group of users is particularly called upon to use the roadways during adverse weather situations. To further exacerbate this user group's challenges, the lowest volumes of mobile sensor observations will inevitably be generated when other drivers stay off the roadway during severe weather events.

It is important for first responders to have access to road condition information through short-term alerts and warnings in a manner similar to other users. However, situational awareness is especially important to emergency vehicle drivers who cannot avoid roadways affected by severe weather events but need to know what they are getting into so that drivers can safely operate their vehicles.

Emergency responders are also especially sensitive to information that affects routing and dispatching decisions. In particular, lane and road obstructions caused by snow or wind-blown debris, for example, is important information used to determine routes, calculate response times, and support decisions to pass a call from one emergency responder to another. Overall, this user group demands road weather information at a level of timeliness, accuracy, and relevance that traditional weather products and services cannot provide.

A particular challenge in this application will be the identification of the effects of adverse weather events that cannot be directly measured with mobile, fixed, or remote weather sensors. These effects may include downed trees and power lines that cause road closures. Non weather-related connected vehicle data that can identify vehicle stops and queue build-ups will be necessary in this situation.

Road Weather Needs in Vehicle Automation

As mentioned earlier, road weather information plays a critical role for higher levels of automation but there is limited research in this area at the time of this writing. The scenario below shows why adverse weather needs to be considered. The vehicle at level 4 automation is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. By design, safe operation rests solely on the automated vehicle system. Such a vehicle needs to consider the effects of adverse weather on its operational functionality. In a blizzard or torrential downpour, the range of certain sensors in a level 4 vehicle may be degraded, resulting in safety concerns. In such situations the vehicle may have to hand control back to the driver, slow down traveler speed, or come to a safe stop to wait for the adverse weather event to pass. This is just one of many adverse weather instances that need to be mitigated for automated vehicles. While connected and shared information will help automation react safely to adverse weather, more is needed. An application that is able to safely give control back to the driver or prohibit automation on a trip that may face adverse weather would greatly improve the protection of the user.

PRIORITIES AMONG CHANGES

The high-priority areas for further development for connected vehicle road weather applications and automated vehicle road weather applications appear to be those that are not being pursued in other parts of the connected and automated vehicle program. Additionally, the Integrated Modeling for Road Weather Condition Prediction is a system that has the potential to benefit all connected vehicle applications and will be explored in Chapter 4 and Chapter 5. The applications that will be explored in greater detail in this ConOps are—

Connected Vehicle System:

- Integrated modeling for road weather condition prediction system.
- Citizen Reporting.

Connected vehicle applications:

- Enhanced maintenance decision support system.
- Information for maintenance and fleet-management systems.
- Weather-responsive traffic-management strategies, including VSLs and signalized intersection control.
- Motorist advisories and warnings.
- Weather Performance Management Application Information for freight shippers.
- Information and routing support for emergency responders.
- Road Weather Module for Automated Vehicle Applications.
- Road Weather Components for V2I Safety Applications.

- Road Weather Components for Traffic Network Mobility Applications.

CHANGES CONSIDERED BUT NOT INCLUDED

Safety and mobility applications are being developed elsewhere in the connected vehicle program. However, the applications that were discussed earlier in this document have been identified with the ability to incorporate road weather enabling systems. Systems like integrated modeling for road weather condition prediction, citizen reporting, MADIS, and the VDT will dramatically improve these applications. An overview focusing on road weather enabling systems integration in specific mobility and safety applications will be discussed in this chapter. Road weather information will be considered in other safety and mobility applications as they further develop.

CHAPTER 4. CONCEPTS FOR THE PROPOSED APPLICATIONS

This chapter provides a discussion of each high-priority application as well as systems enhancements in terms of scope, users, goals and objectives, capabilities, various operational modes, how and where it will operate, what it will interface with, and lines of communication. As described above, the applications include:

- Enhanced Maintenance Decision Support System.
- Information for Maintenance and Fleet Management Systems Application.
- Weather-Responsive Traffic Management.
- Motorist Advisories and Warnings.
- Road Weather Performance Management Application.
- Information for Freight Carriers.
- Information and Routing Support for Emergency Responders.
- Road Weather Module for Automated Vehicle Applications.
- Road Weather Components for V2I Safety Applications.
- Road Weather Components for Traffic Network Mobility Applications.

Each proposed application includes a description, operational policies and constraints, modes of operation, user classes and other involved personnel, and support environment. All connected vehicle road weather applications have the potential to benefit from two enabling systems, the Integrated Modeling for Road Weather Condition Prediction and Citizen Reporting.

CONNECTED VEHICLE ROAD WEATHER APPLICATIONS

ENHANCED MAINTENANCE DECISION SUPPORT SYSTEM

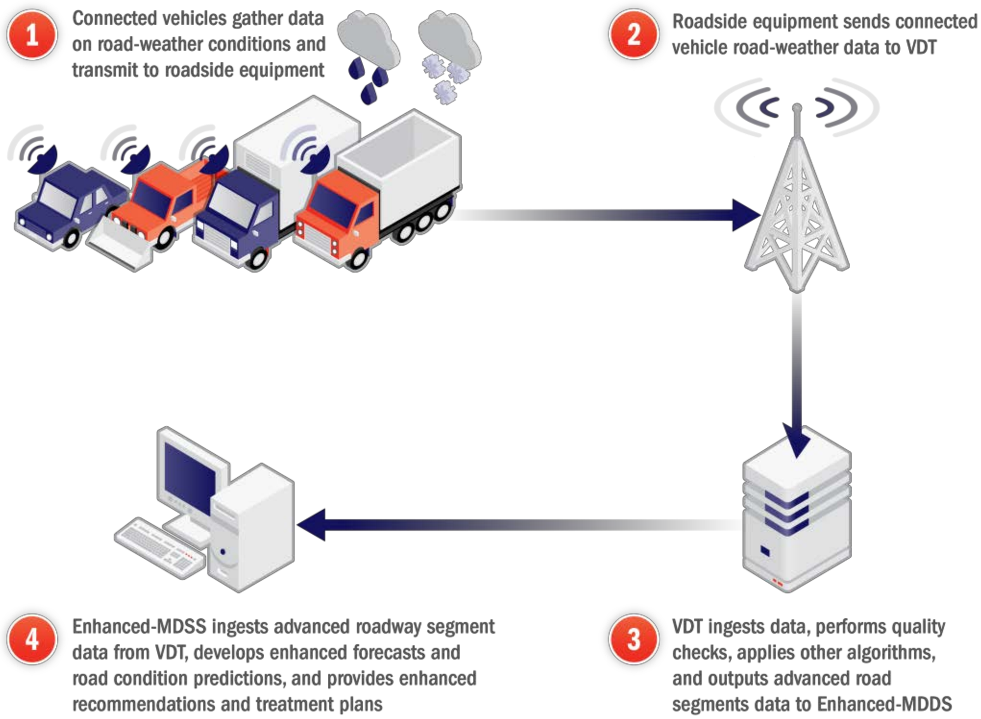
Description of the Proposed Application

State and local transportation agencies must handle multiple tasks and process large amounts of information in the development of their response and treatment plans during winter weather conditions and events. The MDSS is a decision support tool that integrates relevant roadway segment-specific road weather forecasts, coded rules of practice, and maintenance resource data to provide winter maintenance managers with recommended road treatment strategies. Use of MDSS allows maintenance personnel to make both strategic and tactical decisions that improve roadway levels of service and safety and are more efficient in the use of labor, equipment, and chemicals. In the existing system, meteorological and road observations together with output from national weather prediction models provide the input data to MDSS.

The EMDSS builds upon the MDSS to better incorporates mobile and other data into the road weather forecast system. The EMDSS uses non-mobile data, like the RWIS, and connected vehicle data from DOT fleets. Additionally the EMDSS will use the VDT 4.1 to incorporate other connected vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, and surface temperature) and ancillary data from weather stations, satellites, and radar data. The added data gives end users more accurate road weather information along the entire stretch of roadway, and not just at roadside unit sites.

Maintenance providers will increase their efficiency by better monitoring and reacting to road condition changes. Furthermore, the EMDSS helps better equip maintenance for spot treatments on the road, improving safety, mobility, and reducing the environmental impact of the de-icing chemical. Connected vehicles will continue to gather road condition information after treatment plans have been implemented which will provide a continuous measure of the level of service of a roadway and the outcome of the initial treatment.

Figure 2 provides a schematic of how the Enhanced-MDSS application could work.



Source: Booz Allen Hamilton.

Figure 2. Schematic of the Enhanced-MDSS Application.

Subsystems

This application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of several different sources. These sources include connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. Two classes of connected vehicle are anticipated for the application: (1) vehicles operated by the general public and commercial entities (including passenger cars and trucks) and (2) specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface).

Non-mobile data on roadway segments will be provided by MADIS, which ingests data from RWIS, other surface weather stations, radar, satellite, model forecasts, and from other comprehensive systems.

Data Processing Subsystem: Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) and weather data from additional sources will be used to perform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments. The hazard datasets can then be used as a vital input into the EMDSS.

User Interface System: State and local agency maintenance personnel will interact with the Enhanced-MDSS in a manner similar to the existing MDSS. Additional decision support tools may be developed that use the detailed roadway segment-specific data that is newly available from the connected vehicle data sources and the VDT. New techniques will be developed to communicate the enhanced treatment plans and recommendations back to snowplow and maintenance fleet vehicle operators.

Operational Policies and Constraints

This section identifies current constraints and potential future constraints and risks.

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research will clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers may be encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

VDT Implementation

This application will require participating agencies or their contractors to implement and operate the VDT.

MDSS Improvements

The existing federal prototype MDSS will need to undergo enhancements to be able to assimilate and use the connected vehicle road weather information in its operation. This will require additional research and development that must be defined and performed.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation

The typical modes of operation for the Enhanced-MDSS concept are—

- **Normal Mode:** In the normal operating mode, the Enhanced-MDSS will be available in advance of and during all winter weather events, with all designed functionality available.

- **Degraded Mode:** In this mode, some functions are not working properly or may not be available. This could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will operate in the manner of the existing MDSS.

- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

In most cases, vehicle operators will be passive participants in the operation of the Enhanced-MDSS. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. Most vehicle operators will not be recipients of the information that the Enhanced-MDSS generates.

Snowplow and Maintenance Vehicle Operators

In this special class of vehicle operators, the drivers will be passive participants in the collection and communication of connected vehicle road weather data. However, these vehicle operators will be intended recipients of the information that the Enhanced-MDSS generates. Operators of these vehicles will interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events.

Maintenance Personnel

This group of users will interact with the Enhanced-MDSS. They will receive recommendations on winter weather treatment strategies from the Enhanced-MDSS based on roadway segment-specific information from the VDT. They will use the decision support tools available through the Enhanced-MDSS and direct the actions of the snowplow and other maintenance vehicle operators based on the system outputs.

Support Environment

The Enhanced-MDSS concept will operate within the overall CVS. As such, the Enhanced-MDSS requires the deployment of connected vehicle onboard equipment and a DSRC roadside infrastructure or other wireless communications system, such as cellular; access to the certificate management entities defined for the CVS; and suitable data communications backhaul.

It is assumed that the systems operating the VDT will be deployed coincident with the data processing and communications systems required to operate MDSS within a state or local government facility or could be operated by a value-added service provider or other contractor. Appropriate systems administrators, system maintenance, and IT personnel will be required.

A suitable communications infrastructure, in common with the existing MDSS approach, will be required for the maintenance personnel using the Enhanced-MDSS to provide actions and directions to snowplow operators and other maintenance vehicle operators.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

Several enhancements will transpire when the integrated modeling for the road weather condition prediction system is added to the EMDSS. The EMDSS will have the ability to better use predictive and probabilistic models to help improve treatment recommendations. Current EMDSS already have some basic integrated modeling capabilities, however there is the opportunity to build upon them through more comprehensive modeling. For example, being able to anticipate where most accidents occur on roadways based on weather conditions and during specific times of day will give the EMDSS a better prioritization of roadway treatments. Furthermore EMDSS information can be incorporated to the Integrated Modeling for Road Weather Condition Prediction system, which will allow other applications that use the prediction system to consider treatment strategies.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

INFORMATION FOR MAINTENANCE AND FLEET MANAGEMENT SYSTEMS

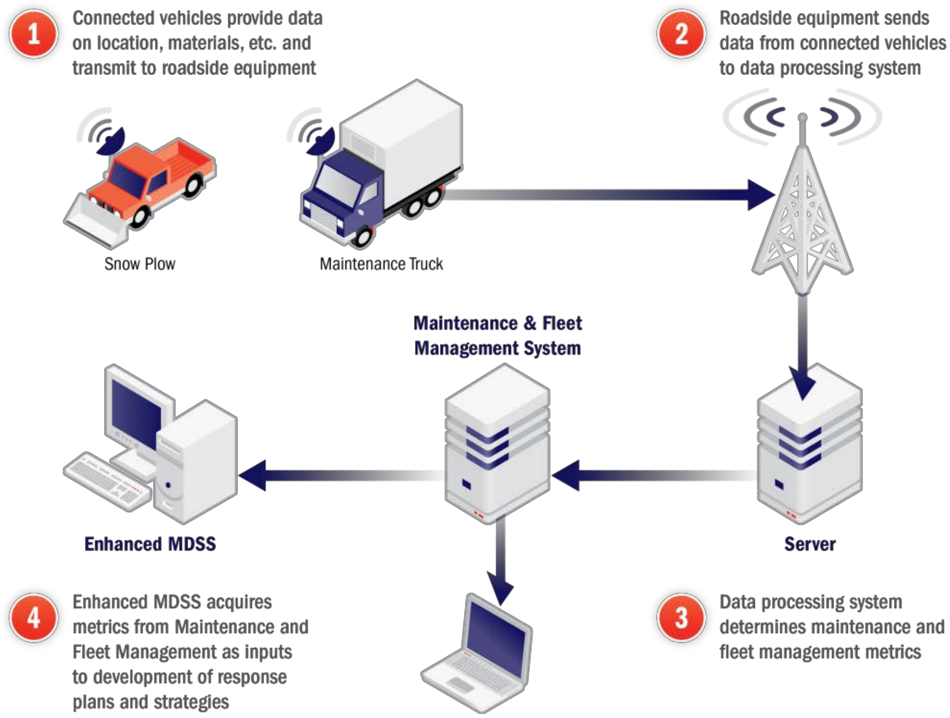
Description of the Proposed Application

This concept is viewed as both a stand-alone application and as an adjunct to the Enhanced-MDSS application described in the previous section. Maintenance and fleet-management systems are primarily concerned with the control of a transportation agency's physical assets, including its maintenance vehicles and materials (which can include the materials for roadway and pavement repair, chemicals and supplies for roadside vegetation control, and the chemicals and related materials used to control roadway icing and snow removal). These systems are used for a variety of purposes, including the management of material and fuel usage and purchases; managing the allocation of staff and other resources; equipment maintenance planning and scheduling; budget monitoring and forecasting; and long-term acquisition support and procurements, including life-cycle cost analyses for equipment and vehicles.

In this concept, connected vehicle information is more concerned with non-road weather data. The data collected may include powertrain diagnostic information from maintenance and specialty vehicles, the status of vehicle components such as plow blades and spreaders, the current location of maintenance vehicles and other equipment, and the types and amounts of materials onboard maintenance vehicles. In addition, connected vehicle information can be used to automate end-of-route and end-of-shift reports, where information on mileage and fuel usage is important. These types of information are key to automating the inputs to Maintenance and Fleet-Management Systems on a year-round basis.

In addition, desirable synergies can be achieved if selected data relating to winter maintenance activities, such as the location and status of snowplows or the location and availability of deicing chemicals, can be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies. Real-time information from mobile assets on material usage can be particularly important to tactical decision making during winter storms. Information from CVSs can also assist the decision-making process as it relates to the selection of the appropriate equipment for the current conditions and situations on the roadways and in decisions on how to move equipment from one geographic location to another to respond to needs. Finally, information from connected vehicles can be used to determine whether drivers and operators are correctly following treatment plans in terms of routes cleared and appropriate chemical distribution.

Figure 3 illustrates how a connected vehicle Maintenance and Fleet-Management System application could work.



Source: Booz Allen Hamilton.

Figure 3. Schematic of Maintenance and Fleet-Management System with Connected Vehicle Road Weather Information.

Subsystems

This application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. In this concept, connected vehicle data is collected both from vehicles used during winter maintenance and from other maintenance vehicles and equipment used year-round. It is assumed that vehicle diagnostic data will be acquired through a CANbus connection. The status of other equipment and information on materials will be gathered via additional specialized sensors installed on the vehicles that monitor material distribution rate and materials remaining.

Data Processing Subsystem: Connected vehicle and other sensor data will be communicated via data backhaul to a data processing system. Outputs from this system will be inputs to the Maintenance and Fleet Management System. When appropriate, the Maintenance and Fleet-Management System will generate data outputs that will be assimilated in the back-end processors of the Enhanced-MDSS for use in developing response plans and treatment strategies.

User Interface System: State and local agency maintenance personnel will interact with the Maintenance and Fleet Management Systems and, when appropriate during winter maintenance activities, the Enhanced- MDSS when they are using the connected vehicle data described in this concept in a manner similar to the existing systems. Additional decision support tools may be required within the Enhanced-MDSS that use the information provided by the Maintenance and Fleet-Management System.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle information. To be as effective as possible, data should also come from private, commercial, specialty and public fleet vehicles to improve year-round maintenance plans and recommendations, additionally this assumes a willingness of state and local agencies to deploy connected vehicle devices and other specialty sensors into their maintenance vehicles.

MDSS Improvements

If the existing MDSS is desired as part of this concept, the MDSS will need to undergo enhancements to be able to assimilate and use the connected vehicle information acquired via the Maintenance and Fleet-Management System in its operation. This will require additional research and development that must be defined and performed.

Modes of Operation

The typical modes of operation for the Maintenance and Fleet-Management System concept are—

- **Normal Mode:** In the normal operating mode, the system will be available in advance of and during all maintenance activities, with all designed functionality available.
- **Degraded Mode:** In this mode, some functions are not working properly or may not be available, which could result from many different situations. In the event that connected vehicle data is not available or the Maintenance and Fleet-Management System or the Enhanced-MDSS is not functioning, the remaining system components will operate in a stand-alone manner.
- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Maintenance Vehicle and Equipment Operators

The drivers of these vehicles will be passive participants in the collection and communication of the identified connected vehicle data. However, in the version of the concept that includes interaction between the Maintenance and Fleet-Management System and the Enhanced-MDSS, these vehicle operators will be intended recipients of the information that the Enhanced-MDSS generates. Operators of these vehicles will interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events.

