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A NEXT GENERATION OF OBSERVATIONS BASED ON PASSENGER VEHICLES

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1. INTRODUCTION

In the United States today, the lower atmosphere is routinely sampled by only about two thousand automated airport weather stations. Even coupled with remote sensing technologies and privately owned mesonets, the number of observations collected is very small given the many small-scale complexities found in the planetary boundary layer. So, other than by deploying several thousand additional in situ observation platforms or augmenting space-based remote sensing technologies, can the weather community possibly obtain a much denser network of surface observations? The answer is yes, and one does not have to go farther than the garage for the solution!

Imagine a capability where millions of privately owned automobiles are equipped with transceivers that are able to transmit data "snapshots" captured from their onboard sensors and safety systems to a nationwide infrastructure connected by high-speed data hubs. Even the most common components of the passenger vehicle can begin to tell a story about the near surface (driver level) atmospheric and pavement conditions through the intelligent utilization of vehicle data elements such as windshield wiper state, external air temperature or the status of an anti-lock breaking system. Is this in the realm of science fiction? Not according to the U.S Department of Transportation (USDOT) and a consortium of automotive manufacturers and private sector interests.

Today, a USDOT initiative called Vehicle Infrastructure Integration (VII) is moving toward developing these capabilities. Automobile companies are working on equipment that can send to and receive messages from the roadside while the federal government, states and the private sector are looking at a wide range of strategies for deploying the roadside communications infrastructure. During 2008 and 2009, a series of demonstrations will take place to move this concept from research to operations. During the spring of 2008, a proof-of-concept test for VII-enabled vehicles will be conducted in Detroit, Michigan. Similar test beds are in use in northern California and planned for New York City. And the Federal Highway Administration (FHWA) and the USDOT Research and Innovative Technology Administration (RITA) will be conducting research to evaluate and validate the viability of using vehicle-based sensor data to generate potentially millions of new weather and pavement condition observations.

This paper will provide details on the FHWA Road Weather Management (RWM) program's efforts to conduct surface transportation weather research in this new paradigm of vehicle-based observations.

2. VEHICLE INFRASTRUCTURE INTEGRATION

All new passenger vehicles on the road today contain small onboard computers to monitor and control various systems such as engine combustion, anti-lock braking or air bag deployment. What if the status of many of these systems could be collected onboard and periodically transmitted to a roadside receiver? What if near real-time information could then be sent back to the originating vehicle to provide advice about weather or road conditions, traffic or collision avoidance? These concepts are the basis for the USDOT's Vehicle Infrastructure Integration initiative.

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2.1 VII Overview

The long term objective of the VII program is to create an enabling communication infrastructure to support both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications in support of both safety and mobility applications (USDOT and RITA, 2007). Safety applications will include an emphasis on developing a crash avoidance capability. Mobility applications will include obtaining better information (in both quality and number of observations) for roadway system management and operations including traffic, incident, and emergency management. This includes the potential to observe and infer both driver-level weather and pavement conditions.

A key requirement for a successful VII deployment is establishing reliable communications. One avenue under consideration is the use of wireless communications based on the Federal Communication Commission's (FCC) allocation of the 5.9 GHz radio frequency for implementing Direct Short Range Communications (DSRC)(Petty and Mahoney, 2007). Use of this frequency would allow for low latency, reliable and secure communications between vehicles and roadside units within approximately 300 meters (984 feet) to 1000m (3280 feet) of each roadside unit (RSU)(USDOT, 2005). A consortium of automobile manufacturers is working on common data and transmission formats. Inclusion of DSRC transponders in some new vehicles may begin with the 2012 model year. There is, however, still a question about how many RSU's may be installed when VII-enabled vehicles hit the showroom floor or what other wireless communication technologies may be in use. There are a number of significant challenges facing the VII program, including funding, private sector participation, governance and privacy. All of these challenges are being addressed by various Task Forces within the VII program. The RWM program is focusing specifically on the weather-related capabilities offered by the VII program and the benefits they can bring to both the transportation and weather communities.

