

The Vision for Use of Connected Vehicle Data in Practical Road Weather Applications

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Executive Summary

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA) are jointly working to promote safety, mobility, and the environment on the nation's surface transportation system through a new connected vehicle initiative. This initiative is a multimodal effort to enable wireless communications among vehicles, the infrastructure, and passengers' personal communication devices. It will enhance Americans' safety, mobility, and quality of life, while helping to reduce the environmental impact of surface transportation.

The purpose of this document is to provide a short overview of the Vehicle Data Translator (VDT) software, a description of several possible applications for key potential end-users of the VDT, and a description of the data standards that are required in order for the mobile weather data to be useful for various road weather impact applications.

Specific examples are provided for an everyday driver, freight-haulers and truckers, emergency medical services, and the road maintenance community. In each case, the intent is to demonstrate how VDT information could alter how people operate in inclement road weather conditions in the future.

Chapter 1 Introduction

The U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA) and Research and Innovative Technology Administration (RITA) are jointly working to promote safety, mobility, and the environment on the nation's surface transportation system through a new connected vehicle initiative. This initiative is a multimodal effort to enable wireless communications among vehicles, the infrastructure, and passengers' personal communication devices. It will enhance Americans' safety, mobility, and quality of life, while helping to reduce the environmental impact of surface transportation.

In the near future, millions of vehicles (both public and private) will be connected and the logistical, mechanical, and environmental data from these vehicles will be communicated (vehicle-to-vehicle and/or vehicle-to-infrastructure), collected, and stored in order to provide diagnostic information of weather impacts to the surface transportation community. These data will include, but are not necessarily limited to, the following observations, which will likely change with changing weather:

- Directly Measured (Controller Access Network Bus [CANBus]) – air temperature, barometric pressure
- Mechanical (CANBus) – wiper status, Anti-lock Braking System (ABS) status, traction/stability control, differential wheel speed, steering angle
- Logistical (CANBus) – speed, location, elevation, heading
- Directly Measured (External) - pavement temperature, friction, salinity, freeze-point

Since 2009, the University Corporation for Atmospheric Research's (UCAR) National Center for Atmospheric Research (NCAR) has worked with FHWA and RITA to develop the Vehicle Data Translator (VDT) software which ingests, parses, processes, and quality checks mobile data observations (e.g., native and/or external) along with additional ancillary weather data (e.g., radar, satellite, fixed observations, and model data). The first two versions of this software were developed with data collected from vehicles in the Developmental Testbed Environment (DTE) during the winter and spring seasons of 2009 and 2010. Results from these studies were published in Drobot et al. (2010) and Chapman et al. (2010). The third version (VDT 3.0) is currently under development and will rely on vehicle observations from several USDOT funded projects (including the Integrated Mobile Data Collection and Application Demonstration Project) in addition to the data previously collected from the DTE experiments.

The purpose of this document is to provide a short overview of the VDT software, a description of several possible applications for key potential end-users of the VDT, and a description of the data standards that are required in order for the mobile weather data to be useful for various road weather impact applications. Information for this report was gathered at various meetings, workshops and conferences over the past year. Personal conversations and interviews with interested stakeholders were also conducted in order to gather useful and accurate information for this report.

Chapter 2 Overview of the Vehicle Data Translator

Figure 1 is a conceptual illustration of the VDT 3.0 software. The system will consist of three main modules (Stage 1, Stage 2, and Stage 3). Each stage provides output that can either be passed on to the next stage or outputted to the user. These stages provide progressively more sophistication to what is being analyzed and computed. The stages are briefly described in this section. For a more comprehensive review of VDT 3.0, please refer to NCAR (2011).

