PREPARING TO USE VEHICLE INFRASTRUCTURE INTEGRATION (VII) IN TRANSPORTATION OPERATIONS: PHASE II

BRIAN L. SMITH, Ph.D., P.E.
Associate Professor of Civil Engineering

B. BRIAN PARK, Ph.D.
Assistant Professor of Civil Engineering

HEMA TANIKELLA
Graduate Research Assistant

NOAH J. GOODALL
Graduate Research Assistant

University of Virginia
Center for Transportation Studies

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16. Abstract:

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    The results of the research effort provide tangible evidence of the potential that VII holds in helping VDOT improve its ability to operate the transportation system. The benefits demonstrated in traffic monitoring and signal control indicate that VDOT should remain active in VII development. However, the research results also illustrate the uncertainty that currently exists in the national VII development effort. Because of this uncertainty, large investments in field deployment of "early" VII equipment were found to constitute an unnecessarily risky action. The results of the research support the conclusion that VDOT should partner with other states and the U.S. Department of Transportation to develop the new generations of system operations applications that will take full advantage of VII capabilities once the technology development converges at the national level. In addition, VDOT should critically examine current equipment standards to ensure that new purchases of items, such as traffic signal controllers, provide the flexibility for VII upgrades in the near future.

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FINAL CONTRACT REPORT

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Brian L. Smith, Ph.D., P.E.
Associate Professor of Civil Engineering

B. Brian Park, Ph.D.
Assistant Professor of Civil Engineering

Hema Tanikella
Graduate Research Assistant

Noah J. Goodall
Graduate Research Assistant

University of Virginia
Center for Transportation Studies

Project Manager
Catherine C. McGhee, P.E., Virginia Transportation Research Council

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ABSTRACT

Vehicle infrastructure integration (VII) is an emerging approach intended to create an enabling communication capability to support vehicle-to-vehicle and vehicle-to-infrastructure communications for safety and mobility applications. The Virginia Department of Transportation (VDOT) has been an active participant in the national VII development effort. This research project critically assessed national development activities and quantitatively evaluated two potential VII-enabled system operation applications: traffic monitoring and signal control.

The results of the research effort provide tangible evidence of the potential that VII holds in helping VDOT improve its ability to operate the transportation system. The benefits demonstrated in traffic monitoring and signal control indicate that VDOT should remain active in VII development. However, the research results also illustrate the uncertainty that currently exists in the national VII development effort. Because of this uncertainty, large investments in field deployment of "early" VII equipment were found to constitute an unnecessarily risky action. The results of the research support the conclusion that VDOT should partner with other states and the U.S. Department of Transportation to develop the new generations of system operations applications that will take full advantage of VII capabilities once the technology development converges at the national level. In addition, VDOT should critically examine current equipment standards to ensure that new purchases of items, such as traffic signal controllers, provide the flexibility for VII upgrades in the near future.

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Brian L. Smith, Ph.D., P.E.
Associate Professor of Civil Engineering

B. Brian Park, Ph.D.
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Hema Tanikella
Graduate Research Assistant

Noah Goodall
Graduate Research Assistant

University of Virginia
Center for Transportation Studies

INTRODUCTION

Vehicle infrastructure integration (VII) is an emerging approach intended to create an enabling communication capability to support vehicle-to-vehicle and vehicle-to-infrastructure communications for safety and mobility applications. [As of January 2009, the U.S. Department of Transportation renamed the VII initiative IntelliDrive^{SM}. Given that the new name had yet to be universally adopted at the time this report was written, this report uses the term *VII*.] The full integration of vehicles and infrastructure has long been a vision of transportation professionals, but the lack of available technology had prevented this vision from becoming a reality. However, recent improvements in information technology have led to the development of Dedicated Short Range Communications (DSRC). DSRC is a short- to medium-range communication technology that supports public safety and private operations in roadside-vehicle and vehicle-vehicle communications. DSRC is a technology that enables the deployment of VII. Further, the rapid development of commercial wireless networks also provides the potential to support VII.

The Virginia Department of Transportation (VDOT) has recognized the potential of VII and the significant impact it will likely have on its mission. Because of this, VDOT has been an active member of the National VII Consortium, a group of transportation agencies and automobile manufacturers working together to develop VII. In addition, VDOT has supported applied research to help VDOT position itself to take a leadership role in VII development and to prepare to make the most of VII in its operations in the future. In 2007, the University of Virginia Center for Transportation Studies (UVA CTS) completed Phase I of a research effort to investigate the implications of VII on system operations (Smith et al., 2007). A detailed VII

simulation environment was developed in this phase. In addition, a preliminary traffic monitoring application was developed and evaluated.