Maintenance Personnel

This group of users will interact with both the Maintenance and Fleet Management System and, when appropriate, the Enhanced-MDSS. They will use the outputs of the Maintenance and Fleet-Management System to support a variety of planning, scheduling, and purchasing activities. They will also use the decision support tools available through the Enhanced-MDSS and direct the actions of the snowplow and other maintenance vehicle operators based on the system outputs.

Support Environment

The Maintenance and Fleet-Management System concept will operate within the overall CVS. As such, the system requires the deployment of connected vehicle onboard equipment, other specialist sensors, and roadside infrastructure; access to the certificate management entities defined for the CVS; and suitable data communications backhaul.

It is assumed that the systems required to acquire and assimilate connected vehicle data into a Maintenance and Fleet-Management System will be deployed coincident with the data processing and communications systems required to operate the existing system within a state or local government facility. However, it is acknowledged that automating the data input process from connected vehicle sources to existing Maintenance and Fleet-Management Systems may present challenges and require specialist development capabilities. Appropriate systems administrators, system maintenance, and IT personnel will be required once the system is operational.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

When the Integrated Modeling for Road Weather Condition Prediction system is added to the information for the maintenance and fleet-management system application, several enhancements will transpire. Similar to the EMDSS, the information for the maintenance and fleet-management system application will use the predictive and probabilistic information to anticipate where maintenance is needed most on specific roadways at certain times. Additionally, the onboard equipment that monitors the amount of treatment materials will be added to the prioritization for the treatments of roadways, giving maintenance personnel a better understanding of how past treatments affect motorists.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

WEATHER-RESPONSIVE TRAFFIC-MANAGEMENT STRATEGIES

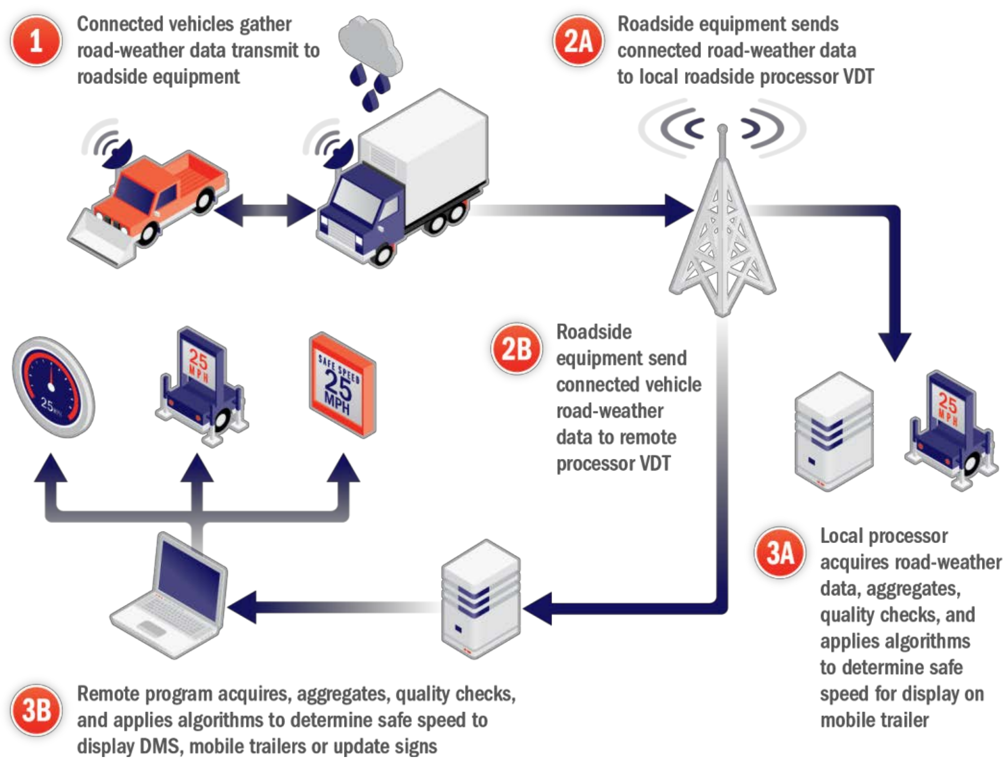
Description of the Proposed Weather-Responsive VSL Application

Earlier in this report, the concept of weather-responsive traffic management is discussed. Work underway elsewhere in the connected vehicle program is addressing several traffic-management applications in the areas of V2I safety and dynamic mobility, including signal and stop sign violations, speed harmonization, queue warning, and cooperative adaptive cruise control. This work acknowledges the benefits of integrating road weather information into the applications.

One area that is not being considered elsewhere is VSL for ATDM. This concept describes a Weather- Responsive VSL. VSL systems provide real-time information on appropriate speeds for current conditions and warn drivers of coming road conditions. VSL systems are gaining particular attention for work zone safety management. In this application, the systems consist of multiple roadside monitoring and display trailers, each independently powered and controlled. Each speed trailer uses detectors to measure traffic speed and roadway conditions. A local processor assimilates this information along with other inputs, such as nature and duration of roadwork activity, to determine the appropriate advisory speed or speed limit, which is displayed on a trailer-mounted variable speed sign. The posted speeds can vary throughout the work zone. Opportunities also exist to display variable speed information on infrastructure-mounted DMS or on in-vehicle signing systems.

CVSs provide opportunities to enhance the operation of VSL systems and dramatically improve work zone safety during severe weather events. Additional road weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed advisories or limits to reflect prevailing weather and road conditions.

Figure 4 provides a schematic of how a weather-responsive VSL could operate in a work zone.



Source: Booz Allen Hamilton.

Figure 4. Schematic of Weather-Responsive VSL System.

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles with their associated onboard equipment and the appropriate infrastructure at the roadside. Connected vehicles in this application are anticipated to be primarily vehicles operated by the general public and commercial entities (i.e., passenger cars and trucks). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2).

Data Processing Subsystem: Two potential alternatives are illustrated for this subsystem. The first assumes that data processing occurs primarily at the roadside using systems installed coincident with portable speed limit sign trailers. This approach may be most suitable for short-lived or mobile work zones (such as paving or striping operations) or in areas where a data communications backhaul capability is not readily available.

The second alternative assumes that data acquired at the roadside are communicated to a remote facility (such as a maintenance shed or a traffic operations center [TOC]) via backhaul. Data processing is performed using systems installed at the remote facility. This deployment approach may be more suitable for long-term construction projects where a semi-permanent speed signing infrastructure is installed or for broader VSL applications where speed limit information will be displayed routinely on freeway DMSs or through in-vehicle signing systems.

Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data and weather data from sources like satellites and radar will be included to preform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments.

Information Display Subsystems: In the concept where data processing occurs at the roadside, the information display subsystem will comprise the local, mobile speed limit display trailers commonly used in work zones. Where data processing occurs in a remote facility, VSL information can be displayed on any appropriate signage for which communications capabilities exist. This may include freeway and arterial DMS. After a suitable connected vehicle field infrastructure is deployed, the information display system could also include in-vehicle signing devices.

Description of the Proposed Weather-Responsive Signalized Intersection Application

A further area of WRTM that provides a particular opportunity for the use of road weather connected vehicle data is in signalized intersection control during deteriorating and adverse weather conditions. Research shows that benefits may accrue to traffic at signalized intersections during inclement weather through the use of the following strategies:

- Changes to the clearance interval (the yellow and all-red period) at signalized intersections.
- Changes to green intervals to accommodate start-up lost time and longer discharge headways particularly on snow, slush, or ice covered pavements.
- Development and implementation of special signal timing or coordination plans for use during adverse weather events, particularly under snow and ice conditions.

Road weather information collected by CVSs can be processed and used in algorithms associated with a local traffic signal controller to adjust intervals in response to current road and weather conditions. Information from connected vehicles can also be transmitted to remote agency locations where it is used in algorithms that provide recommendations to traffic managers to implement special signal timing plans more appropriate for prevailing road weather conditions.

Figure 5 provides a schematic of how a weather-responsive signalized intersection could operate.

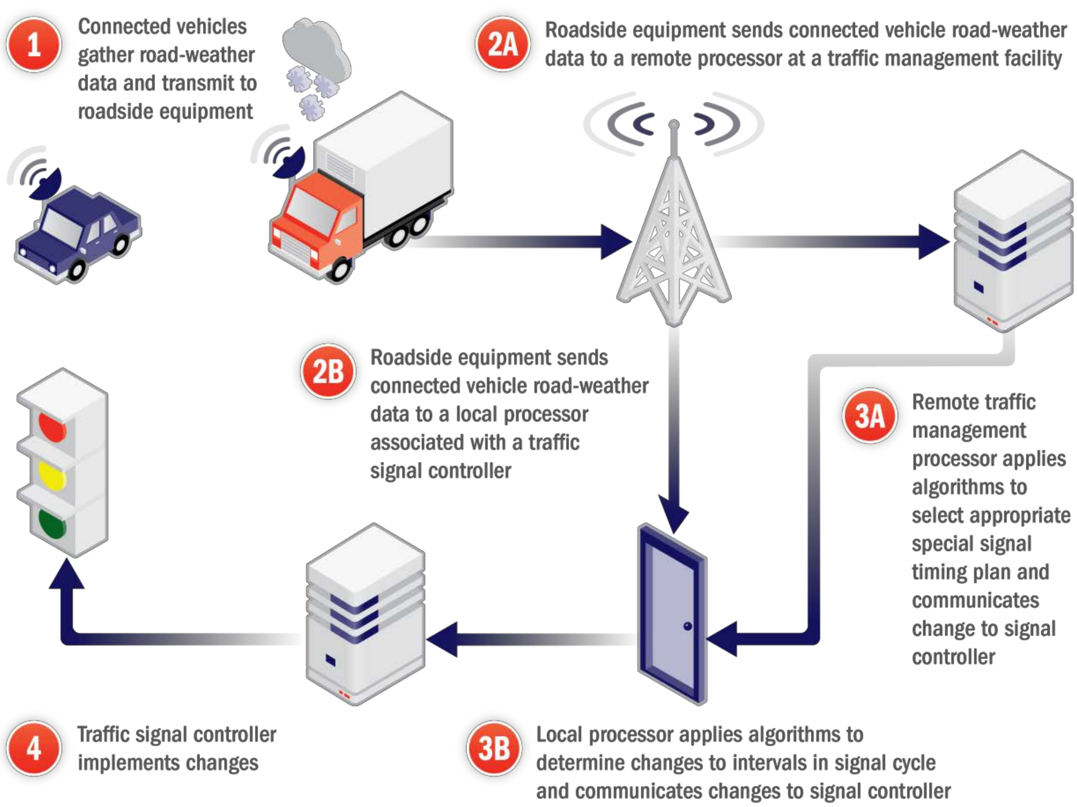


Figure 5. Schematic of Weather-Responsive Signalized Intersection System.

Source: Booz Allen Hamilton.

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles with their associated onboard equipment and the appropriate infrastructure at the roadside. Connected vehicles in this application are anticipated to be primarily vehicles operated by the general public and commercial entities (i.e., passenger cars and trucks). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2).

Data Processing Subsystem: Two potential alternatives are illustrated for this subsystem. The first assumes that data processing occurs at the roadside using systems installed coincident with a traffic signal controller at a signalized intersection. This approach is considered suitable for small changes to green intervals or clearance intervals during a signal cycle to accommodate changes in vehicle speeds and headways caused by poor weather-related pavement conditions.

The second alternative assumes that data acquired at the roadside is communicated to a remote facility (most likely a traffic-management facility) via backhaul. Data processing is performed using systems installed at the remote facility. This deployment approach will be suitable for identifying the appropriate special signal timing plan and implementing that plan for the duration of a weather event.

In both cases, the acquired connected vehicle road weather data is processed using a VDT to generate weather and road condition variables. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (such as timestamps, geographical coordinates, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, and surface temperature) as well as weather data from sources like satellites and radar will be included to preform quality checks on the information that is processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments. Outputs from the VDT along with other traffic data, other atmospheric weather information, surface weather observations, and information about the signalized intersection configuration and signal timing plans are used in new algorithms to develop appropriate signal timing changes under the prevailing traffic, weather, and road conditions.

Information Display Subsystems: In the concept where data processing occurs at a remote facility, a visual display will provide information to traffic managers for use in their selection of the signal timing plan. In both scenarios, the form of information display to drivers is the existing traffic signal head.

Description of the Proposed Weather-Responsive Ramp Metering Application

Ramp metering is common WTRM strategy used to manage demand at freeway entrance ramps. Ramp meters are installed to control the number of vehicle entering the freeway, to reduce freeway demand, and to break up platoons of vehicles released from upstream traffic signals. Strategies for operating ramp metering systems include pre-timed, traffic-responsive, isolated and system-wide ramp metering. During inclement weather conditions, freeway and ramp speeds could be significantly reduced, and reduced pavement friction can impact stopping distance and vehicle acceleration capabilities, which are all important factors in determining appropriate ramp metering timing parameters. CVS will offer comprehensive real-time traffic and road weather information which will be used in algorithms to improve the performance of ramp metering.

Insert figure

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles with their associated onboard equipment and the appropriate infrastructure at the roadside. Connected vehicles in this application are anticipated to be primarily vehicles operated by the general public and commercial entities (i.e., passenger cars and trucks). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2).

Data Processing Subsystem: Two potential alternatives are illustrated for this subsystem. The first assumes that data processing occurs primarily at the roadside using systems installed coincident with traffic signals installed on freeway ramps.

The second alternative assumes that data acquired at the roadside are communicated to a remote facility (such as a maintenance shed or a traffic operations center [TOC]) via backhaul. Data processing is performed using systems installed at the remote facility.

Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data and weather data from sources like satellites and radar will be included to preform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments.

Information Display Subsystems: In the concept where data processing occurs at the roadside, the information display subsystem is traffic signals. Where data processing occurs in a remote facility, the traffic signal timing adjusts accordingly to the road and weather condition. After a suitable connected vehicle field infrastructure is deployed, the information display system could also include in-vehicle signing devices.

Description of the Proposed Weather-Responsive Lane-Use Restriction Application

Lane-use restrictions is a WRTM strategy that will benefit greatly from connected vehicle data. Key outcomes of this strategy include reduction in crashes, injuries and fatalities, both for restricted vehicle types and collateral impacts to other vehicles during adverse weather events; increased efficiency and reduced time for maintenance to return lanes and roads back to level of service; improved travel times and reliability, as well as reduced speed variability for general traffic on restricted roadways. This application gathers weather and pavement conditions from road sensors, cameras, weather services, field personnel (including lane conditions for multi-lane roadways), and road weather forecasts from weather services. The information is then disseminated through DMS to notify motorist. CVSs will enhance lane-use restrictions through incorporating road weather information gathered from connected vehicles and in algorithms to refine restrictions during prevailing weather and road conditions.

Insert figure

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles with their associated onboard equipment and the appropriate infrastructure at the roadside. Connected vehicles in this application are anticipated to be primarily vehicles operated by the general public and commercial entities (i.e., passenger cars and trucks). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2).

Data Processing Subsystem: Two potential alternatives are illustrated for this subsystem. The first assumes that data processing occurs primarily at the roadside using systems installed coincident with over-the-lane DMS (ODMS) and with portable DMS. The use of portable DMS approach may be most suitable for short-lived or mobile work zones (such as paving or striping operations) or in areas where a data communications backhaul capability is not readily available.

The second alternative assumes that data acquired at the roadside are communicated to a remote facility (such as a maintenance shed or a traffic operations center [TOC]) via backhaul. Data processing is performed using systems installed at the remote facility.

Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data and weather data from sources like satellites and radar will be included to preform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments.

Information Display Subsystems: In the concept where data processing occurs at the roadside, the information display subsystem will comprise of ODMS. Where data processing occurs in a remote facility, lane restriction information can be displayed on any appropriate signage for which communications capabilities exist. After a suitable connected vehicle field infrastructure is deployed, the information display system could also include in-vehicle signing devices.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and, in one of the suggested deployment approaches, the availability of an appropriate roadside and data backhaul infrastructure. Additional research will clarify the levels of vehicle fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers are encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

Enhancement of Mobile Speed Limit Trailers

This application, in one of the recommended deployment approaches, will require state and local agencies to equip mobile speed limit trailers used in work zones with the appropriate roadside data acquisition components and the systems needed for data processing by the VDT and the speed limit selection algorithm.

Enforceability of Variable Speed Limits

Depending on the proposed deployment approach, enforcement of VSLs may require state or local legislation to be enacted.

Enhancement of Traffic Signal Controllers

This application will require state and local agencies to equip traffic signal controllers with the appropriate roadside data-acquisition components and the systems needed for data processing by the VDT and the algorithm that will identify required changes to the signal cycle.

Enforceability of Lane-Use Restrictions

Depending on the proposed deployment approach, enforcement of lane use restrictions may require state or local legislation to be enacted.

Modes of Operation

The typical modes of operation for the WRTM concepts are:

- **Normal Mode:** In the normal operating mode, the WRTM applications will be available in advance of and during all appropriate severe weather events with all designed functionality available. Details of Normal Mode of operation may vary depending on the operational policies of the agency. For example, in the VSL application, during periods when the work zone is inactive, some agencies may wish to display no speed limit information irrespective of the prevailing traffic, weather, and road conditions.

- **Degraded Mode:** In this mode, some functions are not working properly or may not be available. This could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will operate in the manner of existing work zone speed limit displays.
- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

From a data-delivery standpoint, vehicle operators will be passive participants in the operation of the WRTM applications. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. From an information-dissemination standpoint, all vehicle operators (irrespective of whether they were a data provider) will be recipients of the information generated either by the Weather-Responsive VSL and lane restrictions displayed on either ODMS, work zone speed limit display trailers, or Weather-Responsive Signalized Intersection application and displayed on the signal head in the conventional manner.

Work Zone Personnel

In the Weather-Responsive VSL application, this group of users will be responsible for the correct placement of speed limit sign trailers and for activation of the roadside data processing system in situations where speed limit information is displayed only when the work zone is active.

Traffic Operations Personnel

This group of users will interact with the Weather-Responsive VSL in the deployment scenario, where data processing takes place at a remote TOC. They will be presented recommendations on appropriate speeds by roadway segment under the prevailing conditions and will make decisions to post speed limit information on the DMS under their control. This group of users will also interact with the Weather-Responsive Signalized Intersection and the ramp metering application in the deployment scenario where data processing takes place at a remote traffic management facility. They will be presented recommendations on appropriate special signal timing plans under the prevailing conditions and will make decisions to implement the plans on the signal systems under their control. Furthermore, this group of users will be involved with data analysis and address operational procedures and operator training to support decisions to impose restrictions or closures, including coordination with all agencies involved in closure decisions present lane restrictions.