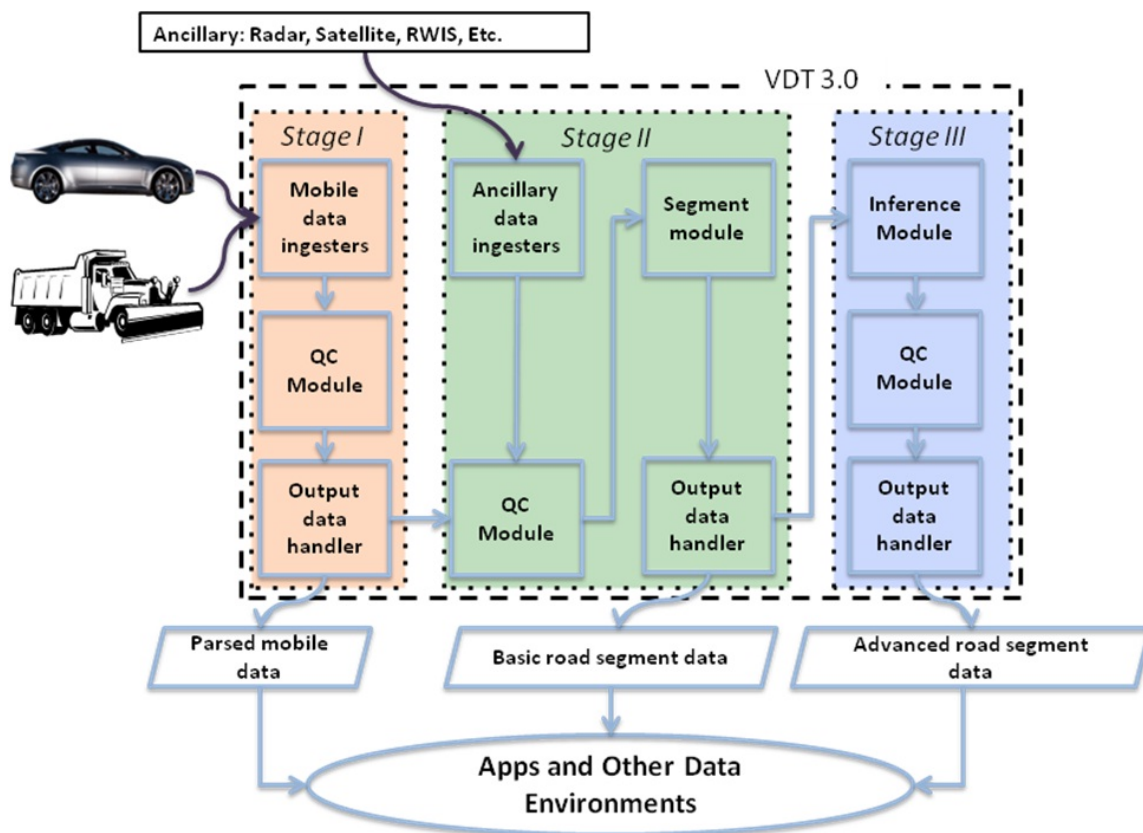


Figure 1. Schematic of VDT 3.0 data processing (image courtesy of UCAR).

Stage 1

The initial ingest of the mobile data occurs in this stage. Simple Quality Checking (QCh) is performed on the raw data before it is passed on to the output data handler. The QCh is performed to test for illogical location (e.g., latitudes greater than 90°N) or temporal (e.g., time-of-day greater than 23:59:59) information connected to the vehicle observation. Once the data passes the simple QCh, it

is passed on to the output data handler module where it is made available to the user and passed on to the next stage.

Stage 2

In Stage 2, ancillary weather data (e.g., radar, satellite, surface observations, and model data) are ingested for the more sophisticated QCh and analyses that are then performed. The QCh module in this stage performs QCh similar to that used in the *Clarus* system on fixed weather station observations. After QCh is performed, the data that passed are pushed on to the segment module, which computes road segment and gridded statistical information about the mobile data. All QCh'd mobile data as well as the road segment and gridded statistical data are then passed to the user and/or to Stage 3.

Stage 3

In Stage 3, the inference module employs various logical techniques (fuzzy logic, decision trees, etc.) to produce advanced road segment and gridded assessments. Diagnostic output for visibility, precipitation, and pavement condition (among other information) is then generated to provide impact information that is passed through one more QCh module. This final QCh module assigns a confidence value to the segment/grid assessment and then passes the assessment to the output data handler for dissemination to the final end-user.

Chapter 3 VDT and Connected Vehicle Applications

This section discusses how VDT and/or connected vehicle output might one day be used by a variety of user groups, including specific discussions for:

- Traveling Public
- Freight Haulers
- Emergency Medical Services (EMS) / First Responders
- Maintenance Decision Support System (MDSS) / Maintenance Management System (MMS)

VDT and Connected Vehicle Information for the Everyday Driver

Each year, around 24% of passenger vehicle crashes are weather-related, which results in an average of nearly 7,400 people killed and 673,000 injured (Pisano et. al 2008). In terms of economics, weather causes almost 25% of non-recurring traffic delays across the United States.

