Observing Road Weather Conditions Using Passenger Vehicles

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ABSTRACT

The acquisition of road weather information on temporal and spatial scales that will support advancements in timely, accurate diagnoses and forecasts of near surface conditions will inherently result in an increase in roadway safety and mobility. Currently, in the United States, heavy reliance is placed on automated airport observing platforms, mesonets, and remote sensing technologies for information concerning the planetary boundary layer; however, these data do not provide adequate amounts of near surface information at the scales required by the roadway transportation community. Although the deployment and use of Road Weather Information Systems has aided in the diagnosis and prediction of road weather conditions at select points along routes, there remains a need for a denser network of weather and road condition observations.

A potential solution to the need for high-resolution atmospheric and road condition data can be found in a United States Department of Transportation (USDOT) initiative called Vehicle Infrastructure Integration (VII). The concept of VII involves vehicle-to-vehicle and vehicle-to-infrastructure communications through Dedicated Short Range Communications (DSRC)-wireless radio communication at 5.9 GHz. Automobiles will have the capacity to wirelessly transmit and receive messages that carry information concerning road weather conditions. For example, vehicle data elements such as temperature, wiper state, and Automated Braking System (ABS) status can be transmitted and used to directly or indirectly assess weather and road conditions. It is envisioned that VII-enabled weather-related data will result in the enhancement and development of operation-specific road weather products and applications for surface transportation stakeholders, such as traffic, incident, maintenance and emergency managers, weather information providers, and the traveling public.

During the spring of 2008, a Proof of Concept (PoC) will be conducted in the Detroit, Michigan area, with support from the USDOT. The fundamental goals of the VII PoC include demonstrating and examining elements of the VII concept (e.g., data flow) and exploring the viability of using VII-enabled data in the development of various applications. This paper discusses and summarizes current and future weather-related mobile data elements, road weather applications and product improvements and developments that may result from VII-enabled data, and the research and development being supported by the USDOT Federal Highway Administration's Road Weather Management Program in an effort to facilitate the use of VII-enabled weather and road condition data.

Keywords: weather, Vehicle Infrastructure Integration, VII, road weather, mobile observations.

1. INTRODUCTION

In the United States, disparate weather events have a considerable impact on all surface transportation sectors of operation. In terms of roadway operations, adverse weather conditions routinely lead to a reduction in safety, mobility, and efficiency. In order to mitigate the impact inclement weather has on the U.S. roadway network, improved analyses and forecasts of weather and road conditions are required. The process of enhancing our ability to diagnose and predict road weather conditions is strongly linked to our ability to observe the parameters of interest at appropriate temporal and spatial scales. What is clearly evident is that a denser network of boundary layer observations will not only result in an improved depiction of the current state of the atmosphere, but it will also aid in increasing the accuracy of weather forecasts. The need for additional boundary layer observations may potentially be addressed through VII. VII may also have the capacity to provide supplemental information regarding pavement conditions.

VII employs the use of DSRC at 5.9 GHz in order to facilitate vehicle-to-vehicle and vehicle-to-infrastructure communications, enabling the wireless transmission of data and information. While the original motivation for VII strictly involved the development of safety-related technologies and applications (e.g., crash avoidance), the idea that VII can be used as a tool for road weather products and applications has become readily apparent. VII-enabled data have the potential to fill some of the needs of the surface transportation and atmospheric science communities for high-density road weather observations because of the dense nature of the sampling of both the atmosphere and roads. These data are unique in that they will provide real-time or near real-time observations of the atmosphere (e.g., temperature, pressure, etc.), as well as the state of various onboard vehicle sensors of interest (e.g., wiper state, anti-lock braking system, traction control system, etc.), which can potentially be used to infer road weather conditions. The observations enabled through VII can be used either independently or in conjunction with ancillary data sets to derive weather parameters (e.g., ambient air temperature, precipitation occurrence, etc.) or to diagnose relevant pavement conditions (e.g., dry, wet, icy, etc.).