Support Environment

The WRTM concepts will operate within the overall CVS. As such, the WRTM applications require the deployment of connected vehicle onboard equipment and roadside infrastructure, access to the certificate management entities defined for the CVS, and suitable data communications backhaul where data processing occurs at a remote facility.

It is assumed that the data processing and communications systems operating the Weather-Responsive VSL will be deployed on mobile work zone speed limit sign trailers or within a state or local government facility, and the data processing and communications systems operating the Weather-Responsive Signalized Intersections will be deployed in association with existing or upgraded traffic signal controllers or within a state or local government facility. Appropriate systems administrators, system maintenance (including field maintenance personnel for the trailer-based equipment), and IT personnel will be required.

A suitable communications infrastructure, in common with existing traffic operations practices, will be required for the personnel using the WRTM applications.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

When the Integrated Modeling for Road Weather Condition Prediction system is added to weather-responsive traffic-management strategies several enhancements transpire.

Predictive and probabilistic information from the system will be incorporated to the VSL application to aid in the process of advising motorists of speed limit changes. This gives the application the potential to warn motorists prior to traveling, as well as en route to adjust speed limits. This enhancement helps motorists consider alternative routes where speed limits have not been lowered, which will create for safer travels as well as safer working conditions for maintenance personnel. The Integrated Modeling for Road Weather Condition Prediction system, could also archive information from the VSL application. This will give the predictive system historic information of how the speed limits adjust depending on weather and work zones. This enhance would also have the same effect on lane restriction motorists would be able to identify safer and faster travel routes around roadways with lane restrictions. The ramp metering application will also be able to use predictive information to enhance signal patterns

The Integrated Modeling for Road Weather Condition Prediction system will also enhance the weather-responsive signalized intersection application. Like the VSL application, predictive and probabilistic information from the system will help better inform motorists when making travel decisions. Signalized intersections adjust traffic light timing based on adverse weather conditions. With the predictive system will improve signalized strategies by identifying where and when traffic conditions are worst allow the signalized intersection application to proactively adjust. Additionally information gathered from the application can be added to the Integrated Modeling for Road Weather Condition Prediction system. This will allow other applications that use the system to consider weather-responsive signalized intersections into other applications.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

MOTORIST ADVISORIES AND WARNINGS

Description of the Proposed Application

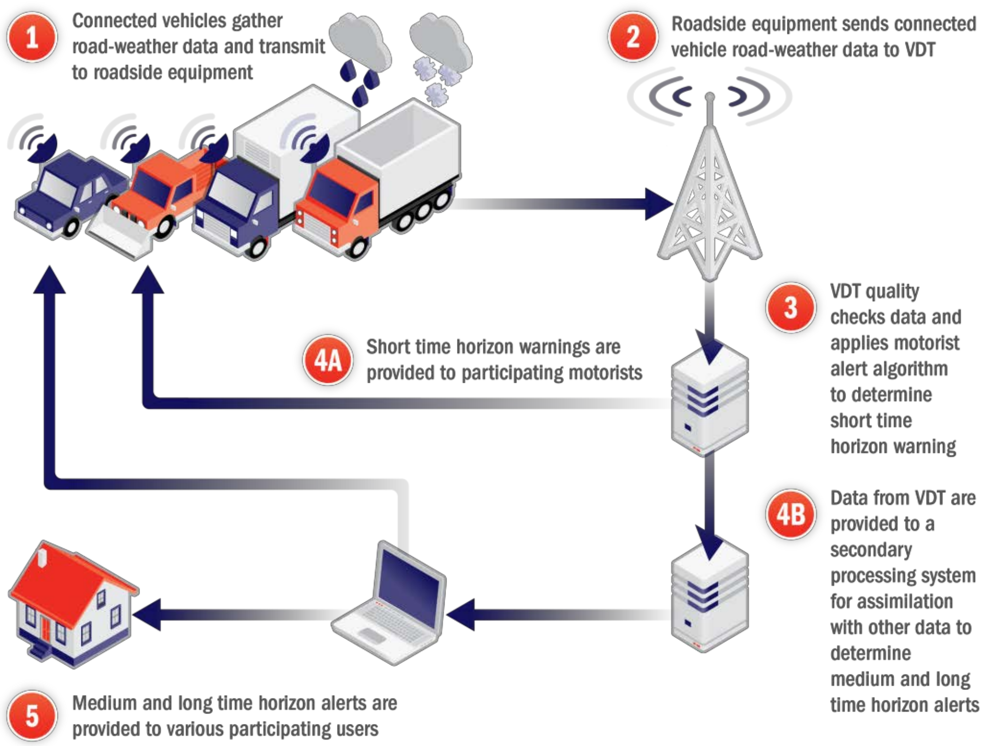
Motorists currently have access to a variety of traveler and weather information from multiple sources and providers and through many different media. State DOTs typically provide information on significant traffic incidents and delays; work zones; and the impacts of severe weather events, such as road closures caused by winter storms or flooding. Travelers can access this information through 511 systems or other phone-based hotlines or agency websites or see it displayed on roadway infrastructure such as DMS, or—increasingly—through social media. Public agencies usually provide this information to the traditional media outlets, as well, so travelers can obtain information from radio and television broadcasts. Atmospheric weather information is similarly distributed by the public sector: Travelers can access NWS watches, warnings, statements, and advisories through a variety means, and broadcast media outlets use NWS Doppler Radar feeds to create weather forecasts.

The private sector also offers several sources, tools, and services to provide motorist with weather and travel information. Increasingly, the private sector is packaging traveler information with consumer navigation products or providing the information through applications on smart phones or other personal mobile devices. Business models vary from free applications, from those with a small, one-time fee to those that are subscription based.

In all cases, the value of the information provided to the traveler is directly related to the breadth and quality of the data collection capabilities. Within this environment, information on segment-specific weather and road conditions is not well represented, even though surveys suggest that this information is considered to be of significant importance to travelers.

The ability to gather road weather information from connected vehicles will dramatically change this situation. Two information loops can be envisioned in this application: The first emphasizes gathering and disseminating spot warnings and advisories directly to individual motorists in the fastest possible means, while the second focuses on the integration of road weather information into a broader set of advisories but over a longer time period. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to travelers through a variety of means as alerts and advisories within a few minutes. In combination with observations and forecasts from other sources and with additional processing, medium-term advisories of the next 2–12 hours to long-term advisories for more than 12 hours into the future can also be provided to motorists. In both situations, the connected vehicle information provides the opportunity to create advisories and warnings with greater temporal and geographic resolution than is otherwise currently available.

Figure 6 provides a schematic of how a road-weather motorist advisory and warning system could operate.



Source: Booz Allen Hamilton.

Figure 6. Schematic of Road Weather Motorist Advisory and Warning System.

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of connected vehicles with their associated onboard equipment and the necessary roadside infrastructure. Two classes of connected vehicle are anticipated for the application: vehicles operated by the general public and commercial entities (including passenger cars and trucks) and specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface).

Data Processing Subsystem: Connected vehicle road weather data will be communicated via data backhaul to a remote VDT or to roadside VDT, where connected vehicle road weather data is communicated from vehicles via DSRC. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) and weather data from sources like satellites and radar will be included to preform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments.

These outputs will be available to a variety of public and private-sector users for use in tools that generate medium- and long-horizon alerts and warnings.

Information Generation Subsystem: Data outputs from the VDT will be available to other information processing systems that may reside in public agencies or be operated by commercial service providers. These systems are intended to produce tailored information content for the various user systems, particularly for medium- and long-horizon motorist alerts and warnings. Additional decision support tools may also be developed for state and local agency traffic and maintenance operations personnel who use the detailed roadway segment-specific data that is newly available from the connected vehicle data sources and the VDT.

User Interface Subsystems: Outputs from the road weather motorist alerts algorithm (i.e., the short time horizon alerts) and outputs from other information generation subsystems will be provided in a manner that makes the information accessible through as many user interfaces (UI) as possible. These will likely include phones and other personal mobile devices, websites, infrastructure-based displays, and traditional broadcast media.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research may clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively. In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers are encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

VDT Implementation

This application will require participating agencies to implement and operate the VDT. The VDT is currently in a development phase; therefore, the impacts of this requirement are currently unknown.

Algorithm and Information Processing System Development

As described, this concept relies on the development of new algorithms to rapidly analyze connected vehicle road weather data to generate short time horizon alerts plus the systems and communications required to push these alerts to users. In addition, the concept describes other information processing systems that will generate and distribute medium- and long-horizon motorist advisories and alerts.

This will require additional research and development that must be defined and performed.

The concept further assumes that information processing and the development of new information products will occur in both the public and private sectors. It is likely that the development of tailored information content by the private sector will be driven by market forces rather than a desire to disseminate weather and road condition information to improve roadway safety for the public good.

Interfaces to Other Systems

The concept assumes that the short-, medium-, and long-horizon motorist alerts and advisories will be delivered through a variety of systems, including public-sector websites, 511 and other phone-based information systems, DMSs, and social media. Suitable interfaces will need to be developed to existing systems of these types that reside in the public sector.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that are effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation

The typical modes of operation for the Road Weather Motorist Advisory and Warning System concept are—

- **Normal Mode:** In the normal operating mode, the system will be available during all adverse weather events, with all designed functionality available. The system will provide short time horizon alerts to system users, with minimal delay from the time of data acquisition.
- **Degraded Mode:** In this mode, some functions are not working properly or may not be available, which could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will be unable to provide short time horizon motorist alerts. Medium and long time horizon alerts may be delivered using data available from only national weather models and fixed and remote sensor systems.

- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. During Maintenance Mode, it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

From a data-delivery standpoint, vehicle operators will be passive participants in the operation of the Road Weather Motorist Advisory and Warning System. While operating their vehicles, onboard equipment with collect connected vehicle road weather information and will communicate this information to appropriate roadside equipment. From an information-dissemination standpoint, all vehicle operators (irrespective of whether they were a data provider) may be recipients of the information the system generates depending on the user devices available to them.

Traffic and Maintenance Operations Personnel

These groups of users may interact with the Road Weather Motorist Advisory and Warning System. They may be required to disseminate information via the traffic-management infrastructure or to maintenance personnel in the field.

Public Agency Traveler Information Providers

This group of users may be required to disseminate information from the Road Weather Motorist Advisory and Warning System to the public via 511 or other phone-based systems or through agency websites.

Commercial Service Providers

This group of users will receive information from the data processing subsystems and will develop information products tailored to the needs of their customers.

Support Environment

The Road Weather Motorist Advisory and Warning System concept will operate within the overall CVS. As such, the Enhanced -MDSS requires the deployment of connected vehicle onboard equipment and roadside infrastructure, access to the certificate management entities defined for the CVS, and suitable data communications backhaul.

It is assumed that the systems operating the VDT and other information processing systems will be deployed within a state or local government facility. Appropriate systems administrators, system maintenance, and IT personnel will be required.

Suitable communications infrastructure, in common with the existing traveler information and traffic operations systems, will be required for the dissemination of alerts and advisories to users.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

When the Integrated Modeling for Road Weather Condition Prediction is added to the motorist advisories and warnings application, several enhancements will transpire. The predictive and probabilistic information will help better inform motorist when making travel decisions. The MAW will be able to take into account the duration of the trip, departure time, as well as weather and traffic conditions to give the best travel routes.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

ROAD WEATHER PERFORMANCE MANAGEMENT APPLICATION

Description of the Proposed Application

The USDOT Connected Vehicle Program focuses on developing a multi-modal network of vehicle and environmental data transmitted from mobile platforms (e.g., private, commercial, or transit vehicles) in the transportation system to other vehicles, devices, or stationary infrastructure. As more vehicles get outfitted with a suite of instrumentation and computers to log a variety of data sets for transportation agencies, there will be greater increases in spatial and temporal resolution of traffic and weather data. This increase in data will not only have a marked impact on real-time operations, but also on post-event processing, performance measurements, and future planning.

Road Weather Performance Measurement and Management (RWPMM) apply to both traffic management and highway maintenance activities. Traffic management strategies during adverse weather (also called Weather-Responsive Traffic Management or WRTM) include changing signal timing, posting weather related messages, and changing speed limits to improve mobility and safety based on real-time road conditions. Snow removal and ice control during winter and pavement repair during summer are examples of maintenance activities. Identifying and understanding performance measures that are important to both traffic management and maintenance activities affected by the weather are critical in developing an effective performance measurement and management tool. DOT fleet vehicles outfitted with sensors and communication devices will greatly enhance the DOT's ability to assess the usage and success of resource deployment. Because weather is a central component to maintenance operations, DOT maintenance divisions have a significant opportunity to benefit from connected vehicle applications. For example, data logged from plow and spreader controllers, truck-mounted atmospheric and pavement sensors, and on-board GPS would be transmitted to a DOT processor and bare pavement regain time could be calculated at operational timescales. This streamlined data acquisition will optimize the performance measurement process, allowing for adjustments to be made in much smaller time intervals. Moreover, the dataset derived from connected vehicles can lead to standardized performance measurement methods which will allow for the comparison of results across the agency.

The performance management tool will highlight the potential for connected vehicle data to enhance and transform road weather performance measurement and management processes in State DOT's traffic management and maintenance operations. The tool should incorporate mobile traffic and weather observations to evaluate how well transportation agencies are performing weather-related traffic management and maintenance activities. Performance measures that are important to State DOTs can vary based on the type and severity of weather events as well as the priorities and constraints faced by each State. The tool should be scalable and flexible, or, in other words, able to incorporate a variety of activities and performance measures as the parameters for performance management. This will enable any State DOT to adopt or customize the tool with minimal effort.

The outputs from this tool should help transportation agencies evaluate their performance and identify areas for improvement. For example, one can use the Enhanced-MDSS during winter operations to compare average traffic speeds and delays with historical data for similar weather events. This will help maintenance managers compare their performance. Based on real-time traffic and weather data, the tool can determine the need to improve performance or maintain current levels.

In combination with other sources, the tool should use data sets obtained from Dedicated Short Range Communications (DSRC) equipment. The DSRC data could come from a State DOT and/or the Basic Safety Message (BSM) data emulator. Other data sources can include the Integrated Mobile Observations (IMO) datasets, Weather Telematics data, etc.

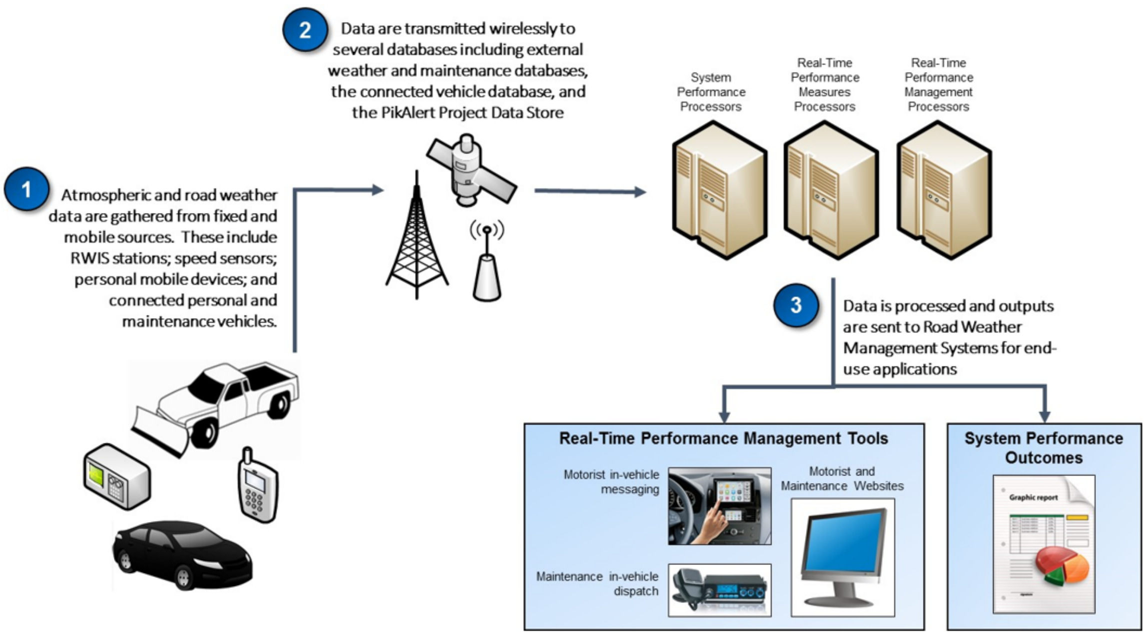


Figure 7. Schematic of the Performance Measurement and Management Tool.

Subsystems

This application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of information from connected vehicles, roadside equipment, and Citizen Reporting. Two classes of connected vehicles are anticipated for the application: (1) vehicles operated by the general public and commercial entities (including passenger cars and trucks) and (2) specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface). Citizen reporting could also be included in this concept, which would add an additional source that can gather real-time road information. This concept possibly will also use archived traffic and weather condition data to help create probabilistic models for predicting road weather and traffic conditions.

Data Processing Subsystem: Data from connected vehicles, roadside equipment, Citizen Reporting, and other sources will be communicated via data backhaul to a VDT 4.1. The VDT 4.1 will use the data input to create highly detailed weather and road condition outputs. Vehicle-based data and data from weather sources, such as satellites, will be included to preform quality checks on the processed information. These data outputs will be provided to the algorithms that will analyze system level performance in real time.

User Interface System: Outputs from the real-time performance management processors will be provided to real-time performance management tools, such as the motorist in-vehicle messaging, maintenance in-vehicle dispatch, motorist and maintenance websites, and system performance outcomes tools. These will likely include phones and other personal mobile devices.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research will clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers may be encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

VDT Implementation

This application will require participating agencies or their contractors to implement and operate the VDT. The VDT is currently in a development phase; therefore, the impacts of this requirement are currently unknown.

Performance Management Enhancements

The existing performance management processes and metrics will need to undergo enhancements to be able to assimilate and use the connected vehicle road weather information in its operation. This will require additional research and development that must be defined and performed.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation

- **Normal Mode:** In the normal operating mode, the performance management tool will be available in advance of and during all winter weather events, with all designed functionality available.

- **Degraded Mode:** In this mode, some functions are not working properly or may not be available. This could result from many different situations. In the event that connected vehicle road weather data is not available or the VDT is not functioning, the system will operate in the manner of existing performance management processes.

- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

In most cases, vehicle operators will be passive participants in the collection and communication of connected vehicle road weather data. The performance management tool would generate and relay outputs in the form of advisories and warnings to motorists. Examples include queue ahead warning, speed recommendations, and Pikalert advisories.

Snowplow and Maintenance Vehicle Operators

In this special class of vehicle operators, the drivers will be passive participants in the collection and communication of connected vehicle road weather data. However, these vehicle operators will be intended recipients of maintenance dispatch information that the tool generates. Operators of these vehicles will interact with appropriate in-vehicle devices to receive instructions on their actions during winter weather events.

Maintenance Personnel

This group of users will interact with the tool via a website to track and analyze metrics that will help them evaluate and optimize the performance of their network. The system level performance outcomes can be used to tweak maintenance strategies in real time to improve performance. Key factors such as traffic mobility, maintenance effectiveness, and maintenance costs are provided as system performance outcomes.

Support Environment

The performance management tool concept will operate within the overall CVS. As such, the tool requires the deployment of connected vehicle onboard equipment and a DSRC roadside infrastructure or other wireless communications system, such as cellular; access to the certificate management entities defined for the CVS; and suitable data communications backhaul.

It is assumed that the deployment of systems operating the VDT will coincide with the deployment of the data processing and communications systems required to operate the tool within a state or local government facility. This could also be operated by a value-added service provider or other contractor. Appropriate systems administrators, system maintenance, and IT personnel will be required.

Enabling Concept Enhancements

Integrated modeling for the road weather condition prediction system

Since this application is being developed at the same time as the Integrated Modeling for Road Weather Condition Prediction system, enhancements have already been considered.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

INFORMATION FOR FREIGHT CARRIERS

Description of the Proposed Application

This application can be considered a special case of the Road Weather Motorist Advisory and Warning System described in the previous section. Truck drivers have similar access to the variety of traveler information systems that are available to all road users. However, the available traveler information options are invariably intended for use by passenger car drivers. The limitations of the existing systems with respect to the type and quality of information provided have particular impacts on motor carriers.

Prevailing and forecast weather conditions and the impacts of weather on the roadways are especially significant to freight carriers. Drivers must be conscious of current roadway conditions to safely operate the vehicles and must be aware of approaching weather events or deteriorating conditions to plan their hours of service and to seek suitable truck parking locations. Because of the nature of many truck trips, multistate information is also especially important.

In the event that a particular roadway segment becomes impassable because of weather conditions, truck drivers face greater challenges in rerouting. Truck drivers must coordinate with their dispatchers to ensure that an alternative route is suitable, considering highway weight restrictions, bridge height restrictions, or geometric issues such as tight turning radii. Dispatchers must also consider other operational factors, such as delivery schedules, when making decisions to delay a trip or reroute because of weather events.

The ability to gather road weather information from connected vehicles will significantly improve the ability of freight shippers to plan and respond to the impacts of severe weather events and poor road conditions. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to both truck drivers and their dispatchers through a variety of means as alerts and advisories with low latency. In combination with observations and forecasts from other sources, and with additional processing, medium-to-long-term advisories can also be provided to dispatchers to support routing and scheduling decisions. Because these decisions must consider a variety of other factors, such as highway and bridge restrictions, hours-of-service limitations, parking availability, delivery schedules, and—in some instances—the permits the vehicle holds, it is envisioned that the motor carrier firms or their commercial service providers will develop and operate the systems that use the road weather information generated through this concept. This connected vehicle information can also support decisions made by state agencies relating to the temporary suspension of commercial vehicle permits because of prevailing weather and road conditions. Up-to-date information on actual conditions at high resolution may allow temporary restrictions to be lifted in a timelier manner.

Figure 8 provides a schematic of how a road weather advisory and warning system for freight carriers could operate.

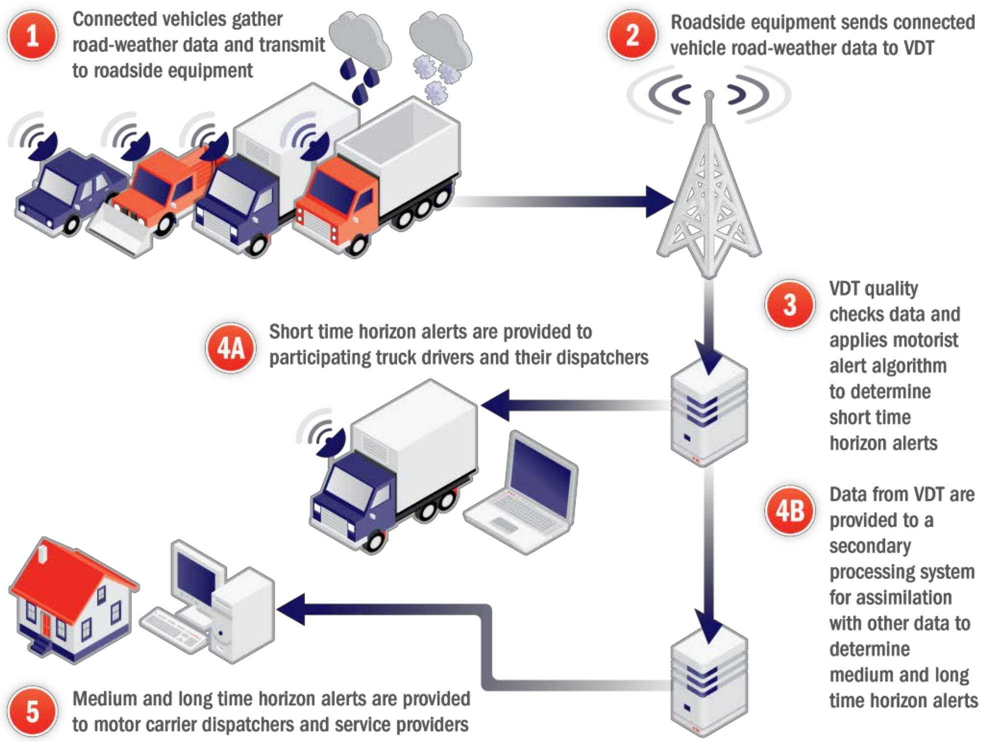


Figure 8. Schematic of Road Weather Advisory and Warning System for Freight Carriers.

Source: Booz Allen Hamilton.

Subsystems

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. Two classes of connected vehicle are anticipated for the application: vehicles operated by the general public and commercial entities (including passenger cars and trucks) and specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface).

Data Processing Subsystem: Connected vehicle road weather data will be communicated via data backhaul to a VDT 4.1. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) and data from weather sources like satellites and radar will be included to preform quality checks on the information processed. These data outputs will be provided to a road weather motorist alerts algorithm to generate short time horizon alerts that will be pushed to tuck drivers and their dispatchers.

In addition to the VDT outputs, the short time horizon alerts that are pushed to truck drivers will include high-wind advisories. This information will be acquired from other fixed and remote observation systems and will be provided with as much geographic precision as possible.

VDT output data will supplement other data sources (such as data from national weather models and from surface weather and road weather observation systems) and will be assimilated in back-end processors for use in the various weather and pavement temperature models. The outputs from these processes will be available to motor carrier dispatchers and their service providers for use in tools that generate medium- and long-horizon alerts and warnings and that may determine route and schedule adjustments for individual vehicles based on the weather and road conditions.

Information Generation Subsystem: Data outputs from the VDT will be available to other information processing systems that may reside in freight shipper facilities or be operated by commercial service providers. These systems will be intended to produce tailored information content for the various user systems, particularly for medium- and long-horizon alerts and warnings.

User Interface Subsystems: Outputs from the road weather motorist alerts algorithm (i.e., the short time horizon alerts) and outputs from other information generation subsystems will be provided in a manner that makes the information accessible through UIs that are appropriate for the truck cab environment or trucking firm dispatcher.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research may clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data are especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers are encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

Algorithm and Information Processing System Development

As described, this concept relies on the development of new algorithms to rapidly analyze connected vehicle road weather data to generate short time horizon alerts plus the systems and communications required to push these alerts to truck drivers and dispatchers. In addition, the concept describes other information processing systems that will generate and distribute medium- and long-horizon motorist advisories and alerts. This will require additional research and development that must be defined and performed.

The concept further assumes that information processing and the development of new information products will occur primarily in the private sector. It is likely that the development of these systems by the private sector will be driven by market forces. An analysis of the needs of the motor carrier industry for these products and the likelihood of their development by commercial service providers may be appropriate prior to additional development of this concept by USDOT.

Interfaces to Other Systems

The concept assumes that the short-, medium-, and long-horizon alerts and advisories will be delivered through a variety of systems native to trucks and trucking dispatch offices. Suitable interfaces will need to be developed to these existing systems.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation

The typical modes of operation for the Road Weather Advisory and Warning System for Freight Shippers concept are—

- **Normal Mode:** In the normal operating mode, the system will be available during all adverse weather events, with all designed functionality available. The system will provide short time horizon alerts to system users with minimal delay from the time of data acquisition.

- **Degraded Mode:** In this mode, some functions are not working properly or may not be available, which could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will be unable to provide short time horizon motorist alerts. Medium and long time horizon alerts may be delivered using data available from only national weather models and fixed and remote sensor systems.

- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. During Maintenance Mode, it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

From a data-delivery standpoint, vehicle operators will be passive participants in the operation of the Road Weather Advisory and Warning System for Freight Shippers. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. From an information dissemination standpoint, vehicle operators (other than truck drivers, who are described as a separate class below) will not be recipients of the information that this system generates.

Truck Drivers

From a data-delivery standpoint, truck drivers will be passive participants in the operation of the Road Weather Advisory and Warning System for Freight Shippers. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. From an information-dissemination standpoint, participating truck drivers will be recipients of the information that this system generates.

Truck Dispatchers

Dispatchers will be recipients of all of the information that this system generates. Dispatchers will use the information to advise truck drivers or to reroute and reschedule truck trips.

Commercial Service Providers

This group of users will receive information from the data processing subsystems and will develop information products tailored to the needs of their customers.

Support Environment

The Road Weather Advisory and Warning System for Freight Shippers concept will operate within the overall CVS. As such, the system requires the deployment of connected vehicle onboard equipment and roadside infrastructure, access to the certificate management entities defined for the CVS, and suitable data communications backhaul.

It is assumed that the systems operating the VDT and other information processing systems will be deployed within a state or local government facility. Appropriate systems administrators, system maintenance, and information technology (IT) personnel will be required. Suitable communications infrastructure will be required for the dissemination of alerts and advisories to truck drivers, dispatchers, and commercial service providers.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

When the Integrated Modeling for Road Weather Condition Prediction system is added to the information for freight carriers' application, several enhancements transpire. Similar to the MAW application, predictive and probabilistic information will help better inform freight carriers when making route decisions. The freight industry is time sensitive, therefore it is important to note the predictive system will help anticipate weather conditions, road closures, work zones, and other variables that delay trips. It will account for those variables and make immediate adjustments for route guidance to ensure on time arrival.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

INFORMATION AND ROUTING SUPPORT FOR EMERGENCY RESPONDERS

Description of the Proposed Application

Emergency responders, including ambulance operators, paramedics, and fire and rescue organizations, have a compelling need for the short, medium, and long time horizon road weather alerts and warnings that have been described for the two previous concepts. This information can help drivers safely operate their vehicles during severe weather events and under deteriorating road conditions.

In addition, however, emergency responders have a particular need for information that affects their dispatching and routing decisions. Information on weather-affected travel routes—especially road or lane closures caused by snow, flooding, and wind-blown debris—is particularly important. Low-latency road weather information from connected vehicles for specific roadway segments together with information from other surface weather observation systems, such as flooding and high winds, will be used to determine response routes, calculate response times, and influence decisions to hand off an emergency call from one responder to another responder in a different location.

Figure 9 provides a schematic of how a road weather-sensitive emergency responders system could operate.

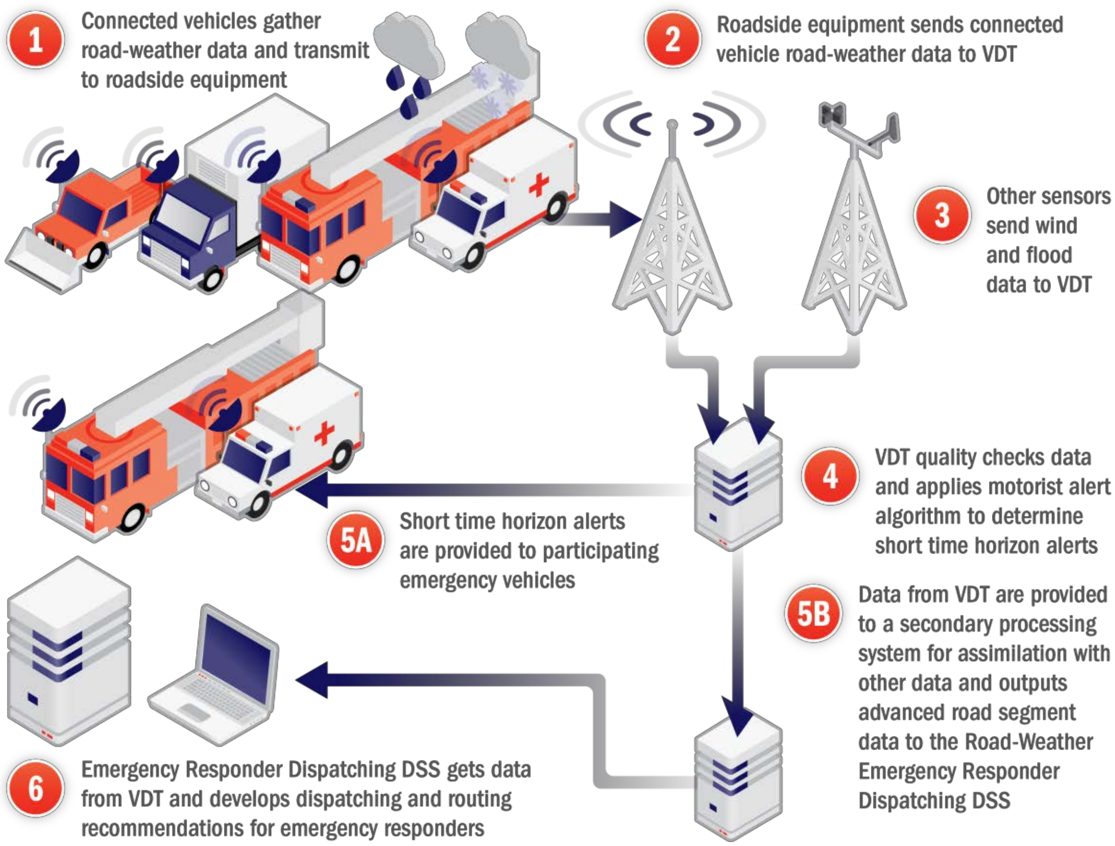


Figure 9. Schematic of Road Weather Emergency Responder Dispatching DSS.

Source: Booz Allen Hamilton.

Subsystems

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. Three classes of connected vehicle are anticipated for the application: vehicles operated by the general public and commercial entities (including passenger cars and trucks), emergency vehicles (including ambulances and fire trucks), and specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while emergency and public agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles.

Data Processing Subsystem: Connected vehicle road weather data will be communicated via data backhaul to a VDT 4.1. The VDT 4.1 will create highly detailed weather and road condition outputs based on this data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, and surface temperature) and data from weather sources will be included in order to preform quality checks on the information that is processed. These data outputs will be provided to a road weather motorist alerts algorithm to generate short time horizon alerts, which will be pushed to emergency vehicle drivers and first-responder dispatchers.

In addition to the VDT outputs, the short time horizon alerts that are pushed to emergency vehicle drivers and dispatchers will include information on high winds, standing water, and flooding of roadways. This information will be acquired from other fixed and remote observation systems and will be provided with as much geographic precision as possible.

VDT output data will supplement other data sources (such as data from national weather models and from surface weather and road weather observation systems) and will be assimilated in back-end processors for use in the various weather and pavement temperature models. The outputs from these processes will be passed to a new Road Weather Emergency Responder Dispatching Decision Support System (DSS).

Road Weather Emergency Responder Dispatching DSS: Data outputs from the VDT will be available to a new Road Weather Emergency Responder Dispatching DSS that may reside in an emergency responder facility or a transportation agency. This system will be intended to analyze the complex interactions between current and forecast road weather conditions, other current surface weather observations, current roadway traffic conditions (including average traffic speeds and congestion conditions by roadway segment), and the communications needs with road agencies (such as information on which roads are plowed; the status of removing wind-blown debris from roadways; and the presence of incidents, work zones, or other situations causing lane or roadway closures).

User Interface Subsystems: Outputs from the Road Weather Emergency Responder Dispatching DSS will be provided in a manner that makes the information accessible through UIs that are appropriate for the emergency vehicle or emergency responder dispatcher.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of emergency responders and state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research may clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data are especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers are encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

Road Weather Emergency Responder Dispatching DSS Development

As described, this concept relies on the development of new algorithms to rapidly analyze connected vehicle road weather data to generate short time horizon alerts plus a new Road Weather Emergency Responder Dispatching DSS. This will require additional research and development that must be defined and performed. An analysis of the needs of the emergency responder community for this system may be appropriate prior to additional development of this concept by USDOT.

Interfaces to Other Systems

The concept assumes that the short time horizon alerts and advisories will be delivered through a variety of systems native to emergency vehicles and emergency responder dispatch facilities. Suitable interfaces will need to be developed to these existing systems.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation

The typical modes of operation for the Road Weather Emergency Responder Dispatching DSS concept are—

- **Normal Mode:** In the normal operating mode, the system will be available during all adverse weather events, with all designed functionality available. The system will provide short time horizon alerts to system users with minimal delay from the time of data acquisition.

- **Degraded Mode:** In this mode, some functions are not working properly or may not be available, which could result from many different situations. In the event that connected vehicle road weather data is not available or the VDT is not functioning, the system will be unable to provide short time horizon motorist alerts. Medium and long time horizon alerts may be delivered to the Road Weather Emergency Responder Dispatching DSS using data available from only national weather models and fixed and remote sensor systems.

- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. During Maintenance Mode, it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Vehicle Operators

From a data-delivery standpoint, vehicle operators will be passive participants in the operation of the Road Weather Emergency Responder Dispatching DSS. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. From an information-dissemination standpoint, vehicle operators (other than emergency vehicle drivers, who are described as a separate class below) will not be recipients of the information that this system generates.