When assessing safety and efficiency on the roads, the traveling public already has access to several resources (e.g., 511 systems, traveler and/or traffic information). Although access to this information is becoming easier with increasing coverage and speed of the Internet, smart phones, and in-vehicle telematics technology, recent survey results suggest travelers are not currently obtaining much weather information while on the road (AMS 2011). Yet, these survey results clearly show a desire for weather information, more than even accident information.

With the research and development of the VDT, practical road weather impact information will be generated and passed along to the traveling public through the various communications and telematics channels. The weather information (e.g., slickness, visibility, precipitation type/rate) will be specific to the road surface and can be directly pushed to communications' infrastructure such as 511, in-vehicle communications devices, and smart phones (Figure 2). Content providers in the private sector can also use this information to provide tailored applications to the end-user including forecast traffic times, smart-routing, and forecasted road impacts and/or hazards.

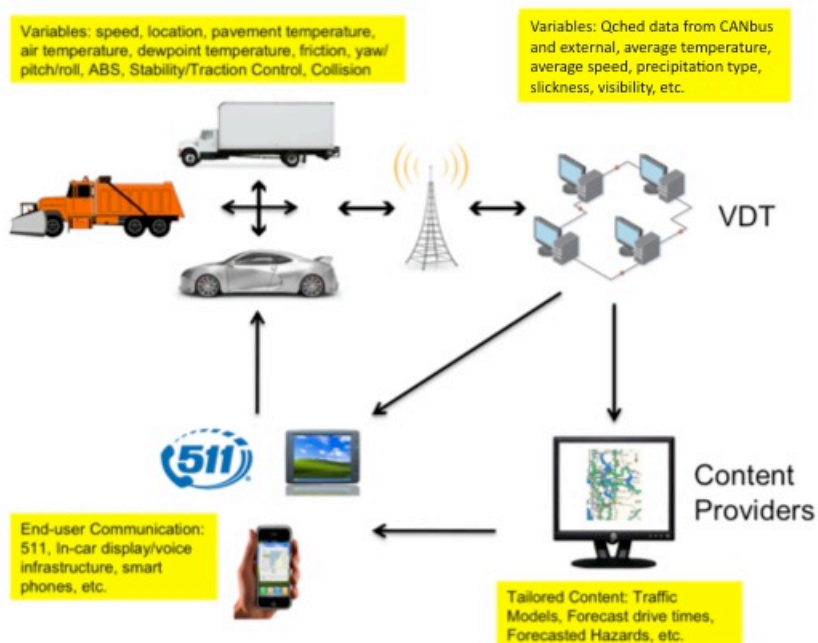


Figure 2. Flow diagram for information from connected vehicles and the VDT to the traveling public (image courtesy of UCAR).

Tactical Scenario

During an anticipated typical morning drive to work, Samantha embarks on her normal 30-minute commute. The morning is clear but cold. Along the commute, Samantha begins to encounter some light fog but the roads are dry and traffic is moving at usual speeds of 55-65 MPH. Two miles before she drives through a low river valley with a couple of small bridges and longer viaduct spanning the river, Samantha hears an audible warning of “Slow Down – Slick Roads in approximately two miles”. The audible warning was issued from the road hazard application installed on the car’s navigation equipment. Samantha responds to the alert and begins to steadily slow down. A few seconds later, another alert is sounded saying “Collision alert – 1.3 miles... take next exit for re-routing” and Samantha heeds the warning. She takes the exit and is advised to re-route to another set of roads. She is also told her expected time to her final destination will be delayed by approximately 20 minutes from her usual commute time. She stops and calls her work to let them know that she will be a few minutes late due to a wreck. After taking the new route, Samantha tunes into the local radio station in order to satisfy her curiosity as to what might have happened on her normal route. During the traffic report, the reporter explains that due to frost on the road and foggy conditions, four cars were involved in an accident on the viaduct and it is anticipated that traffic will be delayed by 1.5 to 2 hours. She is hopeful that everyone is okay, and relieved to have the connected vehicle re-routing information.

VDT and Connected Vehicle Information for Freight-haulers and Truckers

Weather impacts to the trucking/freight industry are significant in the United States. The Large Truck Crash Causation Study (LTCCS 2005) found that adverse weather was present in approximately 13 percent of the crashes studied. FHWA (2002) reported that across 281 metropolitan areas in the United States in 1999 over \$3 billion was lost due to weather-related freight shipping delays.