This report communicates the results of Phase II of the VII research effort, which focused on two primary areas:

1. *VDOT participation in the national VII development effort.* The national VII development effort changed significantly over the past year. The research team assisted VDOT by representing VDOT at national meetings and exploring the impacts of program changes on potential VDOT uses of VII.

2. *Investigation of VII-enabled operations applications.* While many have referred to "potential" VII benefits for system operations, there is little tangible evidence that this will be the case. The research team did the prototype for and evaluated two "first-generation" VII-enabled system operations applications that hold great potential to support VDOT's mission.

PURPOSE AND SCOPE

The purpose of this project was to provide support to VDOT in preparing for the maximum utilization of VII in system operations. To achieve this purpose, the research focused on (1) representing VDOT in the national VII development effort, and (2) developing and evaluating prototype first-generation VII-enabled system operations applications.

METHODOLOGY

Three tasks were completed to achieve the objectives of this project:

1. *Analysis of the impact of the national VII program on VDOT.* The research team analyzed the national VII program to assist VDOT in its participation in VII development. To accomplish this task, the research team actively participated in the national VII working group, analyzed products of the working group, and developed plans for prototype VII deployment and research programs.

2. *Development of a VII-enabled traffic monitoring application.* A potential VII benefit that is commonly cited is improved traffic monitoring. In order to assess the level of benefit, the research team conducted a simulation study in which a VII-enabled traffic monitoring application was compared to a traditional wireless location technology application in the Tyson's Corner region of Northern Virginia. The prototype VII-enabled application was created using a sophisticated stratified sampling design that takes advantage of VII's ability to select judiciously where and when to sample a targeted set of vehicle locations.

3. *Analysis of VII benefits to traffic signal control.* Another expected benefit of VII that is frequently identified is improved traffic signal control. In this task, the research team evaluated the ability to use the individual vehicular data available from VII to support improved utilization of the "gap-out" feature of actuated signal control. Again, the simulation environment was utilized to quantify the benefit of this VII-enabled application.

RESULTS

Analysis of Impact of National VII Program on VDOT

UVA CTS actively participated in the national VII program in order to (1) gain deep insight into the program and its potential for VDOT, and (2) represent Virginia in the national development effort. Participation in the program included attendance at the following events/meetings:

- December 2007, VII Working Group Meeting, Palo Alto, California
- January 2008, VII Briefing to RITA Leadership, Blacksburg, Virginia
- February 2008, VII Working Group Meeting, Detroit, Michigan
- August 2008, VII Working Group Meeting, Detroit, Michigan
- November 2008, VII Executive Leadership Team Meeting, New York.

Potential VII Pilot Deployments

In 2008, the program went through significant changes, moving away from a focus on the use of DSRC to a greater use of "after-market" and commercial technology. Further, emphasis on field, proof-of-concept testing was reduced. Based on these changes, the research team identified potential VII pilot deployments that VDOT could consider for future work in the area.

In early 2008, the research team worked with VDOT to identify potential pilot deployments of VII in an effort to pursue federal funding under the SafeTrip-21 (Safe and Efficient Travel Through Innovation and Partnerships in the 21st Century) Program. Pilot deployments identified by the project team were proposed for a 2-mi corridor of I-66 and Lee Highway, between Nutley Street and I-495, in Northern Virginia. The projects were as follows:

1. Stop Sign Violation Warning
2. Winter Maintenance
3. Traveler Information.

Details of each project are provided in Tables 1 through 3.

Table 1. Stop Sign Violation Warning

Description	The vehicle's navigation system stores a database of stop sign locations and uses GPS location data to detect if the vehicle is approaching a stop sign at a dangerous rate of speed. If the vehicle is approaching at a rate deemed too fast, the in-vehicle navigation system can then alert the driver. The pilot project will include stop signs along Lee Highway between Nutley Street and I-495. Stop signs at 15 intersections along Lee Highway will be part of the pilot project.
Communications	Commercial wireless
Expected Benefits	Reduction in crashes
Diagram	

GPS – global positioning system.