2.2 Potential Data Elements

All VII-enabled passenger vehicles will have a few capabilities in common:

- Each vehicle will have a transceiver to both transmit and receive data (called probe messages)
- Each vehicle will have a GPS capability to report location and heading
- While not all vehicles will have the same type or amount of equipment onboard, a common, minimum set of data will be available for vehicle-to-infrastructure communications (such as vehicle speed, windshield wiper state and headlight state)
- It will be up to the automobile manufacturers to design and implement a human machine interface (HMI) within the vehicle that effectively conveys information without distracting the driver

In addition to these basic elements, Figure 1 shows a list of vehicle-based data elements identified by the National Center for Atmospheric Research (NCAR) as potential sources of weather information. Items in red may be available in the first demonstration (see Section 3.2). Elements such as Anti-lock Braking System (ABS), Vehicle Stability Control (VSC) and Vehicle Traction Control (VTC) could be used to infer pavement conditions and a friction index. Windshield wiper state, headlight state and vehicle speed could be used to determine the occurrence of precipitation, while windshield wiper rate could aid in the diagnosis of precipitation rate. These derived precipitation parameters, together with exterior air temperature could potentially be utilized in the assessment of precipitation type. Furthermore, these elements could be integrated with conventional weather data sets (e.g., Doppler weather radar) to create more complete vehicle-based road weather observations (Petty and Mahoney, 2007).

Based on current plans, vehicle diagnostics and supplementary data elements, including those outlined in Figure 1, will be collected on the vehicle by a processor that polls onboard systems at specific intervals. The polling intervals are controlled by both pre-programmed and random "events". Periodic collection of data elements, called snapshots, will occur based solely on the movement of the vehicle as an inverse function of its speed (USDOT, 2005). A vehicle traveling at interstate speeds may collect snapshots every 20 seconds while a vehicle traveling on a secondary arterial at a slower speed may collect data every 6 seconds. Snapshot generation can also be triggered if an "event" is noted in one of the vehicle systems. An event would be a change in state of a system, such as turning the vehicle traction control from "off" to "on" or from activation of a safety system such as the anti-lock braking system.

Finally, snapshots can be generated when a vehicle begins moving or when it comes to a stop. Current design allows for a maximum of 30 snapshots to be stored onboard the vehicle before older or lower priority data gets overwritten.

3. DEVELOPMENTAL PLANS FOR VII

At the time of this writing (early January 2008), some of the plans for the development and deployment of VII are still being developed by USDOT. Presently, a three phased approach is being considered; Operational Tests, Enable a Phased Network Deployment and Monitor Cutting Edge Technologies. These three phases will run in parallel.

3.1 VII Phase 1

Phase 1 of VII development will focus on accelerating the availability of currently available travel information and services through field test beds. This phase is called SAFE TRIP-21 for "Safe and Efficient Travel through Innovation and Partnerships in the 21st Century." Rather than focusing on manufacturer-installed sensor polling and communications devices, this demonstration will emphasize the use of after market devices for data acquisition and communications. Applications associated with this demonstration will include safety, mobility, environmental stewardship, energy independence and security. A showcase for this operational test is planned for the World Congress on Intelligent Transport Systems in New York City during the fall of 2008.

3.2 VII Phase 2

Phase 2 of VII development is focused on completing the applied research necessary to support a phased nationwide deployment of VII capabilities and data exploration. Emphasis will be on increasing market penetration of VII-enabling devices, increasing geographic coverage of V2I capabilities and enhancing the functionality of after market devices. The information obtained from the Phase 1 operational tests will be used to refine the entire VII approach. This phase will also explore federal policy on investing in application development, data privacy policies, governance and business models for sustainment of the operational system.

One of the main activities planned for Phase 2 is called the VII Proof of Concept (PoC) Test. Current plans call for the installation of up to 57 RSU's along Interstate and primary arterials in a portion of metropolitan Detroit. Figure 2 provides a graphical depiction of the test bed which includes instrumentation along 75 miles of roads, 32 miles of which will be centerline Interstates or divided highways. Twenty five vehicles will be outfitted with DSRC transponders and will be driven through the test bed during the six week demonstration, currently planned for March and April, 2008. Six public sector applications will be tested: Traveler Information, Traffic Signal Optimization, Ramp Metering, Corridor Management, Planning and Weather. All of the data collected during the six week period will be made available to the weather application team in support of data exploration and statistical analysis.

3.3 VII Phase 3

Phase 3 of VII development will focus on monitoring and assessing developing technologies that may be incorporated into the VII system to enhance system performance or reduce costs.

4. WEATHER DATA ANALYSIS

The initial emphasis during the operational tests will be to capture data from vehicles during as many different types of weather and traffic conditions as possible. This includes acquisition of data during both daytime and nighttime conditions, along with attempting to drive through and capture vehicle-based data from liquid, freezing and frozen precipitation events.