Through conversations with persons involved in shipping freight across the United States and information gathering at a workshop where freight-haulers were involved, the following is a list of relevant weather that produces negative impacts to the freight industry:

- Snow and Ice – slick roads and low visibility
- Heavy Rain – slick roads and low visibility
- Fog, Smoke, and Blowing dust
- High Winds
- Thunderstorms, Hail and Tornadoes
- Hurricanes

Having near real-time access to connected-vehicle information through the VDT and/or commercial applications will be critical in the future to provide useful weather information to the freight-haulers on impending impacts to trucking routes. Smart-routing around areas that will be highly impacted by adverse weather is needed to allow for the safe and efficient transport of goods across the country. On a daily basis, freight companies and independent truckers have to make critical go/no-go and routing decisions due to weather conditions that are sometimes several states away. Having real-time mobile observations from passenger vehicles and fellow freight-haulers combined with ancillary weather data from the VDT will allow much needed support for the complex decisions to be made.

With connected-vehicle information through the VDT, diagnostic information (such as segments with poor visibility or slick roads) would help support the critical decisions that freight companies and individual truckers must make. This information could be provided directly from the VDT to a communications portal for the truckers (such as 511) or to the private sector, which could tailor the information specifically to company or individual needs (Figure 3).

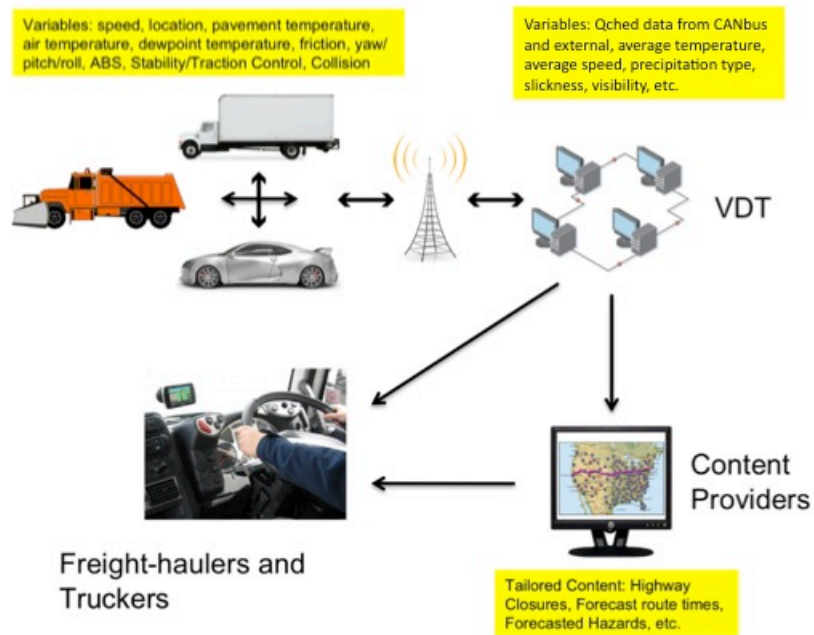


Figure 3. Flow diagram for information from connected vehicles and the VDT to freight-haulers and/or truckers (image courtesy of UCAR).

Tactical Scenario

Jerry is a long-haul trucker whose normal route is Interstate 80 from Chicago to the Port of Oakland. Upon approaching Cheyenne, he receives a high-wind alert from the National Weather Service over his NOAA Weather Radio for the stretch of I-80 between Laramie and Rawlins, Wyoming. Additionally, the load that he is carrying is lighter than normal. Jerry has six hours left of his 11-hour Federal Hours of Service allocation, which if he drove straight through would allow him to stop in Salt Lake City. He must make a decision: continue to Laramie and park or continue through to Rawlins and risk a blow-over. The road weather application that he uses on board his truck gives him tactical information regarding the weather (specifically the wind over that corridor) and the effects of that wind on like vehicles (with respect to profile and weight) over the past several hours. With no blow-overs reported and the wind forecast to not increase, Jerry decides to push through to Rawlins with Salt Lake City as his goal. His trip through the corridor was windy (as it normally is) but never hit critically unsafe thresholds. His decision was a good one and allowed him to park his rig in Salt Lake City for his required 10 hours of rest where his parking, lodging and eating choices are much more plentiful. His decision also eliminated a full day of unnecessary travel-time and cost on his way to the Port of Oakland.