Emergency Vehicle Drivers

From a data-delivery standpoint, truck drivers will be passive participants in the operation of the Road Weather Emergency Responder Dispatching DSS. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. From an information dissemination standpoint, participating emergency vehicle drivers will be recipients of the information that this system generates.

Emergency Responder Dispatchers

Dispatchers will be recipients of all of the information that this system generates. This group of users will also interact with the new Road Weather Emergency Responder Dispatching DSS. They will use the decision support tools available through the new Road Weather Emergency Responder Dispatching DSS and will direct the handling of emergency calls and the routing of emergency vehicles based on the system outputs. Alternatively, this group of users may interact with a commercial service provider that provides the information from this concept to the emergency responder dispatcher.

Support Environment

The Road Weather Emergency Responder Dispatching DSS concept will operate within the overall CVS. As such, the system requires the deployment of connected vehicle onboard equipment and roadside infrastructure, access to the certificate management entities defined for the CVS, and suitable data communications backhaul.

It is assumed that the systems operating the VDT and the new Road Weather Emergency Responder Dispatching DSS will be deployed either within an emergency responder facility or a state or local government facility. Appropriate systems administrators, system maintenance, and IT personnel will be required. Suitable communications infrastructure will be required for the dissemination of alerts and advisories to emergency vehicle operators and emergency responder dispatchers.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

Several enhancements will be made when the integrated modeling for the road weather condition prediction system is added to the information and routing support for emergency responders' application. The predictive and probabilistic information added to the application will help emergency responders find the most efficient routes when driving in adverse weather. The predictive system will adjust route guidance by anticipating weather conditions, road closures, work zones, and other variables that may cause delays.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

ROAD WEATHER MODULE FOR AUTOMATED VEHICLE APPLICATIONS

Automated vehicle technologies are advancing rapidly but the design, tests, and implementation of these systems and applications do not yet consider road weather. It is important that the impacts of weather conditions on safety-critical control functions of different levels of automation are considered. The RWMP program has developed a concept called the Automated Vehicle in Adverse Weather Decision Support System (AVAW-DSS). This concept incorporates weather data into the decision logic of automated vehicle applications. The goal is to improve safety when automated vehicles operate in adverse weather conditions. The application takes four factors into consideration along with real-time weather data (pavement temperature, dew point, visibility, etc.) and forecasts. The four factors will be appropriately scaled to match the weather condition detected and feed into the decision support system. Examples of the four factors are provided below:

- Driver Behavior: reaction time, gap acceptance, visibility, etc.
- Roadway Characteristics: gradient, curve radius, pavement type, sight distance, etc.
- Vehicle Characteristics: engine capacity, brakes, acceleration, tires, etc.
- Communications / Sensors: range, sensitivity to weather events, communications latency, etc.

For example, if heavy rain is detected, the sensor range value is affected and gap acceptance value is increased for safety considerations. Similarly, other parameters under the four factors mentioned above are adjusted based on the intensity of rain and fed into the system. The decision support system will then use complex algorithms to process this input to provide appropriate control actions for the vehicle to follow. One set of outputs directly relate to the vehicle. These include warnings/advisories such as reduced speed, steering control, braking pressure, etc. The other set of outputs relate to the network and include variable speed limit advisories, adaptive traffic signal timing, etc. Furthermore, road weather safety will be enhanced if automated vehicles are also connected and share information with one another and infrastructure, particularly during adverse weather conditions.

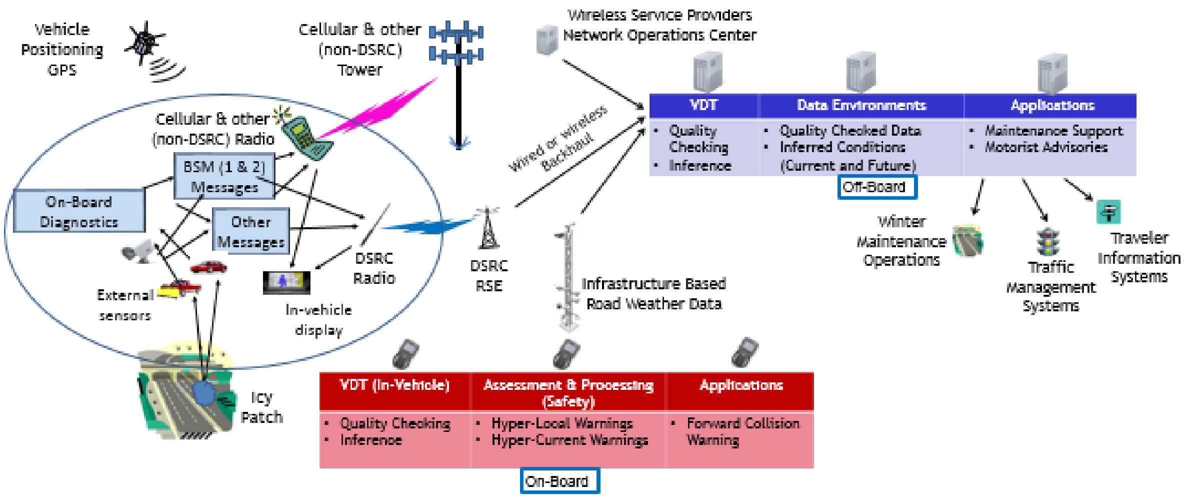


Figure 10. Schematic of Input Data Elements.

Subsystems:

The application will consist of a series of subsystems:

Data Acquisition Subsystem: This subsystem is made up of the automated vehicles, connected vehicles, their associated onboard equipment, and the necessary roadside infrastructure. Three classes of connected and automated vehicles are anticipated for the application: vehicles operated by the general public and commercial entities (including passenger cars and trucks); emergency vehicles (including ambulances and fire trucks); and specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). These classes of vehicles include the mix of automated vehicles at different levels of automation. It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while emergency and public agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles. In addition the system will also receive weather data from fixed infrastructure stations (RWIS), radar, and the National Weather Service Stations (NWS).

Data Processing Subsystem: Connected vehicle road weather data will be communicated via data backhaul to a VDT 4.1. The VDT 4.1 will create highly detailed weather and road condition outputs based on this data input. Vehicle-based data (such as timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, and surface temperature) and data from weather sources like satellites and radar will be included to preform quality checks on the information processed. These data outputs will be provided to a road weather motorist alerts algorithm to generate short time horizon alerts (such as information on high winds, standing water, and flooding of roadways) will be pushed to the users. VDT output data will supplement other data sources (such as data from national weather models and from surface weather and road weather observation systems) and will be assimilated in back-end processors for use in the various weather and pavement temperature models. The outputs from these processes will feed into the decision support system for automated vehicles to generate the appropriate control actions depending on the state and level of automation the vehicle is operating under.

User Interface Subsystems: Outputs from the AVAW-DSS will be provided in a manner that makes the information accessible through UIs that are appropriate for drivers of vehicles (level 0 to level 3 automation). For level 4 automation, the vehicle is directly controlled by the outputs of the system.

Operational Policies and Constraints

Data Availability

The effectiveness of this application is predicated on the availability of connected and automated vehicle road weather information. This assumes a broad penetration of connected and automated vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. Research may clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers are encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

AVAW DSS Development

As described, this concept relies on the development of new algorithms to rapidly analyze connected vehicle road weather data to generate short time horizon alerts and output the most appropriate actions for different levels of automation. This will require additional research and development that must be defined and performed. An analysis of the needs of different levels of automation and driver behavior is important to understand prior to additional development of this concept by USDOT.

Interfaces to Other Systems

This concept assumes that the short time horizon alerts and advisories will generate appropriate control action outputs to be delivered to automated vehicle applications at various levels of automation. Suitable interfaces will need to be developed to these existing systems.

Modes of Operation

The typical modes of operation for the AVAW-DSS concept are—

- **Normal Mode:** In the normal operating mode, the system will be available during all adverse weather events, with all designed functionality available. The system will provide control action outputs for different levels of automation based on state the vehicle.
- **Degraded Mode:** In this mode, some functions are not working properly or may not be available, which could result from many different situations. In the event that connected vehicle road weather data is not available or the VDT is not functioning, the system will be unable to provide control action outputs. In this case the vehicle will rely solely on data obtained from its sensors.
- **Maintenance Mode:** During system maintenance, some subsystems and their functionality may not be available. During Maintenance Mode, it may be possible to bring the subsystems back into operation, if needed.

User Classes and Other Involved Personnel

Automated and Connected Vehicle Drivers

From a data-delivery standpoint, connected vehicle drivers will be passive participants in the operation of the AVAW-DSS. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment and the VDT. Automated vehicle drivers apart from contributing data will also benefit from the AVAW-DSS outputs for the intermediate levels of automation while a fully automated vehicle could benefit from safety actions to prevent incidents in adverse weather conditions.

Agency Vehicle Drivers

From a data-delivery standpoint, drivers of agency vehicles (maintenance, emergency response, etc.) will be passive participants in the operation of the AVAW-DSS. While operating their vehicles, onboard equipment will collect connected vehicle road weather information and communicate this information to appropriate roadside equipment. Agency vehicles at different levels of automation will also benefit from the control action outputs generated by the system apart from contributing data.

Support Environment

The AVAW-DSS concept will operate within the overall CVS. As such, the system requires the deployment of connected vehicle onboard equipment and roadside infrastructure, access to the certificate management entities defined for the CVS, and suitable data communications backhaul.

Appropriate systems administrators, system maintenance, and IT personnel will be required. Suitable communications infrastructure will be required for the dissemination of alerts, advisories, and control actions to the drivers and vehicles.

Enabling Concept Enhancements

Integrated Modeling for the Road Weather Condition Prediction System

Several enhancements will occur when the Integrated Modeling for Road Weather Condition Prediction system is added to the AVAW-DSS. The predictive and probabilistic information added to the application will help vehicles find the most efficient routes when driving in adverse weather. The predictive system will adjust for best route guidance by anticipating weather conditions, road closures, work zones, and other delaying variables. The vehicles could also provide recommendations for best time of travel once the destination information has been entered and the driver can then decide to stay at his or her current location before starting the trip.

Citizen Reporting

Data collected via CR programs will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

DESCRIPTION OF PROPOSED WEATHER ENABLING SYSTEMS FOR CONNECTED VEHICLE V2I SAFETY APPLICATIONS

Stop Sign Violation Warnings

Stop Sign Violation Warning (SSVW) application will improve safety at intersections with stop signs by providing in-vehicle warnings to drivers if they may violate an upcoming stop sign. The warnings are based on the drivers speed and distance to the stop sign. SSVW application will help reduce the number of drivers that run stop signs or red lights, reducing the number of conflicts and crashes. Connected vehicle road weather systems will give stop sign violation warning applications added road weather information, like the road surface coefficient of friction, to include into their algorithms. This application will help to better adjust warning timing to account for variations in stopping distance.

Red Light Warnings

The Red Light Violation Warning (RLVW) application is intended to help a drivers approaching an intersection avoid crashes by warning the driver of an impending red-light violation. The benefit to society increases with growing numbers of RLVW equipped intersections and vehicles. Similar to SSVW, Connected vehicle road weather systems will give red light violation warning applications information, like the road surface coefficient of friction, to include into their algorithms. This application will also help to better adjust warning timing to account for variations in stopping distance.

Curve Speed Warning

The curve speed warning (CSW) application improves roadway curve safety, reduces run off road incidents, and rollover events by alerting drivers that their speed exceeds a safe threshold for current curve and roadway conditions. CSW uses both vehicle-based and infrastructure-based sensor data to assess safe speeds based upon curve geometry, real-time road and weather conditions, vehicle telematics data, and vehicle configuration data. Connected vehicle road weather systems will refine CSW algorithms with connected vehicle road weather data sets, like the road surface coefficient of friction, or hazard datasets. This added information will help to better adjust the timing of disseminating warnings resulting in a more effective CSW.

Spot Weather Information Warning

Spot Weather Information Warning (SWIW) application assists drivers in avoiding crashes in areas prone to adverse weather impacts through in warnings that a crash-imminent situation is possible. This application particularly addresses extreme situations where precautions are not taken, such as reducing speed or seeking an alternate route. The SWIW mitigates adverse weather, which may include relatively high-elevation or low-elevation areas that are more prone to reduced visibility, adverse surface conditions due to rain, snow, ice, or flooding, and high winds. SWIW is designed to gather information from both vehicle-based and infrastructure-based technologies, while the outputs will be disseminated through onboard and roadside signage warning systems to alert motorists. Connected vehicle road weather systems will enhance the SWIW with quality checked and refined road weather information. This application will refine the algorithm and improve the timing precision of SWIW-issued advisory messages, alerts, and warnings in relation to the downstream location of the unsafe condition may vary by the severity of the event

Data Acquisition Subsystem Weather Component

The description of the data acquisition subsystem is directed towards weather-related information for these applications. There may be additional subsystems used by these applications discussed elsewhere.

This subsystem is made up of several different sources. These sources include connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. Two classes of connected vehicle are anticipated for the application: (1) vehicles operated by the general public and commercial entities (including passenger cars and trucks) and (2) specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface).

Non-mobile data on roadway segments will be provided by MADIS, which ingests data from RWIS, other surface weather stations, radar, satellite, model forecasts, and from other comprehensive systems. Furthermore, data collected via CR programs will be incorporated and will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

Data Processing Subsystem Weather Component

The description of the data processing system is directed towards weather-related information for these applications. There may be additional systems not pertaining to weather that are used by these applications and discussed elsewhere.

Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) and weather data from additional sources will be used to perform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments. The hazard datasets can then improve CV application functionality pertaining to road weather.

Integrated modeling for road weather condition prediction will also be incorporated into these applications. Quality checked connected vehicle data from backend systems, archived weather and road data, as well as other data sources needed for probabilistic information will be communicated through integrated modeling. The data will be quality checked and processed by probabilistic models and algorithms to consider random variables (e.g., car accidents, traffic, and work zones).

User Interface System

User interface systems for these applications have been identified elsewhere.

Operational Policies and Constraints

Data Availability

The effectiveness of these systems is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research will clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers may be encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation for Weather Components

The typical modes of operation for the road weather system components of these applications of these are—

- **Normal Mode.** In the normal operating mode, road weather components will be available to the application, with all designed functionality available.

- **Degraded Mode.** In this mode, some functions are not working properly or may not be available. This could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will operate without connected vehicle road weather information.

- **Maintenance Mode.** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

Users Classes, Other Involved Personnel, and Support Environment

This section has been identified and defined elsewhere.

DESCRIPTION OF PROPOSED WEATHER ENABLING SYSTEMS FOR TRAFFIC NETWORK MOBILITY APPLICATIONS

Queue Warning

The queue warning connected vehicle safety application provides vehicle operators sufficient warning of impending queue backup in order to brake safely, change lanes, or modify route such that secondary collisions can be minimized or even eliminated. Connected vehicle road weather data will allow the queue warning application to incorporate weather effects on all aspects of conditions that lead to queue back up. For instance, queue warning algorithms would need to change if adverse weather conditions are added to daily recurring congestion caused by bottlenecks. Connected vehicle road weather information would be able to produce the road surface coefficient of friction, which will give more accurate warnings tailored to weather condition.

Speed Harmonization

The speed harmonization connected vehicle safety application dynamically adjusts and coordinate maximum appropriate vehicle speeds in response to downstream congestion, incidents, and weather or road conditions in order to maximize traffic throughput and reduce crashes. Connected vehicle road weather data will give the speed harmonization holistic weather information that can better consider the effects of weather on roadways. Therefore, safer speeds will be able to be issued and during adverse weather.

Cooperative Cruise Control

The objective of cooperative adaptive cruise control (CACC) is to dynamically and automatically coordinate cruise control speeds among platooning vehicles in order to significantly increase traffic throughput. By tightly coordinating in-platoon vehicle movements, headways among vehicles can be significantly reduced, resulting in a smoothing of traffic flow and an improvement in traffic flow stability. Additionally, by reducing drag, shorter headways can result in improved fuel economy and provides the environmental benefits of lowered energy consumption and reduced greenhouse gas emissions. CACC needs connected vehicle road weather information in order to consider adverse weather conditions effects on platooning speeds and proximities.

Data Acquisition Subsystem Weather Component

The description of the data acquisition subsystem is directed towards weather-related information for these applications. There may be additional subsystems used by these applications discussed elsewhere.

This subsystem is made up of several different sources. These sources include connected vehicles, with their associated onboard equipment and the necessary roadside infrastructure. Two classes of connected vehicle are anticipated for the application: (1) vehicles operated by the general public and commercial entities (including passenger cars and trucks) and (2) specialty vehicles and public fleet vehicles (such as snowplows, maintenance trucks, and other agency pool vehicles). It is assumed that passenger cars and commercial trucks will provide data elements specified in BSM Parts 1 and 2 (including the weather-related data elements in BSM Part 2), while agency-controlled vehicles will provide these data elements and, optionally, additional data elements from specialty sensors installed on selected vehicles (e.g., sensors to measure salinity at the roadway surface).

Non-mobile data on roadway segments will be provided by MADIS, which ingests data from RWIS, other surface weather stations, radar, satellite, model forecasts, and from other comprehensive systems. Furthermore, data collected via CR programs will be incorporated and will increase the timeliness and concentration of weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

Data Processing Subsystem Weather Component

The description of the data processing system is directed towards weather-related information for these applications. There may be additional systems not pertaining to weather that are used by these applications and discussed elsewhere.

Connected vehicle road weather data will be communicated via data backhaul to a VDT. The VDT 4.1 will create highly detailed weather and road condition outputs based on data input. Vehicle-based data (timestamp, latitude, longitude, air temperature, air pressure, speed, brakes, ABS status, traction control event, wiper status, dew point temperature, surface temperature) and weather data from additional sources will be used to perform quality checks on the information processed. The VDT 4.1 uses the granularity of surface weather conditions from connected vehicles combined with existing weather models and observations to create hazard datasets. The hazard datasets include near real-time and forecasted weather and road conditions specific to road segments. The hazard datasets can then improve CV application functionality pertaining to road weather.

Integrated modeling for road weather condition prediction will also be incorporated into these applications. Quality checked connected vehicle data from backend systems, archived weather and road data, as well as other data sources needed for probabilistic information will be communicated through integrated modeling. The data will be quality checked and processed by probabilistic models and algorithms to consider random variables (e.g., car accidents, traffic, and work zones).

User Interface System

User interface systems for these applications have been identified elsewhere.