Table 2. Winter Maintenance

Description	VII RSEs installed along the study area can monitor the status of wipers, headlights, traction control, and anti-lock brakes as well as the road and air temperatures provided by all OBE-equipped probe vehicles. These data will provide transportation management operators and officials with a more accurate picture of weather events on the road. Maintenance vehicles and plows can also be equipped and can transmit chemical levels and application rates. When combined with location data via GPS, TMCs and maintenance departments can more efficiently deploy and operate vehicles.
Communications	Both DSRC and commercial wireless
Expected Benefits	Allows more efficient use of maintenance vehicles, fast response time to changing conditions, and slight savings from more precise chemical applications.
Diagram	

GPS – global positioning system; DSRC – Dedicated Short Range Communications; TMC – traffic management center; OBE – on-board equipment; RSE – road-side equipment.

Table 3. Traveler Information

Description	Using data transmitted both wirelessly and to RSEs from probe vehicles, VDOT can obtain travel times for the project area along I-66 between Nutley Street and I-495. VDOT can provide these travel times, both current and historical, to users via mobile devices, to probe vehicles via OBE, and to the media via the web. VDOT can also provide information on parallel routes, including the Metro Orange Line, and parking availability at the Dunn Loring and West Falls Church stations.
Communications	Both DSRC and commercial wireless
Expected Benefits	Improved decision-making capability for travelers.
Diagram	

DSRC – Dedicated Short Range Communications; TMC – traffic management center; OBE – on-board equipment; RSE – road-side equipment.

In order for these pilot projects to be implemented, VDOT would need to complete the following:

- Purchase on-board equipment (OBE)-equipped probe vehicles.
- Install OBE on three or four VDOT maintenance vehicles.
- Develop a geographic information system (GIS) database of the 15 stop sign locations and integrate it into a navigation system.
- Install road-side equipment (RSE) at three locations along I-66 between Nutley Street and I-495.

Identification of VDOT Action Plan

In 2008, VDOT made significant strides in becoming a major player in national VII development. However, given resource constraints, it is essential that the future involvement of VDOT result in tangible benefits. The research team sees two directions VDOT can consider:

1. *Pilot deployments.* VDOT can follow the lead of states such as California and Michigan and conduct pilot deployments (such as those described previously).

2. *System preparation.* VDOT can seek to develop the operations tools that take advantage of VII capabilities. These tools (such as signal timing) do not currently exist.

Based on the current national environment, Option 2 was identified as being best suited to VDOT. In addition, pilot deployments should be considered when targeted, low-investment opportunities are available. Large investments in pilot deployments are not recommended for the following reasons:

- There is considerable uncertainty in the future of DSRC as the communications "backbone" of VII. Recent federal initiatives, such as SafeTrip-21, have "opened up" VII testing to use commercial wireless communications, as opposed to DSRC. Thus, large-scale investments in a DSRC infrastructure are highly risky at this stage of VII development.

- Pilot deployments involve such a small number of vehicles that the results are not of significant use in evaluating system-level benefits. Given that VDOT is charged with operating the large-scale surface transportation system, it is essential that VII applications provide true system-level benefits. These benefits can be assessed only in tests with large numbers of equipped vehicles.

Therefore, in order to take a leadership role in VII system preparation, VDOT initiated a national pooled-fund study entitled *Research Program to Support the Research, Development, and Deployment of System Operations Applications of Vehicle Infrastructure Integration (VII).* The study was established to serve as the focal point for VII activity by state transportation agencies. Key aspects of this study are:

- It is designed to focus on the development and evaluation of VII mobility applications of interest to transportation agencies, filling the gap created by the recent changes in the federal VII program.
- It will be guided by the participating agencies with a steering committee structure.
- It is designed to complement and coordinate with the federal VII program.
- It was designed as a phased 4-year program. This first 2-year phase is intended for application development and simulation evaluation. The second 2-year phase focuses on field demonstration and evaluation. It is expected that within 2 years, the uncertainty currently associated with the program will be resolved, making field demonstrations less risky.

VDOT has committed to leading this project. VDOT will provide $75,000 in funding per year, and Virginia will serve as the lead state. To date, Florida, New York, Michigan, Texas, California, and the Federal Highway Administration have committed to joining VDOT in this activity, with initiation of the project expected in the summer of 2009.