A VII PoC is scheduled to take place in the Detroit, Michigan area in spring 2008. The purpose of the PoC is to provide a real-time demonstration of the VII concept using 25 well-equipped vehicles over a six-week period. The weather-related VII data generated from the PoC will be used to:

- examine vehicle probe data accuracy, trends and biases
- develop algorithms (e.g., derived observations, quality control, etc.)
- investigate statistical requirements for observed and derived parameters
- create and demonstrate a Weather Data Translator (WDT) to ingest and process vehicle probe data
- compare and contrast vehicle probe data elements to other observations

The goals of this paper are to: (1) provide a summary of VII and the future vision for the program, as it pertains to road weather; (2) provide an overview of the potential VII-enabled weather-related data elements, along with anticipated derived observations and products; (3) present an example and an analysis of a severe weather case-study involving a vehicle with the capacity to wirelessly transmit probe data; (4) discuss some of the more pertinent components of the Detroit PoC, as they relate to weather-related research and development; and (5) summarize the overall utility of VII-enabled data for the purposes of improving diagnostic and prognostic weather information in support of roadway operations.

2. VII BACKGROUND

In 2003, a gathering of agencies occurred at the direction of the USDOT during the Intelligent Transportation System (ITS) America annual meeting in Minneapolis, Minnesota. The brainstorming discussions that occurred between these stakeholders led to the ideas, which today, embody the main concepts of VII [1]. There are many different stakeholders that now comprise the VII program including: the USDOT, several major automobile manufacturers, automobile associations, and state departments of transportation [1]. The overarching goal for the program is to develop the VII concept into a nationwide system allowing vehicle-to-vehicle and vehicle-to-infrastructure communications via DSRC technology in support of safety and mobility applications.

From the perspective of the road weather community, the VII concept will enable everyday vehicles to act as probes of their surroundings and environment. The onboard computers contained in vehicles automatically monitor and control many of the systems manufacturers install on today’s vehicles. The goal of VII is to enable communication of the diagnostics of these systems, which includes road weather related elements, to neighboring vehicles and/or roadside receivers in support of both safety and mobility (e.g., crash avoidance, driver-level weather, pavement conditions, etc.) products and applications [1, 4].

Currently, DSRC is the wireless method of communication that is being used for both VII vehicle-to-vehicle and vehicle-to-infrastructure communication. This technology is valuable because it utilizes the 5.9 GHz radio frequency allocated by the Federal Communications Commission (FCC) for independent use. This frequency allows for secure communications between vehicles and roadside receivers within a distance of around 1000m [6]. DSRC will be the primary method of communication for near-term VII efforts in the U.S., including the Detroit PoC; however, additional methods of wireless communication are also being considered for future operations including WiFi, WiMax, Satellite, and Cellular.

The USDOT Federal Highway Administration (FHWA) is presently developing plans for the development and deployment of VII. Currently, three phases, each running concurrently, are being considered; Operational Testing, Enabling of a Phased Network Deployment, and Monitoring of Cutting-edge Technologies. VII Phase 1 [Safe and Efficient Travel through Innovation and Partnerships in the 21st Century (SAFE TRIP-21)] emphasizes the use of after-market data acquisition and communications devices. VII Phase 2 focuses on the applied research necessary for future full deployment of the VII capabilities. The Detroit PoC, which will be described in greater detail in section 4, is one of the main activities planned in 2008 to satisfy the initial requirements of VII Phase 2. VII Phase 3 focuses on the future development of technologies that may be incorporated into the VII system in order to enhance performance and efficiency [4].

3. VII DATA

3.1 Probe Data Elements

Several past studies [2] [4] have highlighted the VII-enabled probe data elements that may be relevant for use in deciphering weather and road conditions. Table 1 provides a comprehensive list of these potential data elements. Note that not all data elements are currently available on production vehicles. The observed data elements section lists the "stand-alone" observations of atmospheric and road conditions. These elements are capable of providing an assessment of the current road weather conditions without the need for other vehicle data elements or supplemental data sets (e.g., radar data, satellite data, RWIS observations, etc.). In contrast, the input data elements section found in Table 1 lists the probe data elements that have the capacity to aid in determining road weather conditions but likely require information from other vehicle data elements and/or additional input from ancillary data sources. The vehicles that are scheduled to take part in the Detroit PoC will be equipped with a subset of the elements [marked with an (*)] listed in Table 1.