VDT and Connected Vehicle Information for EMS

While there have not been a large number of studies which attempt to correlate safety and efficiency of EMS operations to inclement weather, Elling (1989) presented results from a four-year study between 1984 and 1988 which showed that around 25 percent of ambulance crashes occurred during poor weather and/or road conditions. This is consistent with the crash statistics for normal everyday drivers in later studies.

Emergency Medical personnel (First Responders) are highly impacted by adverse weather from both a tactical and strategic decision-making standpoint. The decisions that are being made vary across geographic regions and urban/rural environments. In the future, more work needs to be accomplished to better understand the complexity of the decisions being made by this user group. The following two subsections will discuss the uses of VDT data for both strategic and tactical decision support during weather impacted EMS operations. The information was gathered through discussion of experiences with members of the EMS community at conferences and workshops. The users worked almost exclusively in the urban environment. Therefore, the information provided is biased toward that environment as opposed to EMS operations in rural areas.

Tactical Decision Support

First responders and EMS groups are often deployed in adverse and treacherous weather conditions. Currently, the tactical information specific to the weather and traffic is sparse. The following is a list of weather situations that are highly impactful to this community:

- Winter weather – slick roads, poor visibility, cold temperatures, bridge frost
- Thunderstorms – lightning, heavy rain, poor visibility, flooded roadways
- Hurricanes – lightning, heavy rain, floods, strong winds, poor visibility
- Wildfires – strong winds, poor visibility, high temperatures, poor air quality
- Fog and blowing dust – poor visibility

Safety and efficiency to emergency calls is a huge concern for first responders. Currently tactical information of the status of the roadway is not readily available. During impactful winter weather conditions, a combination of a short-term pavement condition forecast, a diagnostic traffic product, and communications with the road agencies (e.g., which roads are plowed, which roads are closed) is necessary to provide a smart-routing application for this group. Often, ambulances get stuck in traffic during these types of events and response times are severely impacted. Other major short-term safety hazards include lightning during thunderstorms and hurricanes and poor visibility.

Overall, VDT information from surrounding passenger vehicles and other ambulances could provide tactical information for the first responders. In order for a fully useful decision support tool to be developed, work needs to be done, much like the initial work with MDSS, to assess the end-user needs of this group and leverage existing road weather technology to successfully provide tactical and strategic information during inclement weather (Figure 4).

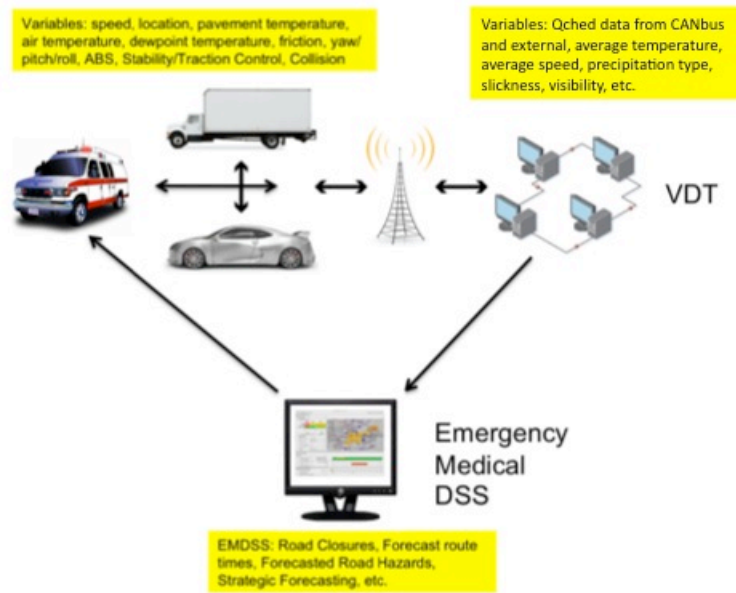


Figure 4. Flow diagram for information from connected vehicles and the VDT to EMS and first responders (image courtesy of UCAR).

