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The Use of Connected Vehicle Observations in Weather Applications for Various Highly Impacted Users of the Roads

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ABSTRACT

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1 INTRODUCTION

The United States 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 – air temperature, barometric pressure
- Mechanical – wiper status, Anti-lock Braking System (ABS) status, traction/stability control, differential wheel speed, steering angle
- Logistical – speed, location, elevation, heading
- Directly Measured - 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 applications for several highly impacted end-user groups are being considered for development and will be discussed in this paper.

2 VDT Overview

The VDT is engineered in a modular way. Figure 1 is a high-level schematic of the design of VDT 3.0.

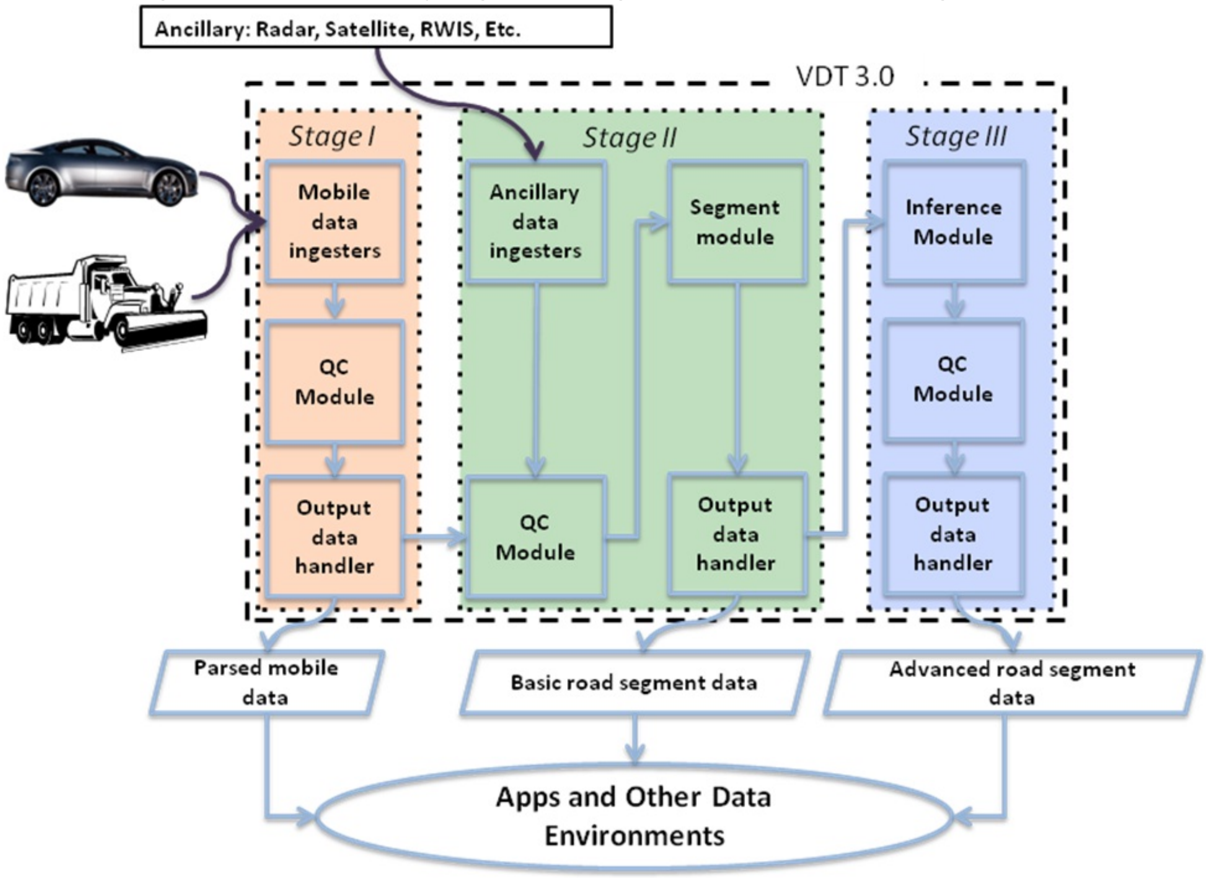

Figure 1. Design schematic for VDT 3.0

The initial stage (Stage I) of the VDT ingests mobile data. If the data are already pre-processed in some way, then the VDT can simply read the metadata and data from the input data. However, the VDT also has routines to directly ingest mobile data from mobile sources or a data collection and forwarding facility, parse them, and then sort them by time, road segments, and grid cells (the road segments and grid cells are user-defined via configuration files). These data are then passed through a *QC Module* that tags data that contain invalid geospatial or temporal information (e.g., latitude values greater than 90°N or time of day greater than 23:59:59). All data are passed through the *Output Data Handler*, which outputs the "parsed mobile data" for use in applications, and also for use in Stage II of the VDT.

Stage II analyses provide the road segment data using QC'd mobile data. The *QC Module* examines individual mobile data (native to the vehicle and/or some add-on sensors) and flags each data point for relevant QC tests. Ancillary data, such as fixed surface station data and radar data, are also ingested by the *Ancillary Data Ingesters*, which perform the same functions as the Stage I *Mobile Data Ingesters module* (except in this case for ancillary data), including time stamping and geolocating. These ancillary data are then used in some of the QC processes, but they are not QC'ed themselves; however, the ancillary data used in the VDT 3.0 is all QC'd by other means before being incorporated into the VDT. All data are passed through to the *Statistics* component, where the mobile data that pass QC are used to compute road segment statistics. Examples of these data would include the mean air temperature over an individual road segment for a given time step, or the percentage of windshield wipers activated over an individual road segment for a given time step. All mobile data with QC flags and the statistical data for the "Basic road segment" data are output from Stage II.

Stage III analyses provide additional value-adds for mobile data. In the *Inference Module*, fuzzy logic algorithms, decision trees, and other data mining procedures are used to produce the "Advanced road segment" data. Examples of these include combining mobile data with radar, satellite, and fixed surface station data to compute a derived 'road precipitation' product over an individual road segment for a given time step. These data are then run through a *QC Module* that assigns a confidence value to the "Advanced road segment" data assessments.

3 End Users

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:

- Travelling Public
- Freight Haulers
- Emergency Medical Services (EMS) / First Responders
- Road Maintenance and Management

3.2 Travelling Public

Each year in the US, 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 travelling public already has access to several resources (e.g., 511 systems, traveller 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 travellers 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 impact information will be generated and passed along to the travelling 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 in-vehicle communications, and smart phones. Outside 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.

3.3 Freight Haulers

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 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 or to the private sector, which could tailor the information specifically to company or individual needs.

3.4 Emergency Medical Services

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 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.

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 the Maintenance Decision Support System (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.

3.5 Road Maintenance and Management

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 Maintenance Management Systems (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.

3.5.1 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 temperature, 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 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.

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

3.5.3 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.

4 Discussion

With the development of connected vehicle technology and the need for better road-level information about the impacts of weather on the users of the roads, research and development is being accomplished to build software to aid in the organization and dissemination of mobile weather observations. The VDT was developed to quality check and merge mobile observations with ancillary weather data (such as radar). Several highly-impacted user groups are being targeted for additional development of applications that use the output from the VDT in a way that is specific to the particular users needs. More work is being undertaken to better understand the mobile observations themselves as well as tune the developed algorithms in the VDT.

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