Observed Data Elements	
*Barometric Pressure	Rain (Rain Sensor)
*External Air Temperature	Sun (Sun Sensor)
Relative Humidity	Pavement Temperature
Input Data Elements	
*Date (Year, Month, Day)	*Brake Status
*Time (Hour, Minute, Second)	*Brake Boost
*Location (Lat/Lon)	Accelerometer (lateral, longitudinal)
*Elevation	*Yaw Rate
*Vehicle Heading	*Headlight Status
*Vehicle Velocity	*Traction Control
*Hours of Operation	*Stability Control
*Wiper Status	Rate of Change of Steering
Wiper Speed/Interval	Impact Sensor
*Anti-lock Braking System Status	Ambient Noise Level
Adaptive Cruise Control Radar	Camera Imagery
Short-range Wide Beam Radar	

Table 1. Potential Weather-Related VII-Enabled Vehicle Data Elements [elements available from the Detroit PoC marked with an (*)].

3.2 Products and Applications

Various weather-related VII probe data elements were discussed briefly in Section 3.1. Also noted was the need, in some cases, to combine the input data elements listed in Table 1 with other VII observations or more conventional weather-related data sets. Table 2 provides a list of potential products and applications to be considered in a fully deployed VII network.

VII-Enabled Products and Applications	
Weather-Related Traffic Hazard Diagnosis	
Precipitation (e.g., rain, snow, etc.)	Severe Thunderstorms
Dense Fog	Hail
Smoke	Flooding
Pavement conditions (e.g., wet, snow covered, etc.)	Blowing snow/Ground blizzards

Numerical Model Initialization	
Surface Pressure	Wind (speed and direction)
Air Temperature	Visibility
Relative Humidity	Precipitation (occurrence, rate and type)
Miscellaneous Products and Applications	
Input for Decision Support Systems	Identification of Radar Anomalous Propagation
Pavement Temperature Analysis	Identification of Virga
Diagnosing Boundary Layer Water Vapor	Air Quality Monitoring
Improved Weather Characterization in Complex Terrain	

Table 2. Potential VII-based derived observations.

It is anticipated that some of the methods and techniques used to derive observations or products will require the utilization of ancillary data, while others will have the capacity to be based solely on vehicle data elements. However, in either case, careful statistical processing will be required in order to make an accurate assessment of the space and time that the vehicle data represent. The process, by which vehicle data and supplementary data are combined to generate a product or application, will likely require the use of expert systems (e.g. fuzzy logic, neural networks, etc.). A hybrid of several expert systems will likely be the most effective method of combining these data, as it mimics the way a human might choose to combine multiple data sets to produce an optimized product. Fig. 1 provides an example of a schematic of the design for an algorithm that predicts heavy precipitation using a fuzzy logic engine that combines multiple supplemental data sets with the wiper state of vehicles. Each input, whether it is vehicle data or conventional weather data, is used in the creation of an interest field. These fields are then combined or fused to create the final interest field. The final interest field is used in conjunction with real-time verification techniques, which gauge the performance of each input, to generate and refine the final product.

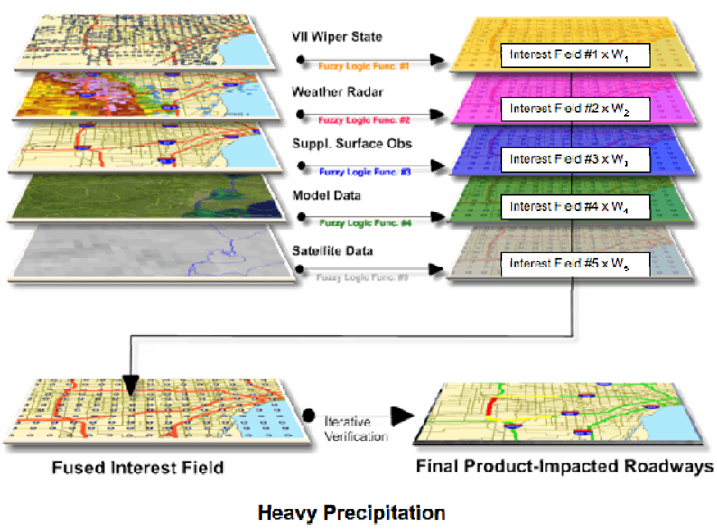

Fig. 1. Schematic of Heavy Precipitation Algorithm [3].