Operational Policies and Constraints

Data Availability

The effectiveness of these systems is predicated on the availability of connected vehicle road weather information. This assumes a broad penetration of connected vehicle onboard equipment into the national vehicle fleet and the availability of an appropriate roadside and data backhaul infrastructure. It further assumes the willingness of state and local agencies to deploy connected vehicle devices and potentially other specialty sensors into the vehicles under their control. Additional research will clarify the levels of agency and general fleet penetration required to generate sufficient data for the application to work effectively.

In addition, in this application, data is especially desired in advance of predicted winter storms and during other severe winter weather events. During these periods, drivers may be encouraged and inclined to avoid travel, which may affect the availability of the required road weather data.

Deployment Coverage

A sufficiently dense network of roadside equipment with adequate geographic coverage will be required to gather connected vehicle road weather data that is effective for the concept. This will be particularly important in areas of complex terrain or where information on short roadway segments is desired.

Modes of Operation for Weather Components

The typical modes of operation for the road weather system components of these applications of these are—

- **Normal Mode.** In the normal operating mode, road weather components will be available to the application, with all designed functionality available.
- **Degraded Mode.** In this mode, some functions are not working properly or may not be available. This could result from many different situations. In the event that connected vehicle road weather data are not available or the VDT is not functioning, the system will operate without connected vehicle road weather information.
- **Maintenance Mode.** During system maintenance, some subsystems and their functionality may not be available. This mode is similar to Degraded Mode, except that during Maintenance Mode it may be possible to bring the subsystems back into operation, if needed.

Users Classes, Other Involved Personnel, and Support Environment

This section has been identified and defined elsewhere.

CHAPTER 5. OPERATIONAL SCENARIOS

This chapter develops operational scenarios for each high-priority application identified earlier in the document. The operational scenarios (also referred to as *use cases*) describe the ways in which the application will operate from the perspective of a typical user. Each operational scenario clearly describes the problem or situation that it is intended to address. Users are introduced, and their interactions with the system and the outcomes they experience are described.

SCENARIO FOR THE ENHANCED MAINTENANCE DECISION SUPPORT SYSTEM

Description

In this scenario, connected vehicles, including participating winter maintenance vehicles, provide road weather information that is combined with other ESS, remote sensor, and meteorological model data form the inputs to the Enhanced MDSS. Outputs from the Enhanced MDSS are provided to state and local DOT winter maintenance personnel in the form of recommended treatment plans. In turn, the treatment plans are provided to the operators of snowplows and other winter maintenance vehicles.

Figure 11 illustrates the scenario for EMDSS.

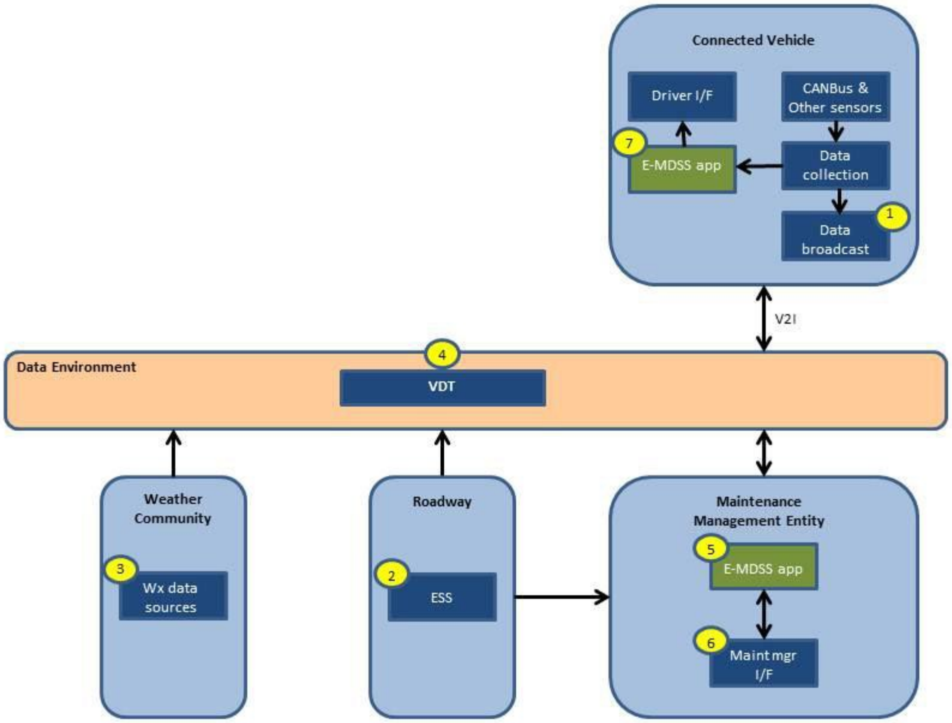


Figure 11. Scenario for the Enhanced Maintenance Decision Support System.

Source: Booz Allen Hamilton.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to the VDT within a data environment.

2. ESS and other remote sensor systems send data to the VDT.

3. The VDT acquires forecast and other meteorological model output data.

4. The VDT ingests data, performs quality checks, applies algorithms, and outputs advanced road segment data to an EMDSS application.

5. An EMDSS application ingests advanced roadway segment data from the VDT, develops enhanced forecasts and road condition predictions, and determines recommended treatments plans.

6. An EMDSS application outputs recommended treatment plans to a winter maintenance manager for approval.

7. Approved treatment plans are communicated to an in-vehicle EMDSS application in snowplows and other winter maintenance vehicles for use by the vehicle operator.

Enhanced System Scenario

The Integrated Modeling for Road Weather Condition Prediction system will be incorporated allowing the EMDSS application to ingest predictive and probabilistic information. The EMDSS will use that information for the outputs' recommended treatment plans to help prioritize approaches in management strategies. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR INFORMATION FOR MAINTENANCE AND FLEET MANAGEMENT SYSTEMS

Description

In this scenario, connected maintenance vehicles of state and local DOTs provide data on location, asset and resource usage, material usage, and vehicle performance to Maintenance and Fleet Management Systems. Output from these systems provides maintenance managers with the information needed for scheduling human resources, planning asset maintenance, budget planning and monitoring, life-cycle cost analyses, procurements, and purchasing decisions. Output from Maintenance and Fleet-Management Systems will also be used as input to the Enhanced-MDSS to identify the impacts of asset locations and the availability of winter treatment materials and chemicals on the recommended treatment plans.

Figure 12 illustrates the Scenario for Information for Maintenance and Fleet-Management Systems.

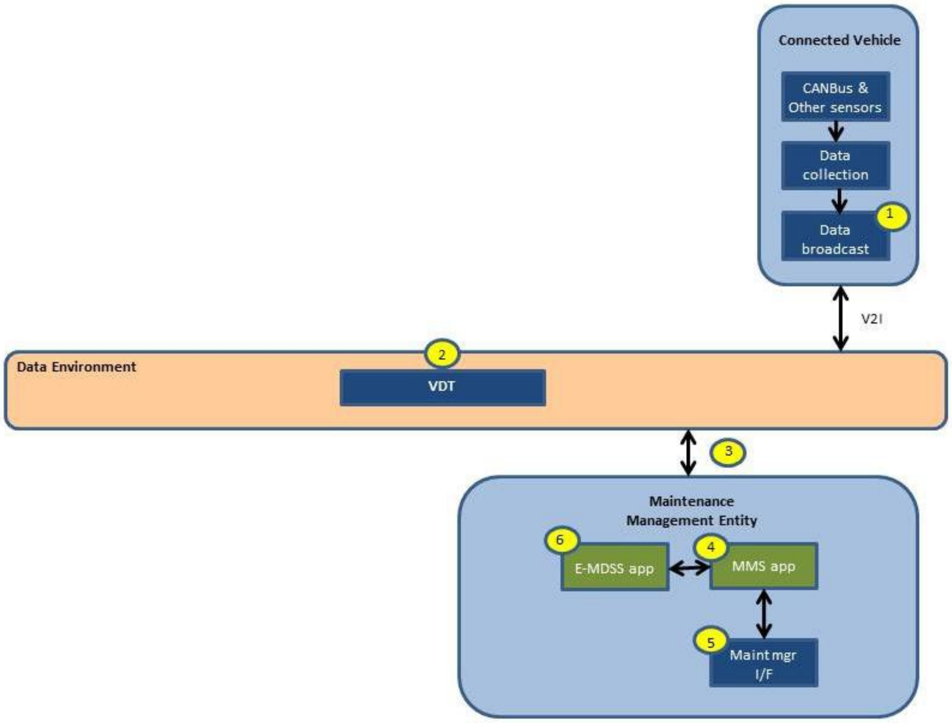


Figure 12. Scenario for Information for Maintenance and Fleet-Management Systems.

Source: Booz Allen Hamilton.

Steps

1. Connected maintenance vehicles broadcast position, vehicle status, and material usage data via roadside equipment to a data environment.
2. Data are aggregated and organized in the data environment.
3. The Maintenance management entity receives the aggregated information from the data environment.

4. A Maintenance and Fleet-Management Application within the maintenance management entity uses the data in algorithms to produce maintenance and fleet-management metrics.

5. Maintenance and fleet-management metrics are presented to maintenance managers via interfaces in existing Maintenance and Fleet-Management Systems for use in planning, scheduling, and decision-making tasks.

6. The Enhanced-MDSS acquires metrics from the Maintenance and Fleet-Management application as inputs to the development of winter storm response plans and strategies.

Enhanced System Scenario

The Integrated Modeling for Road Weather Condition Prediction system will be incorporated allowing Maintenance and Fleet Management Systems application to ingest predictive and probabilistic information. The Information for Maintenance and Fleet-Management Systems will use predictive and probabilistic information for outputs of recommended treatment plans to help prioritize approaches in management strategies as well as help with material distribution. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR VARIABLE SPEED LIMITS FOR WEATHER-RESPONSIVE TRAFFIC MANAGEMENT

Description

In this scenario, connected vehicles traveling on roadways upstream of a work zone provide location and road weather information to local and remote weather-responsive VSL applications. Locally processed data are displayed as a safe travel speed under the current road weather conditions on a roadside mobile speed trailer. With additional data inputs from ESSs, other remote sensors, and meteorological model outputs as well as additional processing through a weather-responsive VSL application at a remote location, refined speed advisories are sent to DMSs, work zone speed signs, and connected vehicle in-vehicle applications to advise motorists of safe speeds.

Figure 13 illustrates the scenario for information for maintenance and fleet management systems.

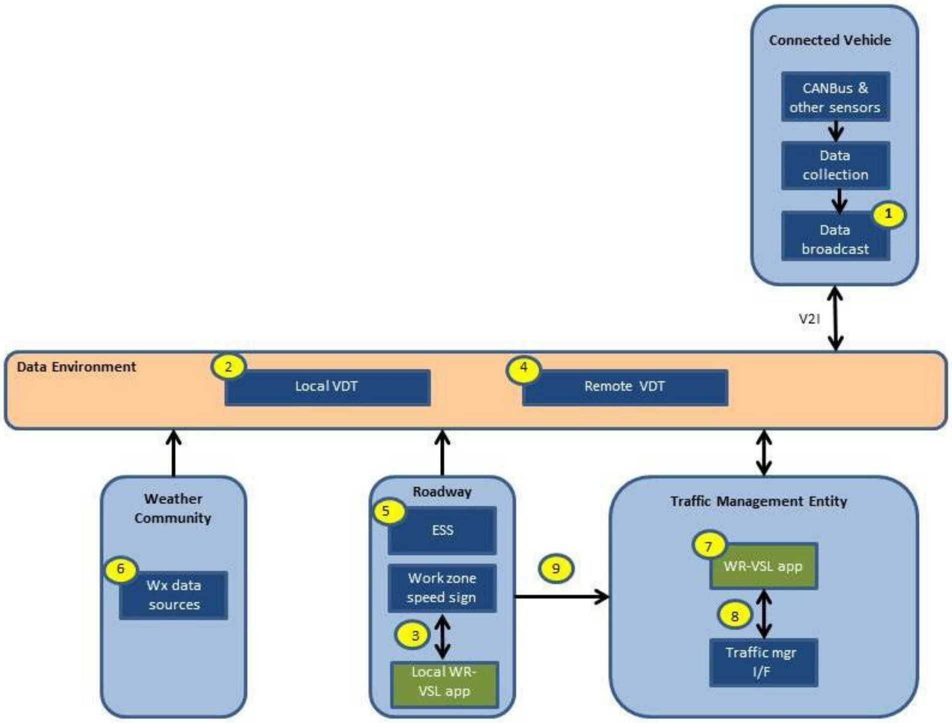


Figure 13. Scenario for Variable Speed Limits for Weather-Responsive Traffic Management.

Source: Booz Allen Hamilton.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a local VDT processor at the roadside.

2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a local weather-responsive VSL application.

3. The Local weather-responsive VSL application applies algorithms and outputs safe speed for display on a mobile work zone speed limit sign.

4. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to the remote VDT processor.

5. ESSs and other remote sensor systems send data to the VDT.

6. The VDT acquires forecast and other meteorological model output data.

7. The VDT ingests data, performs quality checks, applies algorithms, and outputs advanced road segment data to a weather-responsive VSL application in a traffic management entity.

8. The weather-responsive VSL application applies algorithms and outputs recommended safe speed to a traffic manager for approval.

9. Approved safe speed recommendations are communicated to mobile work zone speed limit signs, DMSs, and connected vehicle in-vehicle signs.

Enhanced System Scenario

The Integrated Modeling for Road Weather Condition Prediction system could enhance this scenario by preemptively notifying connected vehicles about the speed limit adjustments. Furthermore, the application could also suggest alternate routes, which would create safer working environments for maintenance personnel and motorists. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR WEATHER-RESPONSIVE SIGNALIZED INTERSECTION

Description

In this scenario, connected vehicles traveling on roadways upstream of a suitably equipped signalized intersection provide location and road weather information to local and remote weather-responsive signal applications. Locally processed data are used to determine adjustments to intervals in the signal cycle under the current road weather conditions, which are then implemented by the traffic signal controller. With additional data inputs from ESSs, other remote sensors, and meteorological model outputs as well as additional processing through a weather-responsive signal application at a remote location, appropriate special signal timing plans are selected and implemented through the traffic signal controller.

Figure 14 illustrates the scenario for a weather-responsive signalized intersection.

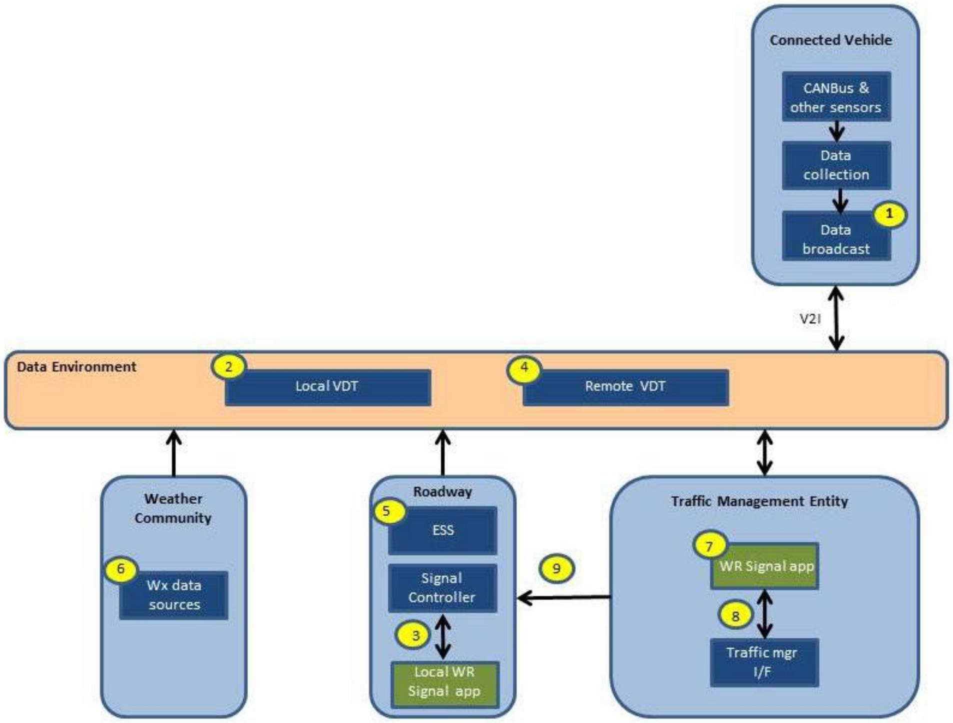


Figure 14. Scenario for Weather-Responsive Signalized Intersection.

Source: Booz Allen Hamilton.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a local VDT processor at the roadside.

2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a local weather-responsive signal application.

3. The local weather-responsive signal application applies algorithms and outputs adjusted signal intervals to the traffic controller.

4. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to the remote VDT processor.

5. ESSs and other remote sensor systems send data to the VDT.

6. The VDT acquires forecast and other meteorological model output data.

7. The VDT ingests data, performs quality checks, applies algorithms, and outputs advanced road segment data to a weather-responsive signal application in a traffic management entity.

8. The weather-responsive VSL application applies algorithms and outputs recommended special signal timing plan to a traffic manager for approval.

9. The approved signal timing plan is communicated to the traffic signal controller.

Enhanced System Scenario

With system enhancements, the weather-responsive signalized intersection application would incorporate the ability to create probabilistic and predictive information. This information could be used to run preemptive, hypothetical outcomes for adjusting the signal timing. Traffic signal controllers could run tests until they have the optimal timing for that specific weather condition. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR THE WEATHER-RESPONSIVE RAMP METERING APPLICATION

Description

Add figure

In this scenario, connected vehicles traveling on roadways that enter and exit through a ramp provide location and road weather information to local and remote weather-responsive ramp metering applications. Locally processed data are displayed as a warning light, safe travel speed, or a change in signal timing under the current road weather conditions on a roadside mobile speed trailer or a ramp control signal. With additional data inputs from ESSs, other remote sensors, and meteorological model outputs as well as additional processing through a weather-responsive ramp metering application at a remote location, refined speed advisories are sent to DMSs, ramp control signals, and connected vehicle in-vehicle applications to advise motorists of safe speeds or warnings.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a local VDT processor at the roadside.
2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a local weather-responsive ramp metering application.
3. The Local weather-responsive ramp metering application applies algorithms and outputs safe speed or warning for display on a limit sign or a ramp control signal.
4. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to the remote VDT processor.
5. ESSs and other remote sensor systems send data to the VDT.
6. The VDT acquires forecast and other meteorological model output data.
7. The VDT ingests data, performs quality checks, applies algorithms, and outputs advanced road segment data to a weather-responsive ramp metering application in a traffic management entity.
8. The weather-responsive ramp metering application applies algorithms and outputs recommended safe speed of a new signal timing pattern to a traffic manager for approval.
9. Approved safe speed recommendations or signal timing patterns are communicated to ramp metering signals speed limit signs, DMSs, and connected vehicle in-vehicle signs.