Tactical Scenario

LifeSaver Ambulance is called to a 911 emergency approximately 10 miles away from the station. Heavy snow has been occurring for the past five hours and roads are slick. The usual call time for this distance is 12 minutes. The on-board tactical navigation application has the start and end point programmed and the paramedics head out on the call. The normal route for the ambulance would be along several city thoroughfares in the heart of the city. Traffic is normally not an issue because the city's traffic lights are equipped with ambulance detectors, which will switch the lights along the ambulance route to green prior to the ambulance entering the intersection. However, the navigation application immediately suggests an alternate route. The navigation system has the benefit of tracking where the city's plows have been since the snow started. The system can also track real-time speed of generic passenger vehicles. The normal route the ambulance would have taken had not been plowed in the previous three hours and the speeds on this route were 25% of the normal speed limit. The new "out-of-the-way" route suggests backtracking to the interstate, which had been plowed and speeds were down only 10%. The paramedic took the system's advice and while the ambulance arrived 2 minutes later than normal, the usual route would have caused a delay of more than 20 minutes, which in some circumstances is the difference between life and death.

Strategic Decision Support

Strategically accurate forecasts of adverse weather, such as hurricanes, blizzards and floods, are important because of the potential impact to staffing levels and pre-storm vehicle readiness. During major winter storms, decisions need to be made on proper timing for ambulance maintenance (e.g., snow chain installation) as well as necessary staff additions to make up for delayed call times. While the VDT and connected vehicle information will not provide direct information for strategic decision support, the assimilation of the observations (e.g., pavement temperature) into road impact models will indirectly benefit the forecast. A decision support system much like MDSS should be considered for research and development because of the complex weather and decision-making environment associated with this highly-impacted user group. The output from the VDT could be leveraged for such a system to provide more accurate road (and route) impact forecasts.

VDT and Connected Vehicle Information for Road Maintenance Community

MDSS is a single-platform decision support system that provides relevant weather, road-weather, and treatment recommendations to various end-users that are in charge of maintaining the pavement during winter operations. The system was developed with funding from USDOT FHWA and it has been widely deployed over many snow-affected states and some foreign countries over the past ten years.

Many states also use a version of MMS, which provides a platform for agencies to manage (and keep track of) resources, including personnel/labor, equipment, and material, used in snow-fighting. Noblis (2009) described a concept of operations for the sharing of information between MDSS and MMS. This document describes the benefits of VDT output for each of these stand-alone systems and then provides insight into the usefulness of the data for a scenario where data are being shared between MDSS and MMS.

MDSS Users

Currently, the federal prototype MDSS ingests Automatic Vehicle Location (AVL) information from snowplows. However, these data are merely used for display purposes. Federal projects are currently in the works to utilize the AVL infrastructure to transmit mobile observations, both native (e.g., Controller Access Network Bus (CANBus)) and external (e.g., pavement temperature, friction, salinity), directly into the VDT software for dissemination. The following road segment-based output from the VDT will be available for an MDSS to pass along to the end-user:

- Atmospheric weather variables – Air temperature, dewpoint, barometric pressure
- Road Weather variables – Pavement temperature, friction, salinity
- Non-weather variables – Average vehicle speed, percent of engaged ABS, percent of engaged stability/traction control
- Inferred variables – Slickness, visibility, precipitation rate and type

The atmospheric and road weather variables will also be beneficial for the back-end data assimilation into the various weather and pavement temperature models. This will enable the MDSS forecast to be

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more accurate in problem areas (such as complex terrain) and in areas with sparse surface observations. The addition of real-time mobile chemical sensors that measure salinity and/or freeze-point will provide valuable information that can be fed back into the MDSS system in order for the treatment recommendations to be optimized specific to the section of road that is to be treated.

MMS Users

There are many varieties of MMS systems, both homegrown by the agencies themselves and commercial off-the-shelf options. MMSs are generally software systems that track resources (e.g., material, equipment, labor) for the road maintenance departments. For an MMS to be successful, it relies on the input of high-quality data about expended resources and material as well as equipment readiness information (Noblis 2009). With existing AVL and the maturation of more sophisticated connected vehicle technology, valuable information (e.g. location, treatment rates and amounts,) pushed directly from maintenance vehicles into MMS types of systems is possible. All three phases of VDT-based connected vehicle information would be beneficial for an agency's MMS. The following non-weather connected vehicle (Stage 1) information would be beneficial to an MMS system:

- Vehicle trouble codes
- Oil pressure
- Fuel usage
- Miles and locations traveled
- Material used – types, amounts, and locations
- Speed

Technology is coming on line that can provide the road maintenance community with real-time information regarding the state of the pavement prior to treatment. These include systems that can measure the pavement temperature and chemical concentration from a mobile platform. After simple QC is performed on these observations, the MMS can track which sections of roads and/or bridges are dropping close to critical temperature ranges as well as which sections have adequate (or inadequate) residual chemical left over from previous treatments. Useful road weather information from Stage 1 of the VDT to an MMS for tactical purposes includes:

- Air Temperature
- Dewpoint Temperature
- Pavement temperature
- Friction measurements
- Salinity or Freeze-point measurements

Possible VDT-based (Stage 2 and 3) information from maintenance vehicles and surrounding connected passenger vehicles will provide valuable tactical information to an MMS. Some examples of these fields are included in the following:

- Average speeds
- Average pavement and air temperatures
- Slickness
- Precipitation type/rate
- Visibility

The combination of providing Stage 1 (raw observations) and Stage 2-3 (inferred observations) VDT-based information into an MMS would be ideal in providing the system with near real-time tactical

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information. A more strategic use of these observations in a data-sharing environment between MDSS and MMS is discussed in the next subsection.

MDSS-MMS Users

In an environment where the end-user has the benefit of both MDSS and MMS, and the two systems are able to share information, the VDT-based connected vehicle output will be useful for optimization of several key strategic parts of each system. The Noblis (2009) document summarized several features of integrating information from the two systems, including: feeding MMS inventory and procedural data into MDSS for improving road weather forecasts and treatment recommendations and feeding MDSS road treatment recommendations, actual treatments, and other real-time conditions into MMS to improve timeliness and accuracy of asset tracking.

The VDT-based connected vehicle data would help to improve the usefulness of the information exchange by providing improved tactical and strategic information from MDSS to the MMS system. Denser observations of pavement temperature, air temperature, and dewpoint temperature will likely improve the weather and road weather forecast generated by MDSS. This improved forecast will enable better decision support from a maintenance management perspective including the scheduling of labor and equipment for various activities (both winter and non-winter). The use of real-time mobile salinity and pavement temperature measurements will help to improve the treatment recommendations forecast from MDSS and also improve the management of material on the roadways. The potential benefits (economically and environmentally) of more accurate treatment recommendations and more efficient material usage, without sacrificing safety, are clear.

Inferred VDT-based information (Stage 2 and 3) will provide both systems with practical road impact information that can be used to better manage an agency's assets. If diagnostics such as precipitation type and road slickness are made available to an MMS, the manager of snow removal resources can be more efficient at moving the proper equipment and personnel to fight the weather. When these resources are moved to areas of greatest impact, the mobile observations around these areas will likely be timelier and the road weather forecasts from MDSS will benefit. Figure 5 is an illustration of the data exchange between connected vehicles, the VDT, and a shared information environment between MMS and MDSS.

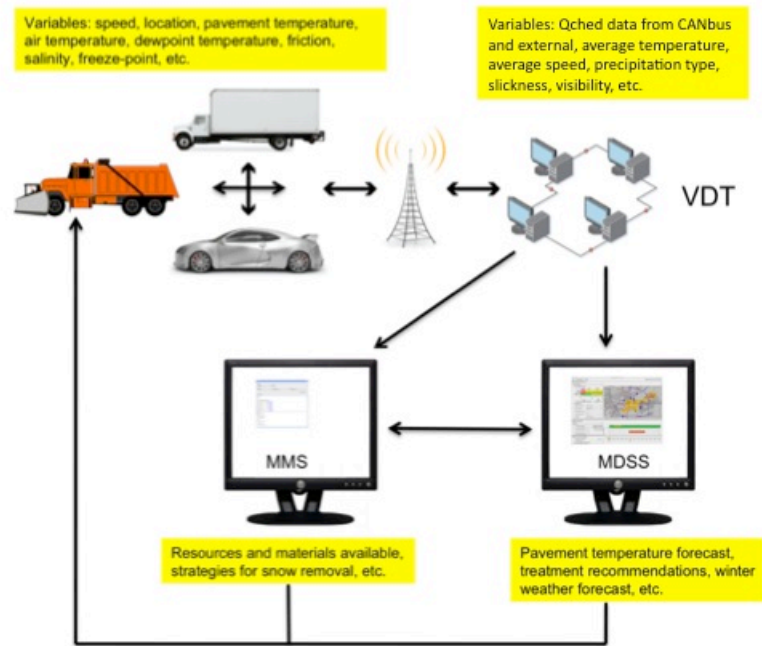


Figure 5. Flow diagram for connected vehicle and VDT information into MDSS and MMS systems (image courtesy of UCAR).