The initial examination of the data from the Detroit PoC will include investigation into the statistical handling of vehicle-based in situ observations and diagnostics, as well as the development of algorithms to derive several key observations and products (e.g., precipitation occurrence, pavement conditions, etc.). As part of this investigation, the most effective means of creating derived variables will be explored. For example, it will be necessary to determine the optimal road segment length and temporal collection periods over which to use vehicle probe data. This will potentially be accomplished through the use of statistical re-sampling procedures, as this will allow multiple simulations of samples of different sizes using available (e.g., PoC test bed) and anticipated data (i.e., from a mature VII network), as well as inferences about the significance of particular sample characteristics.

Additional data handling techniques will also be examined in an effort to determine alternative approaches for estimating derived variables. For instance, in a case in which multiple measurements are available along a discrete section of roadway, several possible representations of the derived variable could be constructed, including median values, most recent measurement, a weighted mean with weights inversely proportional to the amount of time since the measurement was made, etc. Multiple measurements taken along a segment will also allow estimation of the uncertainty in a derived value along that segment. Confidence values would depend on the number of measurements, as well as their variability. It is anticipated that several statistical approaches will be employed to estimate and represent the spatial and temporal uncertainty and consistency of derived variables.

The ultimate goal of the research and development effort is to identify methods and techniques that can be used to generate stable estimates of the derived parameters. However, it is clear that this endeavor will require a significant amount of effort, as there is a limited amount of experience in using vehicle probe data to diagnose road weather conditions.

3.3 Example Case

Fig. 2(a-d) depicts a case study comparison of vehicle-based observations, Road Weather Information System (RWIS) data from the Cleveland, Ohio area and radar data from the Cleveland WSR-88D for 1 June 2007 between 1744 and 1814 UTC. Data from the vehicle used in this case study were gathered and wirelessly transmitted using a system developed by MTS Technologies. The white triangle represents the location of the vehicle and the corresponding readings from its sensors are in the white text above the vehicle location. The stationary yellow triangle represents the location of the RWIS station and its corresponding readings are in yellow text in the bottom right-hand corner of each image. Data were available from the vehicle at one-minute intervals, while base radar reflectivity scans were available on six-minute intervals. Vehicle data elements include information on wiper state: 0 is off, 13 is low, 14 is high, and 1 through 6 are intermittent settings. Barometric pressure, in inches of Mercury (inches Hg), air temperature, in degrees Fahrenheit (^{o}F), and vehicle velocity [miles per hour (mph)] are also supplied. The radar data show reflectivity or echo intensity measured in decibels (dBZ), which generally correlates positively with precipitation rate. Cooler colors indicate lower reflectivity and warmer colors indicate higher reflectivity.

Fig. 2a shows the vehicle approaching the RWIS station at 1744 UTC. Vehicle data indicate that the vehicle's speed is approximately 132 kilometers per hour (km/h; 82 mph), the temperature is 33^{o}C (91.4^{o}F), and the wiper state is equal to zero. The radar at that time indicates low reflectivity or possible light rain showers in the vicinity. Further to the southwest, the radar is indicating higher reflectivity or heavier convective showers, which are moving towards the northeast. The corresponding temperature from the RWIS is 28.9^{o}C (84 ^{o}F).

At 1747 UTC (Fig. 2b), the vehicle passes the RWIS station, and a drop in speed to 101km/h (63 mph) is indicated. A temperature of 28^{o}C (82.4 ^{o}F) is observed, which correlates well with the 28.9^{o}C (84 ^{o}F) reading from the RWIS station. The wiper state is 13, indicating low, continuous wiper speed, and the radar continues to show low reflectivities in the vicinity, which is indicative of light rain.