It is envisioned that data analyses will include:

- A comparison of vehicle-based data to in situ observations (roadside Environmental Sensor Stations (ESS) and nearby automated airport observations)
- A comparison of sensors located in various points on a vehicle, as well as performing vehicle-to-vehicle comparisons
- Determination of statistical biases, quality errors or outliers within the vehicle data set
- Evaluation of data quality versus other vehicle characteristics such as speed, engine temperature, etc.
- Estimation of the minimum number of data samples that would be required to result in a quality set of observations for a specific segment of road during a specific period of time.

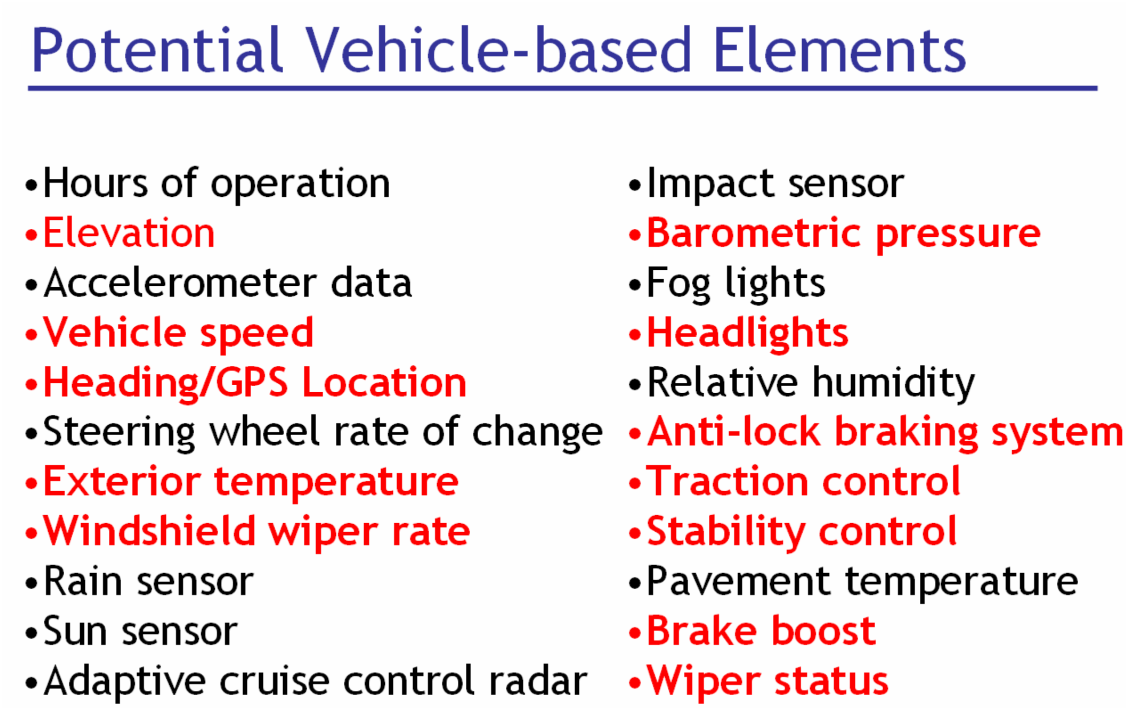

Figure 1. An extensive list of potential vehicle systems and sensors that could provide data for VII-based probe messages. Elements in red may be available for the Phase 2 Proof of Concept demonstration in Detroit during Spring 2008.

Figure 2. Map of the proposed VII test environment in metropolitan Detroit, Michigan. Icons represent planned locations for the 57 roadside units. The map inset shows the test bed region (gold box).

4.1 *Data Integration and Vehicle-based Observations*

Once the characteristics of the vehicle data quality are known and the data are quality checked, research will be conducted to explore the possibility of integrating vehicle data with supplemental weather data sets (e.g., radar, ESS, and airport observations). This research will attempt to design algorithms that can produce a new type of weather observation, that is, one that has been derived integrating vehicle and conventional observations. These observations may be able to provide details on both atmospheric and pavement conditions at high temporal and spatial resolution for specific road segments. This information would have a wide range of uses from providing tailored road condition advisories directly to vehicles to providing a wealth of near surface (e.g., driver level) and pavement observations for national weather analysis and modeling efforts.