Enhanced System Scenario

With system enhancements, the weather-responsive ramp metering application would incorporate the ability to create probabilistic and predictive information. This information could be used to run preemptive, hypothetical outcomes from historical data, which would adjust the signal timing. Traffic signal controllers could run tests until they have the optimal timing for that specific weather condition. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR THE PROPOSED WEATHER-RESPONSIVE LANE-USE RESTRICTION APPLICATION

Description

Add figure

In this scenario, connected vehicles provide location and road weather information to a weather-responsive lane-use restriction application. The weather-responsive lane-use restriction application use algorithms to process the data and issue information on lane closures or lane restrictions to participating connected vehicle drivers. The weather-responsive lane-use restriction application also assimilates the connected vehicle data with road condition and meteorological data from other sources to produce roadway segment-specific lane-use restrictions that are communicated to participating users and connected vehicle drivers.

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a weather-responsive lane-use restriction application.

3. The weather-responsive lane-use restriction application applies algorithms and outputs messages on lane-use restrictions to in-vehicle systems in participating connected vehicles.

4. ESSs and other remote sensor systems send data to the VDT.

5. The VDT acquires forecast and other meteorological model output data.

6. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the weather-responsive lane-use restriction application in a traffic management entity.

7. The weather-responsive lane-use restriction application applies algorithms and outputs messages on lane-use restrictions to a traffic manager for approval.

8. The approved lane-use restrictions are communicated to participating entities for onward distribution to their users or subscribers.

Enhanced System Scenario

With system enhancements, the weather-responsive lane-use restriction application would process additional data, like road segment accident history, construction schedules, etc. The data will be processed with the prediction's probabilistic and predictive algorithms, which will then be incorporated into quality checks, and outputs for weather-responsive lane-use restrictions. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR MOTORIST ADVISORY AND WARNING SYSTEM

Description

In this scenario, connected vehicles provide location and road weather information to a Motorist Advisory and Warning System application. The Motorist Advisory and Warning System application use algorithms to process the data and issue short time horizon advisories and warnings to participating connected vehicle drivers. The Motorist Advisory and Warning System application also assimilates the connected vehicle data with road condition and meteorological data from other sources to produce roadway segment-specific medium and long time horizon advisories and warnings that are communicated to participating users and connected vehicle drivers.

Figure 15 illustrates the scenario for the Motorist Warning Advisory and Warning System.

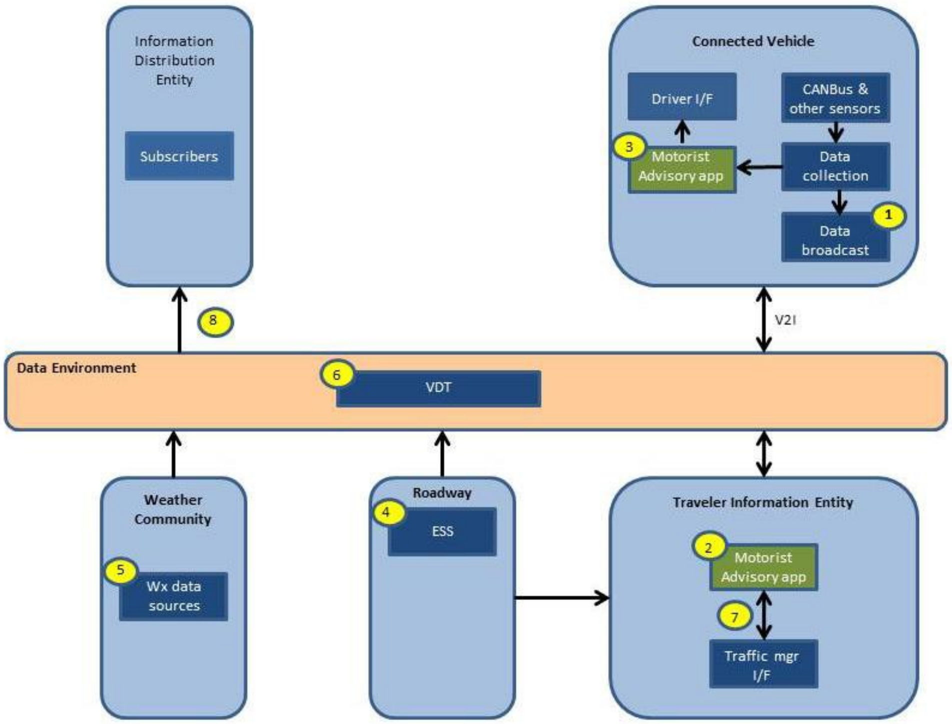


Figure 15. Scenario for Motorist Advisory and Warning System.

Source: Booz Allen Hamilton.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a Motorist Advisory and Warning System application.

3. The Motorist Advisory and Warning System application applies algorithms and outputs short time horizon advisories and warning to in-vehicle systems in participating connected vehicles.

4. ESSs and other remote sensor systems send data to the VDT.

5. The VDT acquires forecast and other meteorological model output data.

6. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the Motorist Advisory and Warning System application in a traffic management entity.

7. The Motorist Advisory and Warning System application applies algorithms and outputs medium and long time horizon advisories and warnings to a traffic manager for approval.

8. The approved medium and long time horizon advisories and warnings are communicated to participating entities for onward distribution to their users or subscribers.

Enhanced System Scenario

With system enhancements, the Road Weather Advisory and Warning System application would process additional data, like road segment accident history, construction schedules, etc. The Motorist Advisory and Warning application will process the data with the prediction's probabilistic and predictive algorithms. This will then be used in advisories and warnings to help drivers of connected vehicles anticipate dangerous road conditions. It would also immediately adjust route guidance by finding safer and faster alternatives. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR ROAD WEATHER PERFORMANCE MANAGEMENT APPLICATION

Description

In this scenario, connected vehicles, including participating winter maintenance vehicles, provide road weather information combined with other ESS, remote sensor, meteorological model data, as well as archived data form the inputs to the weather performance management application. Outputs from the performance management application are provided to state and local DOTs to help evaluate their performance and identify areas of improvement. In the scenario, the performance management application evaluates EMDSS during winter operations by comparing average traffic speeds and delays with archived data for similar weather events.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to the VDT within a data environment.
2. ESSs and other remote sensor systems send data to the VDT.
3. The VDT acquires forecast and other meteorological model output data.
4. The VDT ingests data, performs quality checks, applies algorithms, and outputs advanced road segment data to the weather performance management application
5. The application ingests historic data of approved treatment plans that EMDSS application has used.
6. The application evaluates archived data with the data ingested to compare application performance.
7. The weather performance management application outputs a comparative report and, if necessary, recommendations on how to improve EMDSS performance.

Enhanced System Scenario

Since the performance management application evaluates application, the integrated modeling for the road weather condition prediction system will be evaluated along with the application that it is enhancing. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR INFORMATION FOR FREIGHT CARRIERS

Description

In this scenario, connected vehicles of all types provide location and road weather information to a Road Weather Advisory and Warning System for Freight Carriers application. The Road Weather Advisory and Warning System for Freight Carriers application use algorithms to process the data and issue short time horizon advisories and warnings specifically to participating truck drivers. The Road Weather Advisory and Warning System for Freight Carriers application also assimilates the connected vehicle data with road condition and meteorological data from other sources to produce roadway segment-specific medium and long time horizon advisories and warnings that are communicated to participating trucking firms or their service providers for integration with other routing, scheduling, or restriction information to create information that is relevant to the needs of motor carriers.

Figure 16 illustrates the scenario for information for freight carriers.

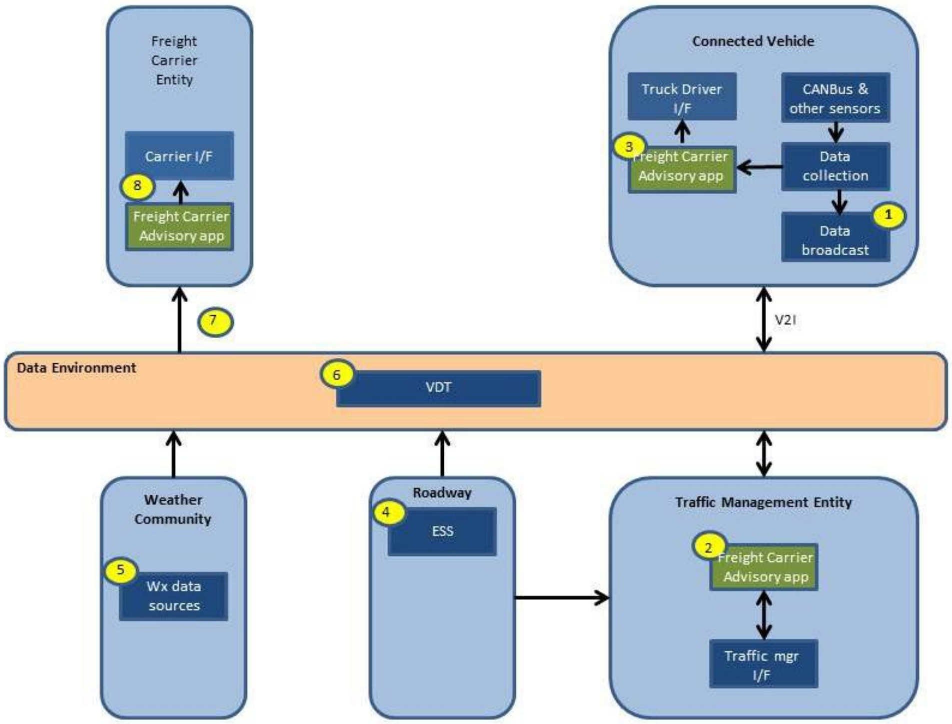


Figure 16. Scenario for Information for Freight Carriers.

Source: Booz Allen Hamilton.

Enhanced System Scenario

With system enhancements, the Information for Freight Carriers application will be able to incorporate probabilistic and predictive information to help find the optimal route specifically for freight carriers. If a freight carrier is notified that extreme weather is approaching the route, it may be advantageous to a take an alternative route. However the alternative route still has a chance of being affected by the storm within the timeframe of the journey. Furthermore, the tertiary route has multiple work zones which will delay the trip and, due to time sensitivity, a fourth route is not an option. Therefore, the integration of the prediction system will identify the route with the highest probability of successfully reaching the destination in the desired timeframe. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

Steps

1. Connected vehicles of all types broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.
2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to a Road Weather Advisory and Warning System for Freight Carriers application.
3. The Road Weather Advisory and Warning System for Freight Carriers application applies algorithms and outputs short time horizon advisories and warning to in-vehicle systems in participating trucks.
4. ESSs and other remote sensor systems send data to the VDT.
5. The VDT acquires forecast and other meteorological model output data.
6. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to systems operated by motor carriers or their service providers for additional processing in a freight carrier entity.
7. Freight carrier applications assimilate additional data relating to schedule and routing restrictions, apply algorithms, and output medium and long time horizon advisories and warnings specific to the needs of participating carriers.

The approved medium and long time horizon advisories and warnings are communicated to participating motor carriers for distribution to their drivers.

SCENARIO FOR INFORMATION AND ROUTING SUPPORT SYSTEM FOR EMERGENCY RESPONDERS

Description

In this scenario, connected vehicles of all types provide location and road weather information to an Information and Routing Support System for Emergency Responders application. The Information and Routing Support System for Emergency Responders application use algorithms to process the data and issue short time horizon advisories and warnings specifically to participating emergency vehicles. The Information and Routing Support System for Emergency Responders application also assimilates the connected vehicle data with road condition and meteorological data—including, in particular, wind and roadway flooding data—from other sources to produce roadway segment-specific medium and long time horizon advisories and warnings that are communicated to participating emergency service providers or their service providers for integration with other routing and scheduling information to create information that is relevant to the specific needs of emergency responders.

Figure 17 illustrates the scenario for Information and Routing Support System for Emergency Responders.

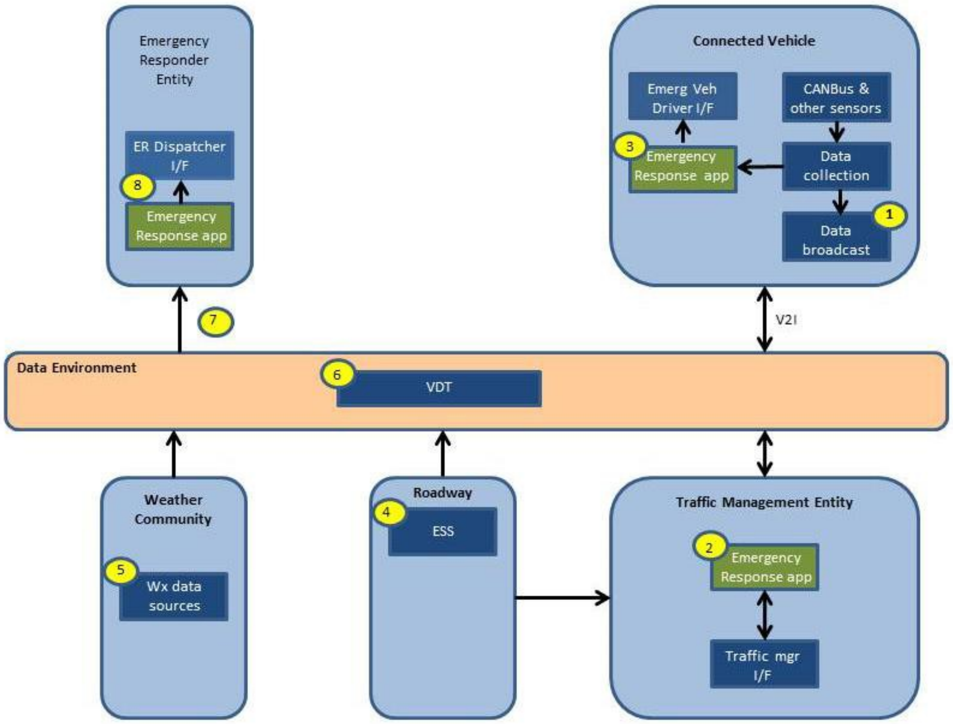


Figure 17. Scenario for Information and Routing Support System for Emergency Responders.

Source: Booz Allen Hamilton.

Steps

1. Connected vehicles of all types broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. The VDT ingests data, performs quality checks, applies algorithms, and outputs near-real-time road segment data to an Information and Routing Support System for Emergency

Responders application operated by an emergency responder or its service provider in an emergency response entity.

3. The Information and Routing Support System for Emergency Responders application applies algorithms and outputs short time horizon advisories and warning to in-vehicle systems in participating emergency vehicles.

4. ESSs and other remote sensor systems send data, including wind and roadway flooding data, to the VDT.

5. The VDT acquires forecast and other meteorological model output data.

6. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the Information and Routing Support System for Emergency Responders for additional processing in the emergency response entity.

7. The Information and Routing Support System for Emergency Responders application assimilates additional data relating to roadway restrictions caused by weather events, emergency vehicle routing, response times, and availability of emergency responders in neighboring jurisdictions; applies algorithms; and outputs medium and long time horizon advisories and warnings specific to the needs of the emergency responder.

8. Approved medium and long time horizon advisories and warnings are communicated to participating emergency response dispatchers for onward distribution to emergency vehicle drivers.

Enhanced System Scenario

With system enhancements, the Information and Routing Support System for Emergency Responders will be able to incorporate and predict information to help find optimal routes specifically for emergency responders. The application will consider departure time as well as weather and traffic conditions to allow the dispatchers to identify best routes. This information will give responders the fastest routes to their destinations and avoid routes with accidents and other delaying variables. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR ROAD WEATHER MODULE FOR AUTOMATED VEHICLE APPLICATIONS

Description

In this scenario, connected and automated vehicles provide location and road weather information to the VDT and WxDE. This data is then processed with other data sources (such as Radar, NWS, RWIS) and quality checked before being provided as input to the AVAW-DSS. The application then uses algorithms to process the data and issue control action outputs to the vehicles based on the vehicle's level of automation and state. As a result, road weather safety will be enhanced if these automated vehicles are connected and share information with one another and infrastructure, particularly under adverse weather conditions.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. ESSs and other remote sensor systems send data to the VDT.

3. The VDT acquires weather forecasts and other meteorological model output data.

4. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the Motorist Advisory and Warning System application in a traffic management entity.

5. The Motorist Advisory and Warning System application applies algorithms and generates short time horizon advisories and warnings. All these data sets feed into the AVAW-DSS application.

6. The AVAW-DSS applies algorithms to the data items described in previous steps to generate control action outputs for automated vehicles operating in adverse weather conditions. These control actions will be tailored to the level of automation and the current state of the automated vehicle (under semi-manual or fully automated mode). In the case of a fully automated vehicle, the control actions are directly implemented by the vehicle automatically.

Enhanced System Scenario

With system enhancements, the AVAW-DSS application could automatically alter route in real time to avoid adverse road weather conditions (black ice, high winds, etc.) and incidents. The AVAW-DSS will process the data with the prediction's probabilistic and predictive algorithms to provide upfront trip recommendations to the user so he or she can decide to wait out a storm or choose an alternate route to get to the destination. For example, consider a situation in which an older adult is using an automated vehicle to get to a health care facility. When the individual enters the vehicle and inputs the destination information, the AVAW-DSS checks with the forecasted and predicted road weather conditions in real time based on data available. If the conditions are clear, the vehicle will proceed to the destination as requested. However, if the predicted conditions are too severe for the vehicle to operate safely, the AVAW-DSS will recommend that the user re-schedule the trip or can even provide alternate recommendations to visit other healthcare facilities on safer routes. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR ROAD WEATHER COMPONENT OF V2I SAFETY APPLICATIONS

Description

In this scenario, connected and automated vehicles provide location and road weather information to the VDT. This data is then processed with other data sources (such as Radar, NWS, RWIS) and quality checked before being provided as input to the V2I Safety Applications. The applications then uses algorithms to process the data and issue control action outputs to the vehicles. As a result, connected vehicle safety applications will be enhanced during adverse weather conditions.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. ESSs and other remote sensor systems send data to the VDT.

3. The VDT acquires weather forecasts and other meteorological model output data.

4. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the Motorist Advisory and Warning System application in a traffic management entity.