At 1754 UTC (Fig. 2c), the vehicle, which is traveling westbound, is located well past the RWIS station. The indicated speed has decreased significantly [80.5km/h (50 mph)] and temperature shows a drop to 24^{o}C (75.2^{o}F). The wiper state is at its maximum of 14, indicating continuous, high wiper speed. The radar indicates a thunderstorm cell with high reflectivity very close to the position of the vehicle. The readings from the vehicle are very consistent with what one might expect. As vehicle operators enter an area of heavy precipitation, their tendency is to reduce speed and set the wiper setting to the highest possible state. From an atmospheric standpoint, the occurrence of heavy precipitation will generally act to suppress the ambient temperature, which is consistent with the reading provided by the vehicle. Note that the vehicle also reports an increase in barometric pressure, which is also consistent with the environmental conditions it encounters. The temperature sensor of the RWIS, to the east of the vehicle's location, also registered a drop of 2.3^{o}C (4 ^{o}F) to 26.6^{o}C (80 ^{o}F).

The vehicle emerges from the convective precipitation at 1814 UTC (Fig. 2d). At this time, the vehicle's speed has increased to 127km/h (79 mph), an increase in temperature to 27^{o}C (80.6 ^{o}F) is observed, and the wiper state is now zero. The radar indicates high reflectivity to the east (between the vehicle and the RWIS station), but there are no significant radar returns over the vehicle's location. The RWIS station continues to show a drop in temperature to 23.3^{o}C (74 ^{o}F) and an increase in RH to 89%, which is the result of the approaching thunderstorm.

This case is a simple but powerful example of the potential benefit of vehicle probe data in diagnosing the surface conditions during a complex weather event. The wiper state was well correlated with what the radar was indicating but at a higher temporal resolution [e.g. 1-min (mobile data) v. 6-min (radar data)]. High temporal resolution precipitation data could prove useful to numerical models, which are continually being enhanced to diagnose the small-scale aspects (e.g., outflow boundaries, start and stop of precipitation, and maximum precipitation intensity) of convective and non-convective systems. Another obvious benefit would be the capability of the vehicles to diagnose and communicate information concerning an adverse road weather event and its impact on traffic flow to vehicles in the region, as well as traffic management personnel. This would provide benefit to vehicle operators by informing them of imminent hazardous situations, allowing them to take appropriate actions to avoid the adverse conditions and potential traffic delays.