Development of VII-Enabled Traffic Monitoring Application

The state of the art in traffic monitoring is to utilize wireless location technology as a means to track "probe" vehicles as they traverse the transportation network. The probe vehicle "track" provides information on vehicle locations over time, which can be used to derive travel times and speeds on particular roadway links. The wireless location technology most commonly

used is cellular phone GPS locations and/or cell handoff information. These systems are proving to be capable of providing quality data on heavily traveled freeways, but they do suffer from limitations on less traveled facilities. One limitation is that the systems do not allow for sophisticated sampling of vehicles. In other words, they simply "track" vehicles if they happen to include occupants using a particular wireless device. There is no capability to tailor samples to specific locations of the transportation network or specific vehicles.

VII, on the other hand, will provide the ability to develop more sophisticated sampling approaches. Given that VII will be dedicated to surface transportation applications, it will allow for more specific targeting of vehicle location/speed samples. In other words, VII will allow traffic monitoring systems to identify specific vehicle sets on specific roadway links to track, based on the intended use of the monitoring data. Therefore, VDOT will be able to leverage investments in VII infrastructure by processing and analyzing VII probe data to derive travel time data. In order to realize this opportunity, there is a need to develop the related processing and analysis algorithms. In this research, a sophisticated stratified sampling design was developed to take advantage of the new sampling capabilities provided by VII and provide the needed monitoring algorithms. This design was then implemented in a simulation environment in order to estimate its performance in the Tyson's Corner region of Virginia, in comparison to the simple random sampling designs used because of the limitations of current wireless location technology.

Stratified Sampling

An attractive alternative to random sampling (often referred to in the probe-based traffic monitoring literature as a "penetration rate") is stratified sampling (Rao, 2000). In this approach, the sample space (in the case of traffic monitoring, this would be the set of vehicles distributed throughout the transportation network) is subdivided into homogenous regions (strata) and sample sizes are specified for each of these regions. In other words, stratified sampling design allows one to fine tune where samples of vehicle location are collected based on the characteristics of sub-areas of the transportation system, not simply based on whether or not a cell phone is being used in a vehicle. Stratified sampling has been successfully used in challenging sampling applications in domains such as hydrology (Thomas and Lewis, 1995) and structural monitoring (Williams et al., 2006). Implementation of stratified sampling involves the following key steps:

1. choice of a stratification variable
2. determination of number of strata boundaries
3. allocation of sample sizes to strata.

For probe-based traffic monitoring, the research team elected to use maximum roadway speed as the stratification variable. Maximum roadway speed did an effective job of separating roadway "classes" (i.e., those with high maximum speeds are generally high-volume freeway facilities, while lower speed facilities tend to be local facilities of less significance to regional monitoring). In Step 2, strata boundaries were identified based on 5-mph increments in the maximum roadway speed stratification variable, plus an attempt by the analyst to group together geographically "near" facilities with similar maximum speeds. This resulted in eight strata,

presented later in this report. Finally, sample sizes were allocated to the eight strata based on expected speed variance in each stratum (estimated using the simulation model).

Simulation Evaluation

In order to measure the impact of sophisticated stratified sampling designs made possible by VII, the research team conducted a case study using simulation. Using a microscopic simulation of the Tyson's Corner network, illustrated in Figure 1, the team created a probe-based traffic monitoring application using traditional random sampling and stratified sampling.

The eight strata identified using the method described previously are illustrated in Figure 2. Table 4 explains the percentage of total samples allocated per strata.