Tactical Scenario

Jose must decide whether or not to bring in an extra shift to pre-treat the roadways overnight. The skies are clear and temperatures are close to freezing. When looking at the temperature and dewpoint observations from trucks already out on the roads and the short-term forecast of pavement temperatures dipping just below freezing for bridges and elevated structures, he decides to activate an extra smaller shift of drivers to spot-treat for bridge frost. In the past, this situation would have warranted a full shift of drivers and full pretreatment of the roadways. However, with the tactical information from the plows and that information providing a more accurate tactical pavement forecast, Jose was able to call in a smaller shift of drivers, use less fuel and chemicals on the roadways, but still pre-treat the bridges which kept slick conditions from forming overnight.

Chapter 4 Mobile Weather Data Needs and Standards

In order for the output from the VDT to be useful, the following is a listing of data elements from the CANBus that are desired from all types of vehicles. This list is not exhaustive and does not include observations from after-market or external sensors.

Tier I (most important)

- External air temperature
- Barometric pressure
- Wiper status
- Headlight status (exterior lights)
- Accelerometer (lateral, longitudinal)
- Anti-lock braking system status
- Traction control
- Stability control
- Rate of change of steering wheel
- Vehicle velocity
- Date
- Time
- Location
- Vehicle heading
- Yaw rate
- Differential wheel speed

Tier II (Useful, would like to have)

- Brake status
- Brake boost
- Impact sensor
- Ambient noise level

Tier III (least important, but will take them if possible)

- Elevation
- Rain (rain sensor)
- Sun (sun sensor)
- Hours of operation
- Adaptive cruise control radar
- Short-range wide beam radar

Table 1. List of desired resolution and range for weather related connected vehicle CANBus observations

Variable	Description	Valid Range	Data Resolution	Temporal
Atmospheric Pressure	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.	650.0 mb – 1200.0 mb	INTEGER (0..65535)	Once every 20 seconds
Spot Wind Direction	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)	Once every second
Spot Wind Speed	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)	Once every second
Air Temperature	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)	Once every 20 seconds
Dewpoint Temperature	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)	Once every 20 seconds
Surface Temperature	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)	Once every second
Solar Radiation	The ultraviolet, visible, and near-infrared (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)	Once every 20 seconds
Total Radiation	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)	Once every 20 seconds
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)	Once every 20 seconds
Precipitation Indicator	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.	1 - 3	INTEGER { precip (1), noPrecip (2), error (3)}	Once every second
Rainfall or Water Equivalent of Snow	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)	Once every second

Table 1. List of desired resolution and range for weather related connected vehicle CANBus observations (continued)

Variable	Description	Valid Range	Data Resolution	Temporal Resolution
Precipitation Situation	Describes the weather situation in terms of precipitation. Intensity meaning: <ul style="list-style-type: none"> • slight < 2mm/h water equivalent • moderate ≥ 2 and < 8 mm/h water equivalent • heavy ≥ 8 mm/h water equivalent 	1 – 15	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)}	Once every second
Roadway Water Level Depth	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)	Once every second
Adjacent Snow Depth	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)	Once every second
Roadway Snow Depth	The current depth of unpacked snow in centimeters on the driving surface	0 cm – 255 cm	BYTE (0..256)	Once every second
Roadway Ice Thickness	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)	Once every second
Detected Friction	Indicates measured coefficient of friction in percent. The value 101 shall indicate an error condition or missing value.	0 – 100	INTEGER (0..101)	Once every second

Currently, mobile weather data standards (specifically J2735) are not fully operational. In order for consistent and useful transmission of mobile weather observations across various communications infrastructures, such as will be involved in VDT ingesting of such observations, a “Weather Report” dataframe with the following variables would be beneficial:

Pressure/Wind

- Atmospheric Pressure
- Spot Wind Direction
- Spot Wind Speed

Temperature

- Air Temperature
- Dewpoint Temperature
- Surface Temperature

Radiation

- Solar Radiation
- Total Radiation

Precipitation

- Precipitation Indicator (yes/no)
- Rainfall or Water Equivalent of Snow
- Precipitation Type
- Roadway Water Level Depth
- Adjacent Snow Depth
- Roadway Snow Depth
- Roadway Ice Thickness

Visibility

- Visibility

Friction

- Detected Friction

Each of these variables should be assigned a unique ID number. Most of the data elements are ported from the NTCIP 1204 standards, with slight modifications for the mobile environment. (NCAR 2011)

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