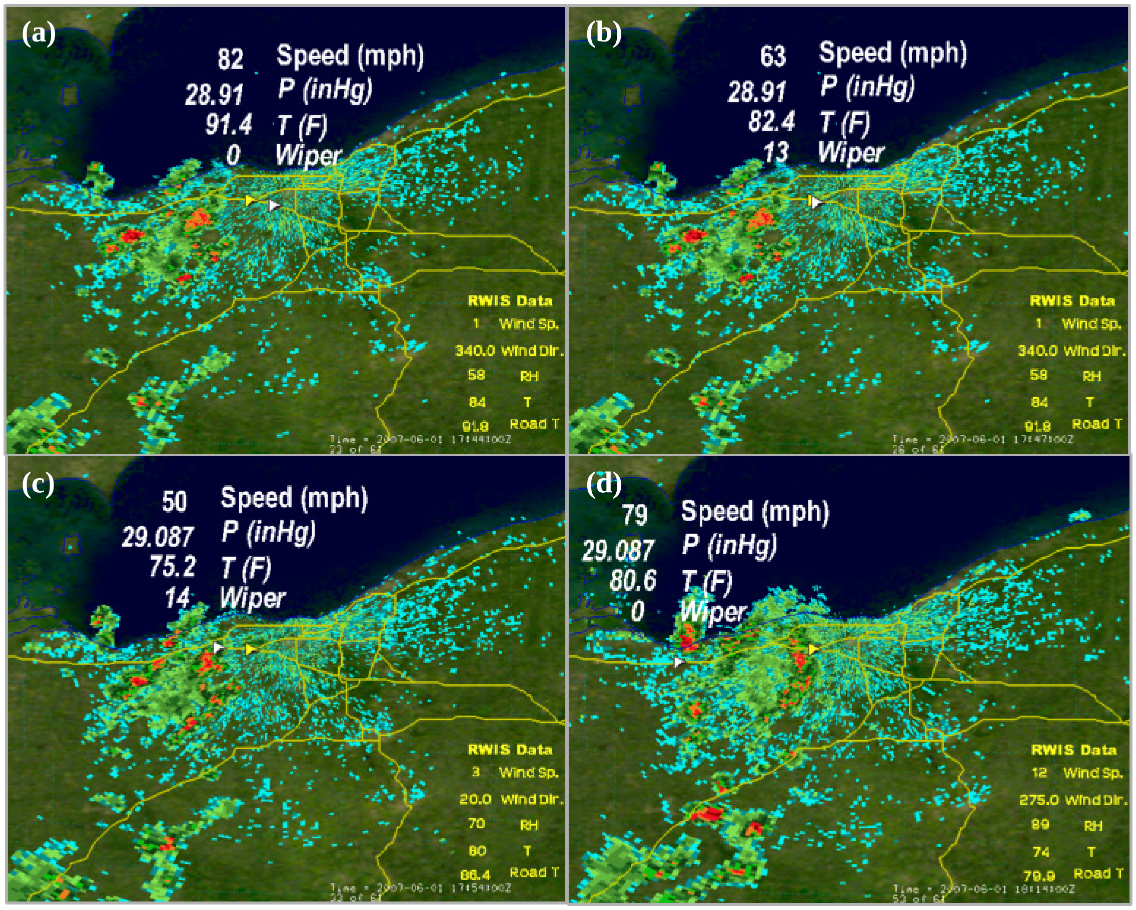

Fig. 2. Vehicle data valid at (a) 17:44 UTC, (b) 17:47 UTC, (c) 17:54 UTC, and (d) 18:14 UTC on 1 June 2007 in the Cleveland, Ohio area overlaid with WSR-88D radar data. Vehicle position denoted by white triangle and yellow triangle signifies RWIS location. (vehicle data courtesy of MTS Technologies)

4. DETROIT PoC

During spring 2008, a PoC will take place northwest of downtown Detroit, Michigan, lasting for about six weeks. The fundamental goals of the VII PoC include demonstrating and examining elements of the VII concept and exploring the viability of using VII-enabled data in the development of various applications. In terms of weather and road condition information, it is anticipated that the PoC will provide a means to assess whether VII-enabled weather-related data elements will be capable of contributing to the enhancement and development of road weather applications and products. Twenty-five vehicles equipped with onboard equipment (OBE) capable of transmitting and receiving data will be operated within a test bed environment that includes 57 Road Side Equipment (RSE) units (Fig. 3). This test environment will provide researchers and developers with an opportunity to test and evaluate the VII concept, including probe data generation and transmission.

In a fully functional VII-enabled environment, millions of vehicles will be acting as probes and will continuously send data to the VII network. For many potential end users of the data, the volume of data will be too vast to efficiently handle. In terms of weather-related elements, it is envisioned that statistical techniques will be essential in order to generate representative values for discrete road segments valid for predefined periods of time. As previously noted, data from the PoC test bed will enable methods and techniques to be explored.