To compare the sampling methods, speed estimation error was used as a performance metric. The fundamental question in the evaluation was: Does stratified sampling produce better results with the same number of samples (i.e., the same total sample size) as does traditional random sampling? The research team applied the sampling methods for different values of total samples sizes, beginning at 2,500, representing the number of samples that result from tracking 5% of the total number of vehicles in the network (this has been established as the minimum threshold necessary for effective monitoring with simple random sampling). Table 5 presents the percentage difference between stratified and simple random sampling for the different values of total samples. As one would expect, as the number of samples increased, both methods had reduced error. However, using stratified sampling allowed for the same accuracy with only 500 samples as can be achieved with 2,500 samples in simple random sampling. Thus, the research clearly indicates that VII will allow for significantly improved probe-based monitoring, even when only 1% of vehicles are sampled.
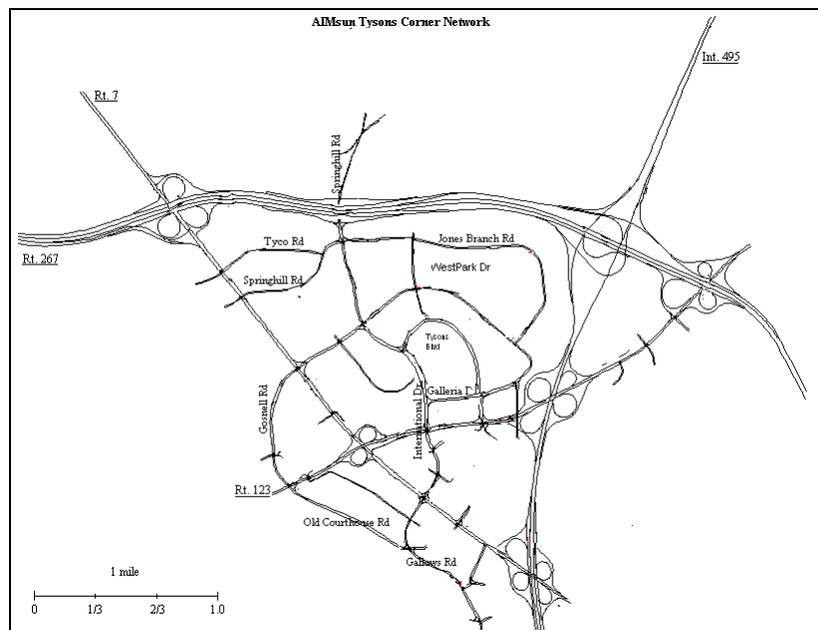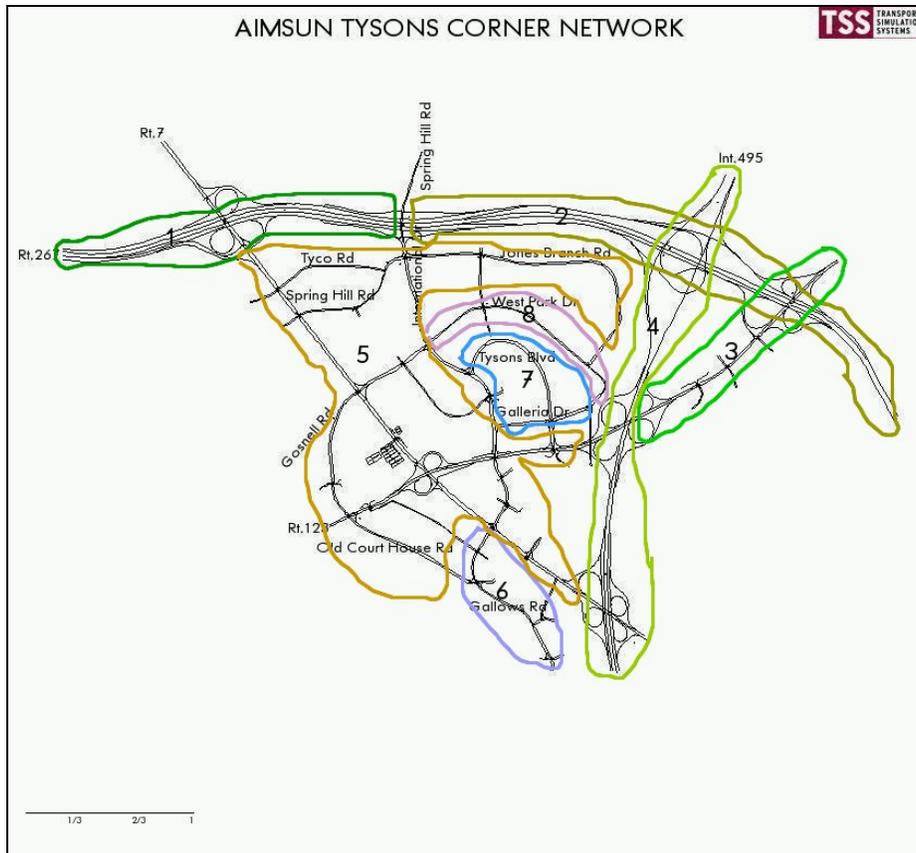

Figure 1. Tyson's Corner Simulation Model

Figure 2. 8 Strata Regions for Tyson's Corner Case Study

Table 4. Sample Allocation Per Strata

Strata	Sample Percentage
1	0.7%
2	13.5%
3	4.4%
4	6.2%
5	12.8%
6	23.7%
7	26.3%
8	12.4%

Table 5. Speed Estimation Error

Total Samples	Cumulative Percentage Error	
	Stratified	**Random**
200	7.60%	7.21%
500	6.85%	7.69%
1000	6.54%	7.22%
1500	6.15%	7.05%
2500	6.10%	6.88%

These findings have significant implications for VDOT deployment of VII infrastructure. Given that VII holds the potential to provide travel time information with quality on par with current commercial travel time services, even when only 1% of all vehicles is "VII-equipped," it demonstrates a concrete benefit that VII investment will provide at early stages of VII development.