Elements that may be included in a future vehicle-based observation might be:

- Road segment ID (e.g., highway route number and mile marker designation)
- Date/time stamp (which represents the ending time of the observation sample window)
- Air temperature (along the specific road segment)
- Precipitation occurrence (yes or no)
- Precipitation intensity (none, light, moderate, heavy)
- Precipitation type (liquid or frozen)
- Barometric pressure
- Pavement condition (not slippery, slippery or a possible pavement friction index)

Research will be conducted to determine the best approaches for creating vehicle-based observations. For example, a correlation study will be performed to compare Doppler weather radar reflectivity data with vehicle wiper status and wiper rate. This study may show that vehicle-based data can be a tool to better define where radar echoes actually produce precipitation that reaches the ground.

Another study will examine the diagnosis of pavement condition or a pavement friction index using vehicle data combined with other ancillary data. This study will potentially correlate anti-lock braking system, vehicle traction control or vehicle stability control activation events with the aforementioned derived precipitation observations and external air temperature to estimate pavement friction.

4.2 *Roadway Segmentation and Data Aggregation*

Although questions remain on how fast VII-enabled equipment will penetrate the U.S. marketplace, a real potential exists for large quantities of vehicle-based data to be made available for processing in the not too distant future. This raises important questions about how to effectively transmit and process large volumes of data in a timely fashion.

The USDOT has been working with NCAR on the concept for a Weather Data Translator (WDT) which would include high speed computers that ingest raw vehicle-based probe messages and supplemental weather data and generate near real-time vehicle-based observations based upon the concept of road segmentation.

4.2.1 Segmentation – “Fixed” or “Localized”

One approach for dealing with what could eventually be a massive amount of vehicle-based data is the concept of either “fixed” or “localized” segmentation of our nation’s roadways into discrete sections. With “fixed” segmentation, each segment of roadway would be partitioned into a fixed length of interstate or arterial extending from one mile marker to the next as shown in Figure 3. Each segment would also have a fixed set of metadata, such as location, terrain description, road type, etc.

On the other hand, if it is determined that fixed segmentation is unreasonable due to its inability to properly capture the presence of microclimates (e.g., heat sources or sinks), complex terrain (e.g., valleys, canyons or mountains) or differences in infrastructure (e.g., asphalt versus concrete, bridges or ramps), then the concept of “localized” segmentation may be able to address this shortfall. Such segmentation would be defined by relevant local features rather than uniform fixed lengths of roadway (Figure 4). For example, a segment may be better defined by aligning it with the span of a bridge or a road surface located along the bottom of a canyon. Most importantly, each road segment would be able to have its own customized set of localized metadata which would