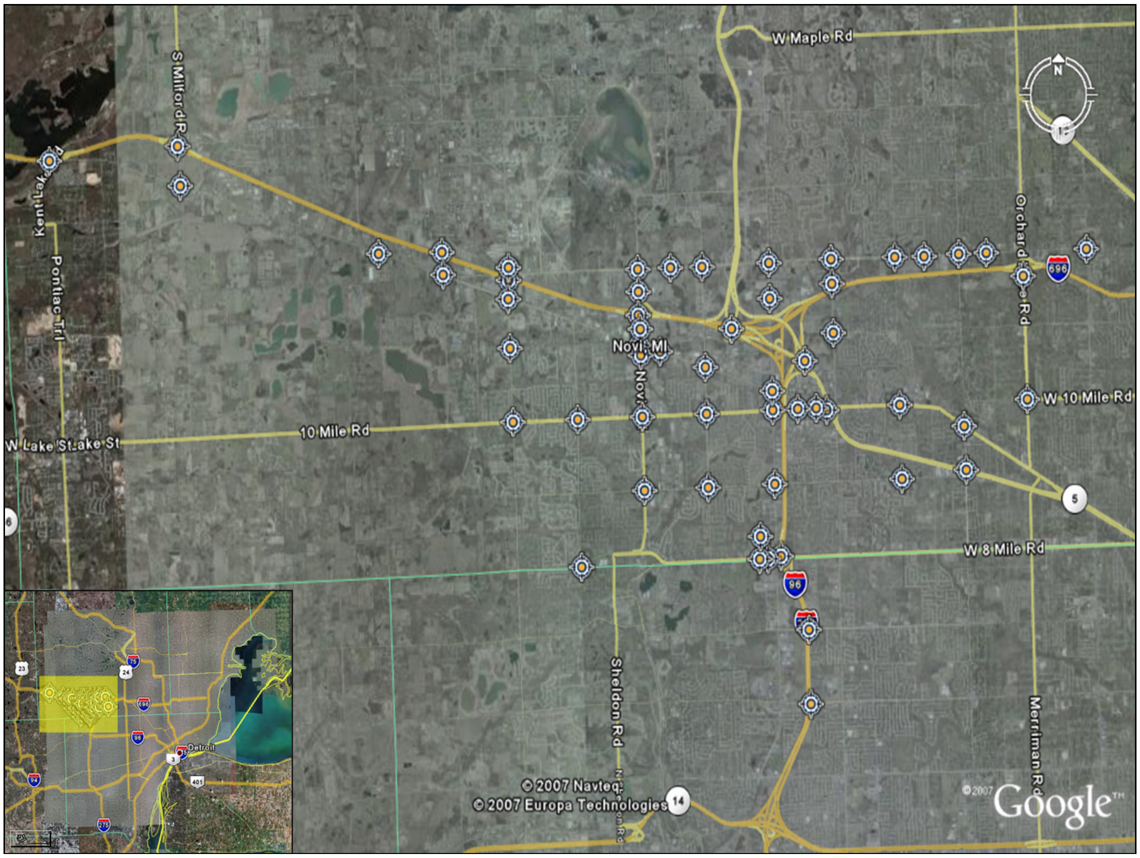

Fig. 3. Map of anticipated VII RSEs locations in the Detroit PoC test bed in spring 2008 (courtesy of Booz Allen Hamilton).

In anticipation of potentially large volumes of data from vehicles, a need has been anticipated for development of infrastructure that can provide an effective way to ingest, parse, quality check, and disseminate weather-related VII-enabled data. A WDT is currently being developed to address this need. The WDT is being designed in such a way as to be well-grounded throughout the different phases of VII deployment from the initial Detroit PoC to full deployment across the United States. The following key data issues are being considered with regards to the initial design of the WDT: volume, latency, quality, representativeness, and format. The successful development of the WDT will fill a foreseen need to extract the data elements from the VII network needed to derive road weather information, filter out unrepresentative samples, quality check the data utilizing supplemental datasets, generate statistical output for specific areas and time periods, and disseminate the quality-checked and statistically-processed data to data subscribers in a timely manner [3]. Fig. 4 is an illustration of the concept of the WDT processing module.

It is anticipated that the WDT will comprise a data parser function which will enable the system to extract road weather information from the VII network. During this step, the data will simply be organized by pre-selected data elements; this will be based on initial probe data research and development. The data will remain in an unprocessed (or raw) format. The data will then be processed using several different data filtering algorithms. This step will enable a first pass for the WDT to eliminate data that is considered extraneous; this is vital to the computationally intensive step that follows involving the quality checking (QC) of the data. QC algorithms are involved in the complex step of processing the data for accuracy against other mobile data and ancillary data sets (e.g. RWIS stations, METARs, etc.). If during this step an observation is deemed either inaccurate or unreliable, a QC flag will be applied, but the data will remain available to the user. After being quality checked, one branch of the data will flow to an output queue to minimize data latency. A second branch (a subset of the full dataset) will be cached and processed to generate statistical values for given locations (grid cell and/or point) and time periods [3]. This should help increase the efficiency of the WDT and provide a manageable data set to users who do not require streaming data. Research will be conducted to design, evaluate, and test the techniques and algorithms that comprise the filtering, QC, and statistical processing components of the WDT.