5. The Motorist Advisory and Warning System application applies algorithms and generates short time horizon advisories and warnings. All these data sets feed into the V2I safety applications.

6. The V2I safety applications apply algorithms to the data items described in previous steps to generate appropriate action outputs in adverse weather conditions.

Enhanced System Scenario

With system enhancements, the V2I safety applications would incorporate the ability to create probabilistic and predictive information. This information could be used to run preemptive, hypothetical outcomes from historical data which would make V2I safety applications preemptively more effective in adverse weather conditions. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

SCENARIO FOR ROAD WEATHER COMPONENT OF TRAFFIC NETWORK MOBILITY APPLICATIONS

Description

In this scenario, connected and automated vehicles provide location and road weather information to the VDT. This data is then processed with other data sources (such as Radar, NWS, RWIS) and quality checked before being provided as input to the Traffic Network Mobility Applications. The applications then uses algorithms to process the data and issue control action outputs to the vehicles. As a result, connected vehicle mobility applications will be enhanced during adverse weather conditions.

Steps

1. Connected vehicles broadcast position and data that can be used to determine road and weather conditions via roadside equipment to a VDT processor.

2. ESSs and other remote sensor systems send data to the VDT.

3. The VDT acquires weather forecasts and other meteorological model output data.

4. The VDT ingests additional data, performs quality checks, applies algorithms, and outputs advanced road segment data to the Motorist Advisory and Warning System application in a traffic management entity.

5. The Motorist Advisory and Warning System application applies algorithms and generates short time horizon advisories and warnings. All these data sets feed into the Traffic Network Mobility Applications.

6. The Traffic Network Mobility Applications apply algorithms to the data items described in previous steps to generate appropriate action outputs in adverse weather conditions.

Enhanced System Scenario

With system enhancements, the traffic network mobility applications would incorporate the ability to create probabilistic and predictive information. This information could be used to run preemptive, hypothetical outcomes from historical data which would make traffic network mobility applications preemptively more effective in adverse weather conditions. Additionally, data from CR programs will refine weather and road condition information, improving data inputs to and enhancing the functionality of all related CV applications.

CHAPTER 6. SUMMARY OF IMPACTS

This chapter provides a summary of key impacts identified during the project.

OPERATIONAL IMPACTS

Among the operational concepts identified and described in this document, several operational impacts have been identified:

- **Need for a Connected Vehicle Infrastructure:** Operational impacts will include the need to deploy, operate, and maintain the connected vehicle field infrastructure; the in-vehicle components in state and locally owned vehicles, including snowplows; and the associated data communications and processing systems. Motor carriers and emergency responders participating in the relevant operational concepts will be required to implement the appropriate in-vehicle components in their vehicles.
- **Implementation of New Systems:** Required new systems will include the VDT and the various systems for each of the identified applications. Implementation of new systems will affect state and local agencies, service providers for motorist advisories and warnings, freight carriers and their service provides, and emergency responders and their service providers.
- **Changes to Existing Systems:** The operational concepts indicate that changes would be required to the existing federal prototype MDSS, existing fleet and maintenance management systems, existing traffic-management systems for the VSL application, and the existing dispatching systems of freight carriers and emergency responders. It is assumed that further enhancements to the VDT would be required to accommodate the applications described in this document.
- **New Data Sources and Data Processing Capabilities:** Each operational concept relies on the availability of connected vehicle data. In addition, other sources of road weather and meteorological data are generally required by the applications. Weather information from MADIS will not be updated until it is fully operational in 2016. In the meantime, sources of data from ESSs and other weather sources will be used.
- **New Operational Procedures:** The new capabilities that will emerge from proposed applications will demand the development of new operational procedures by state and local agencies, emergency responders, and potentially by freight carriers. In particular, the new applications suggest new maintenance procedures (including winter maintenance procedures); new procedures for asset management, budgeting, purchasing, and purchasing decisions within maintenance organizations; new traffic-management procedures relating to weather-responsible VSLs and motorist advisories and warnings; and new dispatching procedures for emergency responders and, potentially, freight carriers.

- **New Training Requirements:** New systems within the maintenance and traffic-management organizations of state and local agencies and emergency responder organizations infer the need for additional training in the use of the systems.
- **Adapting to Climate Change:** The efficient functioning of the applications listed in this document will become more critical when transportation systems are stressed during more frequent or severe weather events. Climate change resilience involves traffic management strategies that decrease the impact of these events. Connected vehicle data will need to be ingested into existing systems in order to enhance agency adaptation strategies.

ORGANIZATIONAL IMPACTS

Among the operational concepts identified and described in this document, the following organizational impacts have been identified:

New Interactions Among Public Agencies: The applications described in this document identify expanded interactions among divisions within state and local transportation agencies, particularly between maintenance management and traffic-management entities, to support weather-responsive VSLs and motorist advisories and warnings. Expanded or new interactions among agencies are also indicated, such as between transportation agencies and emergency responders.

New Interactions with Private Entities: The applications identify several situations in which segment-specific road weather information is potentially provided to private-sector service providers in the areas of motorist advisories, freight information, and emergency responder information.

Improved resilience to climate change and extreme weather.

CHAPTER 7. ANALYSIS OF THE PROPOSED SYSTEM

This chapter provides an analysis of the benefits, limitations, advantages, and disadvantages of the proposed applications.

SUMMARY OF IMPROVEMENTS

The road weather connected vehicle applications will bring out transformative changes in the areas of safety, mobility, productivity, and reliability. Improvements that can be expected from the applications include:

- Improved driver awareness of road and weather conditions, leading to reduced crashes and fatalities.
- Improved information about current and forecasted road and weather conditions, allowing drivers to better plan trips and make informed decisions about taking or deferring trips.
- Improved ability by maintenance agencies to keep roadways clear and to improve road conditions during winter storms, leading to improved roadway safety and mobility for users.
- Improved information availability for maintenance agencies to make better decisions about asset and resource availability and scheduling, equipment maintenance, and equipment and materials purchasing or procurement, leading to greater agency efficiency and productivity.
- Improved ability to advise motorists on safe travel speeds during adverse weather conditions, especially in challenging situations such as work zones.
- Improved ability to respond to the specific road weather information needs of motor carriers, with consequent safety and productivity gains for freight carriers.
- Improved ability to respond to the specific road weather information needs of emergency responders, with consequent safety benefits to emergency vehicle drivers and better routing and response capabilities to emergency calls, with further potential to save lives.

DISADVANTAGES AND LIMITATIONS

This ConOps has identified road weather connected vehicle applications that are considered high priorities and merit further attention. Given the breadth of the applications, this document has been able to address each application at a high level. Additional definition of the applications will be required as the development process proceeds.

At this stage, two significant limitations have been identified that may affect further progress:

- **Need for Additional System Development:** Each application requires the development of new system capabilities, which will take time and investment. Additional development to add new capabilities to existing systems is also called for. Enhancements to the various maintenance management systems agencies use will be required. New data-processing capabilities and the necessary research and development of suitable algorithms to turn connected vehicle data and other road and weather data into meaningful and actionable information will be necessary. Suitable decision support tools for the various system users must also be developed.

- **Need for Close Interaction with New Stakeholder Communities:** Two of the identified applications will require a development effort that involves the deep participation of the freight carrier and emergency responder communities. Although the outreach efforts of the RWMP have started to engage these stakeholders, there will need to be a much expanded effort to more deeply understand the needs and capabilities of these groups from organizational, operational, and system availability standpoints.

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“Tools for Road Weather Management Benefits/Cost Analysis”

“UDOT Citizen Reporting Program”

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“Weather Data Environment Update”

“Weather Response Traffic Information System (WxTINFO)”

“Weather-Responsive Active Traffic Management”

“Weather-Responsive Regional Traveler Information System”

“Weather-Responsive Traffic Signal Control in Utah”

APPENDIX A. ACRONYMS

Acronym	*Definition*
ABS	Antilock Braking System
ATDM	Active Traffic and Demand Management
AVAW-DSS	Automated Vehicle in Adverse Weather – Decision Support System
BSM	Basic Safety Message
CANbus	Controller Access Network Bus
ConOps	Concept of Operations
CR	Citizen Reporting
CVS	Connected Vehicle System
DMA	Dynamic Mobility Applications
DMS	Dynamic Message Sign
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
DSS	Decision Support System
EMS	Emergency Medical Services
EnableATIS	Enable Advanced Traveler Information Systems
ESS	Environmental Sensor Station
ETA	Estimated Time of Arrival
FHWA	Federal Highway Administration
FRATIS	Freight Advanced Traveler Information System
HAR	Highway Advisory Radio
HAZMAT	Hazardous Material
I/F	Interface
INFLO	Intelligent Network Flow Optimization
IT	Information technology
MADIS	Meteorological Assimilation Data Ingest System
MDSS	Maintenance Decision Support System
MoPED	Mobile Platform Environmental Data
NCAR	National Center for Atmospheric Research
NOAA	National Oceanographic and Atmospheric Administration
NWS	National Weather Service
RWIS	Road Weather Information System

Acronym	*Definition*
RWMP	Road Weather Management Program
SAE	Society of Automotive Engineers
TOC	Traffic Operations Center
UI	User Interface
USDOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VDT	Vehicle Data Translator
VSL	Variable Speed Limit
WRTM	Weather-Responsive Traffic Management
Wx	Weather
WxDE	Weather Data Environment

APPENDIX B. DATA IN BSM PART 1 OR PART 2

System	Data Elements	BSM Part 1	BMS Part 2	Wx. Related
All Vehicles				
	Brake system status	X		
	Position (local 3D)	X		
	Vehicle size	X		
	Motion	X		
	Ambient air temperature		X	X
	Ambient air pressure		X	X
	Antilock Brake System active over 100 msec		X	X
	Exterior lights (status)		X	X
	Lights changed		X	X
	Rain sensor		X	X
	Road coefficient of friction		X	X
	Traction Control System active over 100 msec		X	X
	Wiper status		X	X
	Wipers changed		X	X
	Airbag deployment		X	
	Azimuth to obstacle on the road		X	
	Confidence-position		X	
	Confidence-speed/heading/throttle		X	X
	Confidence-time		X	
	Date/time of obstacle detection		X	
	Distance to obstacle on road		X	
	Hazard lights active		X	

	Level of brake application		X	
	Recent or current hard braking		X	
	Stop line violation		X	
	Throttle position (percent)		X	
	Vehicle data		X	
	Vehicle type (fleet)		X	
	Crash delta V			
	Estimated point of impact			
	Number of occupants			
	Occupant medical data			
	Occupant safety belt use			
	Owner ID			
	Toll payment			
	Vehicle fuel type			
	Vehicle ID			
	Vehicle log, including time, location, detection			
	Vehicle resting position			
Emergency Vehicles (only)				
	Light bar in use		X	
	Public safety vehicle responding to emergency		X	
	Siren in use		X	
	Approach road to intersection			
	Intended turning movement at intersection			
Freight Vehicles (only)				

	Descriptive vehicle identifier		X	
	Fleet owner code		X	
	HAZMAT status		X	
	Trailer weight		X	
	Vehicle height		X	
	Vehicle mass		X	
	Vehicle placarded as HAZMAT carrier		X	
	Vehicle type		X	
	Destination and stops			
	Electronic manifest			
	Load matching request			
	Pickup or dropoff time request			
Light Vehicles (only)				
	Cost			
	Departure location			
	Desired mode			
	Destination			
	Destination			
	ETA at destination			
	ETA for pickup			
	EVAC information request			
	Number of occupants in vehicle			
	Origin			
	Ride sharing response			
	Selected route and mode			
	Target arrival time			
	Target departure time			

Maint. Vehicles (only)				
	Maintenance activities			X
	Segment and lanes plowed			X
	Type and amount of road chemical applied			X
Transit Vehicles (only)				
	Connection protection request			
	Current itinerary			
	Passenger count			
	Status versus schedule			
	Transit service type			

APPENDIX C. J2735 SE AND WEATHER DATA

This table summarizes the responses to the USDOT request to incorporate weather data into J2735 SE. The responses align with the current (February 15, 2012) working draft version of the J2735 SE Design Document.

Sampling rate: The original USDOT request was for a sampling rate of 1 Hz. The sampling rate of the individual sensors within the vehicle is beyond the scope of the project. The intention behind the design is that the latest reading from the sensor is included in the snapshot of data. The rate at which snapshots are taken varies according to the vehicle movement and behavior. However, under default conditions, a snapshot will be taken at an interval that varies between 4 and 20 seconds.

Note: *NS* signifies that there is *No Sensor* in vehicles that measure this parameter, nor is it considered that there will be in the near future. Therefore, we do not see any reason to include this variable in J2735 SE.

Original Request from USDOT					Response	
Variable	Name	Description	Valid Range	Resolution	Current Included in J2735 v 2	Comments
Atmospheric Pressure	AtmosphericPressure	The force per unit area exerted by the atmosphere in 1/10ths of millibars, a.k.a. tenths of hectoPascals. A value of 65535 shall indicate an error condition or missing value.	650.0mb – 1200.0mb	INTEGER (0..65535)	Range 580-1090 Resolution 2hPA	This information was developed in conjunction with Noblis (A. Stern) and NCAR
Spot Wind Direction	WindDirection	The direction from which the wind is blowing measured in degrees clockwise from true North. A value of 361 shall indicate an error condition or missing value. The wind direction shall be corrected for vehicle movement.	0° - 359°	INTEGER (0..361)	NS	
Spot Wind Speed	WindSpeed	The wind speed in tenths of meters per second. The value of 65535 shall indicate an error condition or missing value. The wind speed shall be corrected for vehicle movement.	0.0 m/s – 250.0 m/s	INTEGER (0..65535)	NS	

Original Request from USDOT					Response	
Variable	Name	Description	Valid Range	Resolution	Current Included in J2735 v 2	Comments
Air Temperature	AmbientAirTemperature	The air temperature in tenths of degrees Celsius. The value 1001 shall indicate an error condition or missing value.	-100.0°C – 100.0°C	INTEGER (-1000..1001)	-40 to 150 deg C resolution 1 degree	
Dewpoint Temperature	AmbientDewpointTemp	The dewpoint temperature in tenths of degrees Celsius. The value 1001 shall indicate an error condition or missing value.	-100.0°C – 100.0°C	INTEGER (-1000..1001)	NS	
Solar Radiation	SolarRadiation	The ultraviolet, visible, and nearinfrared (wavelength of less than 3.0 micrometers) radiation hitting the earth's surface in watts per square meter. The value of 701 shall indicate a missing value.	0 W/m^2 – 700 W/m^2	INTEGER (0,701)	Arbitrary ranges from 0-7, with 0 = "Complete Darkness", 1 = "Minimal Sun Light", and 7 = "Maximum Sun Light".	Note that vehicle sensors are not quantitative and are used to turn on lights
Total Radiation	TotalRadiation (replaces SunSensor)	The average total radiation hitting the earth's surface in watts per square meter. The value of 1001 shall indicate a missing value.	0 W/m^2 – 1000 W/m^2	INTEGER (0,1001)		See above.
Visibility	Visibility	Surface visibility measured in tenths of a meter. The value 200001 shall indicate an error condition or missing value.	0.0 m – 20000.0m	INTEGER (0..200001)	NS	
Surface Temperature	SurfaceTemperature	The current pavement surface temperature in tenths of degrees Celsius. The value 2001 shall indicate an error condition or missing value.	-100.0°C – 200.0°C	INTEGER (-1000..2001)	NS	
Precipitation Indicator	PrecipYesNo	Indicates whether or not moisture is detected by the sensor. "Precip" equals moisture is currently being detected; "noPrecip" equals moisture is not currently being detected; "error" means the sensor is either not connected, not reporting, or is indicating an error.	N/A	INTEGER { precip (1), noPrecip (2), error (3)}	Arbitrary ranges from 0-7, with 0 = "no rain", 1 = Light mist, and 7 = Heavy Downpour.	Note this sensor is for rain and snow. Some sensors are resistors that are in contact with water, Others use changes of reflected light inside the windshield. Used for automatic wipers. Note that wiper status for both front and rear is included with a swipes per minute value
Rainfall or Water Equivalent of Snow	PrecipRate	The rainfall, or water equivalent of snow, rate in tenths of grams per square meter per second. The value of 65535 shall indicate an error condition or missing value.	0.0 – 11.0 $g/m^2/s$	INTEGER (0..65535)	NS	See above

Original Request from USDOT					Response	
Variable	Name	Description	Valid Range	Resolution	Current Included in J2735 v 2	Comments
Precipitation Situation	PrecipSituation (replaces RainSensor)	Describes the weather situation in terms of precipitation. Intensity meaning: • slight < 2mm/h water equivalent • moderate >= 2 and < 8 mm/h water equivalent • heavy >= 8 mm/h water equivalent	N/A	INTEGER { other (1), unknown (2), noPrecipitation (3), unidentifiedSlight (4), unidentifiedModerate (5), unidentifiedHeavy (6), snowSlight (7), snowModerate (8), snowHeavy (9), rainSlight (10), rainModerate (11), rainHeavy (12), frozenPrecipitationSlight (13), frozenPrecipitationModerate (14), frozenPrecipitationHeavy (15)}	NS	
Detected Friction	MobileFriction	Indicates measured coefficient of friction in percent. The value 101 shall indicate an error condition or missing value.	0 – 100	INTEGER (0..101)	0 (frictionless to 0.98 resolution 0.2 Note this may be NS in the near term as currently it is not available data	Note that the traction control, stability control and ABS activations each create an event snapshot. These event snapshots are given the highest priority for transmission. Additionally they are given the highest priority for retention when snapshots are being removed.
Roadway Water Level Depth	RoadwayWaterLevel	Indicates the depth of the water on the roadway in centimeters. The value 256 indicates an error or missing value.	0 cm – 255 cm	BYTE (0..256)	NS	See above
Adjacent Snow Depth	AdjacentSnowDepth	The depth of snow in centimeters on representative areas other than the highway pavement, avoiding drifts and plowed areas. The value 256 indicates an error or missing value.	0 cm – 255 cm	BYTE (0..256)	NS	See above
Roadway Snow Depth	RoadwaySnowDepth	The current depth of unpacked snow in centimeters on the driving surface	0 cm – 255 cm	BYTE (0..256)	NS	See above

Original Request from USDOT					Response	
Variable	Name	Description	Valid Range	Resolution	Current Included in J2735 v 2	Comments
Roadway Ice Thickness	RoadwayIceThickness	Indicates the thickness of the ice in millimeters. The value 256 shall indicate an error condition or missing value.	0 mm – 255 mm	BYTE (0..256)	NS	See above

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