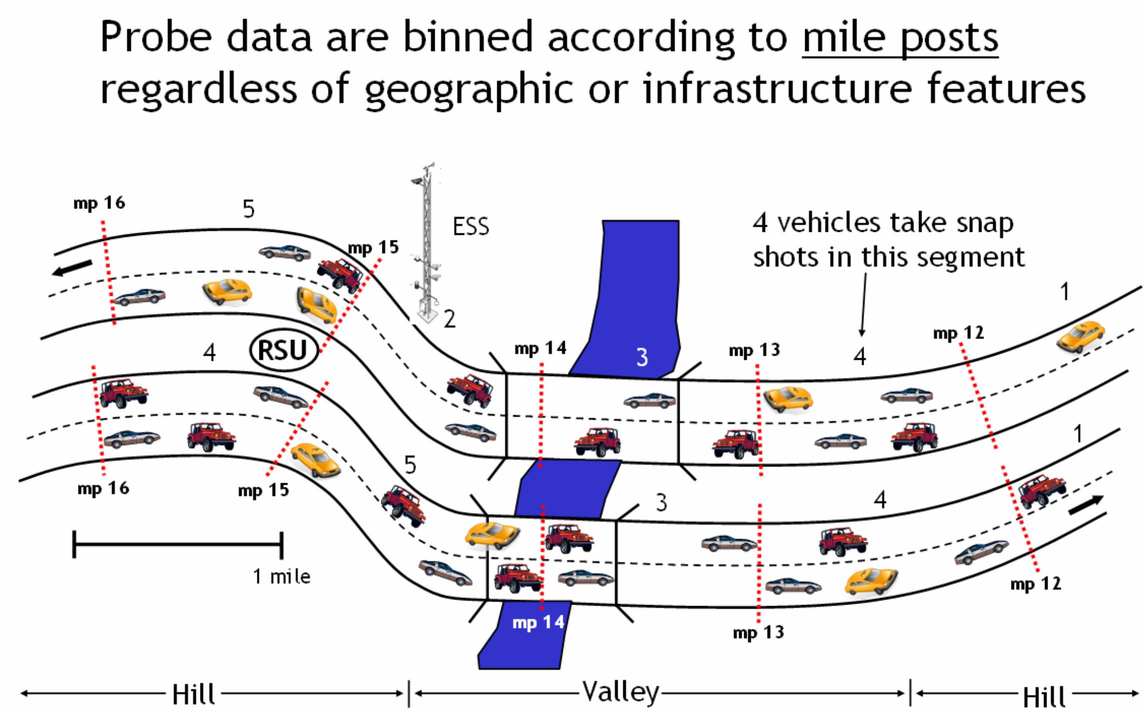

Figure 3. Example of fixed segmentation which is based on evenly dividing roads according to established markers such as mile posts. At highway speeds, snapshots of onboard systems will typically be made in each segment. Snapshots are accumulated within the vehicle's data buffer and uploaded when within range of the roadside unit (RSU).

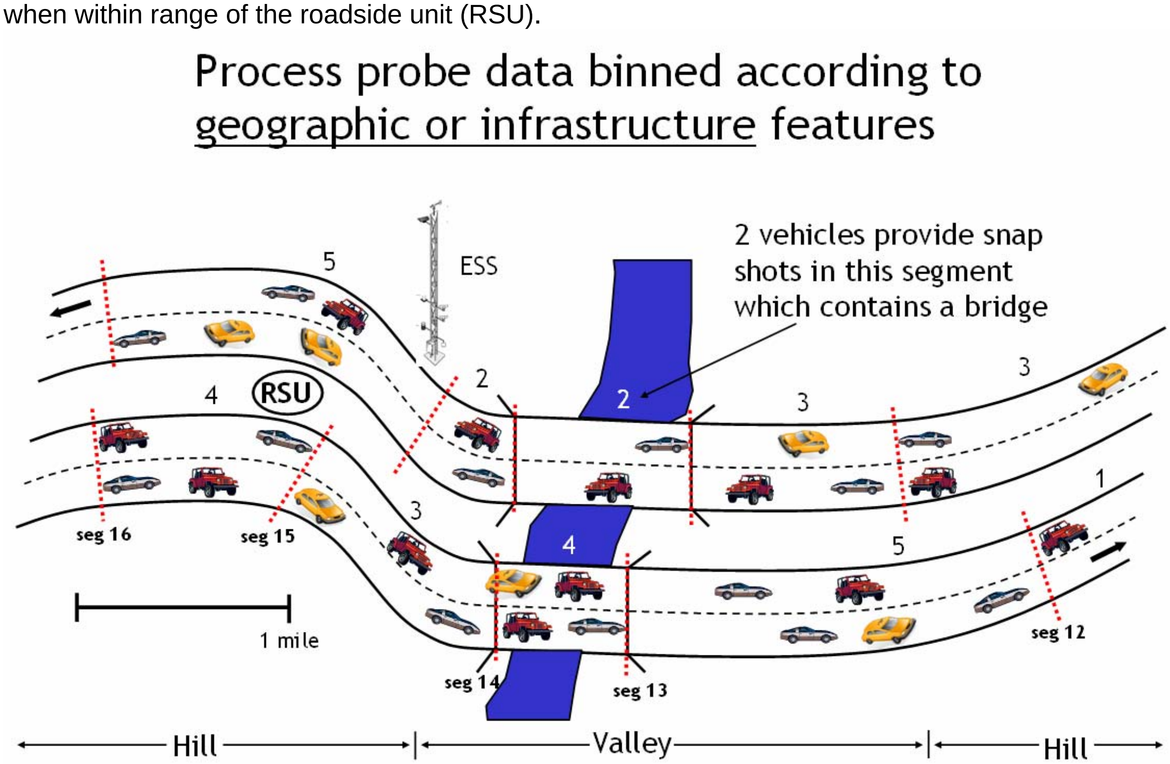

Figure 4. Example of localized segmentation which is based on dividing roads according to infrastructure (such as bridges or pavement type) or geographic features. At highway speeds, snapshots of onboard systems may or may not be taken in each segment. Snapshots are accumulated within the vehicle's data buffer and uploaded when within range of the roadside unit (RSU).

be better able to describe the uniqueness of its location. In addition to drastically reducing the number of data points from individual vehicles to a much smaller number of roadway segments, this approach would also help to eliminate the metadata concerns associated with keeping vehicle information anonymous.