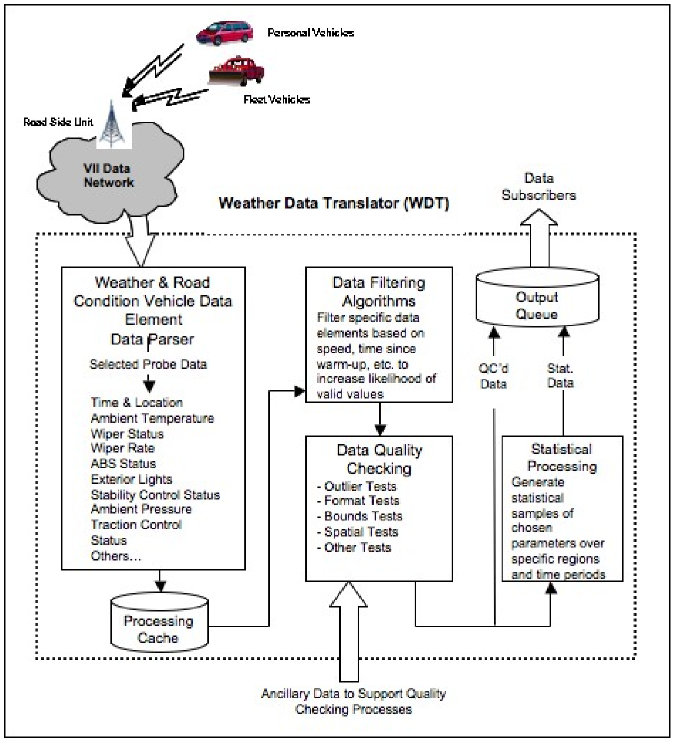

Fig. 4. Illustration of the VII WDT [3].

5. SUMMARY DISCUSSION

VII-enabled data have the potential to provide a significant benefit to the surface transportation industry, specifically roadway operations. The capacity to wirelessly gather vehicle generated observations and diagnostics will likely provide high-resolution data of near-surface atmospheric conditions, along with diagnostic information that can be used to infer the state of the atmosphere and roads (e.g. ABS, wiper state, etc.). Two-way wireless data transmission will be made possible via the use of DSRC, and potentially other wireless communication technologies. In terms of the development of weather-related products and applications, a fundamental component of the VII network will be the transmission of data to RSEs and on to a backhaul network, as this will enable end users (e.g., researchers) to acquire and make use of these data. It is envisioned that these data will be used as either independent observations of road weather conditions, or in conjunction with supplemental observations in order to derive observations, develop road weather products (e.g., fog, precipitation, etc.), or construct applications. The case study presented in section 3.3 illustrates a limited, yet compelling example of the utility of using VII-enabled vehicle data to diagnose areas of precipitation during complex weather events.

In order to demonstrate whether these data will provide the overall benefits discussed above, an extensive statistical analysis must be performed to gauge the quality, accuracy, dependability, and representativeness of the observations. One of the initial steps in this process is the investigation of data obtained from the Detroit PoC test bed. The main goals of the Detroit PoC, as they relate to the evaluation of the efficacy of weather-related vehicle probe data, are to develop the infrastructure (e.g. WDT) that will enable timely processing of the weather-related VII-enabled data, statistically assess and examine data with respect to discrete road segments and temporal scales, and investigate the plausibility of deriving relevant surface transportation information and products. While the numbers of observations from the test bed will be limited, these research and development efforts will help to provide an initial indication regarding the viability of using vehicle probe data in the generation of enhanced road weather products and applications that will lead to improvements in roadway safety, mobility and efficiency.

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