4.2.2 Aggregation

Once segmentation issues have been considered, the next step will be to analyze how much data are required to generate a statistically sound (e.g., free of bias or outliers) vehicle-based observation. Should data be collected for 10 minutes for each segment and then processed for data quality? Are there a minimum number of data samples below which a statistically sound observation cannot be generated? If the numbers of data samples are low during non-peak travel periods but much higher during peak periods, should observation timing be different? Should processing in urban corridors be different from rural routes? These are just some of the questions that will need to be explored during this phase of research.

Figure 5 provides an example of a collection of probe messages during a 5 minute period along a specific road segment. Quality checking algorithms would be run on the binned data and outliers would be removed from the final statistics. A resulting vehicle-based observation could be encoded in the example shown in Figure 6. This example could be the starting point for a new paradigm in weather observations.

Observation for Segment 81-13, Time ending 16 Oct 2007, 09:05 UTC

	Time	Lat	Lon	Air Temp	Wiper Status	Wiper Rate	Baro Pres	Head lights	ABS State	VTC	VSC	Brake Boost
1	09:00	35.661	-95.211	37	0	0	29.41	0	0	0	0	0
2	09:02	35.661	-95.209	35	0	0	29.40	0	0	0	0	0
3	09:01	35.662	-95.210	36	0	0	29.81	0	0	0	0	0
4	09:04	35.662	-95.212	42	0	0	29.43	0	0	0	0	0
AVG				36	0	0	29.41	0	0	0	0	0

Figure 5. Collection of probe messages during a 5 minute period along a specific road segment. Quality checking algorithms would be run on the binned data and outliers would be removed from the final statistics (red values).

I81-13 10/16/07 0905Z 36 NP 29.41 1.0

Figure 6. Example of a vehicle-based observation using data from Figure 5. Segment identification (I81-13) is for Interstate 81 from mile post 13 to 14. The observation was collected over a 5 minute period ending 10/16/07 at 0905Z (UTC). Average bin air temperature was 36 degrees. There was no precipitation (NP) observed. Average barometric pressure was 29.41 inches of mercury. The pavement friction index was 1.0 (meaning good friction).

5. SUMMARY

The Road Weather Management program of the Federal Highway Administration sees the Vehicle Infrastructure Integration (VII) initiative as very important for both the surface transportation and weather communities.

VII research has shown that different systems and sensors on passenger vehicles can be used to directly observe or infer weather and pavement conditions (Stern and Biesecker, 2006). The VII Initiative aims to partner with automobile manufacturers to create an infrastructure that allows for two-way communications between the vehicle and the roadside. The long term objective of the VII program is to create an enabling communication infrastructure to support both vehicle-to-vehicle and vehicle-to-infrastructure communications in support of both safety and mobility applications.

The initiative has evolved to the point where test beds are being set up in several locations around the country. USDOT plans on conducting at least two field operational demonstrations during 2008 to test communications and to study vehicle data quality. Several studies are planned to determine how best to process the potentially large amounts of data for the benefit of the surface transportation community and the entire weather enterprise. How these efforts will affect the weather and climate communities remains to be seen. The USDOT sees great potential in this area, and will continue to explore it as it evolves.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Petty, K.R. and W.P. Mahoney III, 2007: Enhancing road weather information through Vehicle Infrastructure Integration. TRB 86th Annual Meeting Compendium of Papers CD-ROM, Transportation Research Board, National Research Council.

Petty, K.R. and W.M. Mahoney III, 2007: Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII): Feasibility and Concept Development Study, National Center for Atmospheric Research, Boulder, CO.

Stern, A.D. and K.J. Biesecker, 2006: Vehicles as Mobile Sensing Platforms for Meteorological Observations, Mitretek Systems, Inc., Falls Church, VA.

U.S. Department of Transportation, 2005: Vehicle Infrastructure Integration (VII): VII Architecture and Functional Requirements Version 1.1, ITS Joint Program Office. Washington, D.C.

U.S. Department of Transportation (USDOT), Research and Innovative Technology Administration (RITA), Vehicle Infrastructure Integration web page, http://www.its.dot.gov/vii/vii_overview.htm, December 2007.