Analysis of VII Benefits to Traffic Signal Control

The premise behind the gap-out feature in actuated traffic signal control is to use intersection capacity most efficiently by providing right of way to the approach with the greatest demand. When one approach has the green indication, the time between actuations of the system's vehicle detectors is monitored. If the time between actuations reaches a pre-defined threshold, defined as the "gap-out" time, this indicates that there is not sufficient demand on this approach to continue the green indication. Then, if the vehicle detectors on the other approach have detected one or more vehicles in queue, the green indication is reallocated to this approach. What is important to note in traditional actuated signal control is that, based on the design, no vehicles may be served during the gap-out time period while the controller is waiting to "see" if any more vehicles arrive. This represents unused capacity in the system.

VII will provide detailed individual vehicular data, including vehicle headways. In essence, these detailed data will allow signal systems to "look" further upstream and to gather a much more complete understanding of vehicle locations that from a simple presence detector. With this enhanced information, a traffic controller will be able to terminate the current green immediately (based on the knowledge that upstream headways are above the gap-out time threshold) without "wasting" the gap-out time waiting to see if vehicles arrive at a fixed detector. Thus, the VII-enabled approach (referred to as dynamic gap-out) developed and evaluated in this research allows for fuller use of intersection capacity.

The research team developed a dynamic gap-out feature that takes advantage of higher resolution vehicle location data available in VII. With the dynamic gap-out system, vehicle headways were analyzed at a distance of 300 ft upstream of the stop bar. With this added functionality in the actuated controller, the controller can predict if a vehicle will reach the stop bar within the pre-determined gap-out time. Hence, the controller would be able to predict if gap-out will occur. This then allows the gap-out time to be transferred to demand on the other approach.

The benefits of dynamic gap out were estimated using a microscopic simulation model (VISSIM) to investigate signal control at a generic four-legged intersection. The traffic signal timing plans were optimized for both traditional and dynamic gap-out cases to ensure a "fair" comparison between the two methods. The evaluation considered 50 different volume (i.e., demand) scenarios, covering volume-to-capacity ratios from 0.1 to 1.0. The results indicated that for volume-to-capacity ratios of 0.25 or larger, the dynamic gap-out approach reduced delay consistently on the order of 12%.

CONCLUSIONS

- VII holds potential in helping VDOT improve its ability to operate the transportation system.

- The benefits demonstrated in traffic monitoring and signal control indicate that VDOT should remain active in VII development.

- Because of the uncertainty that currently exists in the national VII development effort, a large investment in field deployment of "early" VII equipment is an unnecessarily risky action.

- VDOT should partner with other states and the U.S. Department of Transportation to develop the new generations of system operations applications that will take full advantage of VII capabilities once the technology development converges at the national level.

RECOMMENDATIONS

1. *VDOT's Operations and Security Division should remain actively involved in the National VII Consortium.* The results of this research demonstrate that decisions currently being made by the consortium, such as VII architecture details, will have a significant impact on VDOT's ability to use the data resulting from VII effectively to support operations. As an active member of the coalition, VDOT can be sure that VII development will occur in a way that will support VDOT's future needs.

2. *VDOT's Operations and Security Division should continue to lead the national pooled fund study to develop and evaluate VII-enabled system operations applications.*

3. *VDOT's Traffic Engineering Division and Operations Regions should critically examine current equipment standards to ensure that purchases provide the flexibility for VII upgrade in the near future.* Examples of this include the following recommendations that are being developed by AASHTO's VII Working Group:

   - By 2012, all new traffic signals and traffic signal modernizations should include a DSRC radio broadcasting basic SPAT (Signal Phase and Timing) and GPS corrections for lane-level positioning accuracy.

   - By 2014, all toll authorities in the United States should use DSRC, operating at 5.9 GHz, for all tolling activities

COSTS AND BENEFITS ASSESSMENT

Given that VII is still in the development stages, there is not sufficient information to assess quantitatively the costs and benefits of the use of VII. However, this research clearly

demonstrated that VII offers the potential to benefit VDOT by supporting collection of high-quality traffic data (even in early stages of VII incorporation in private automobiles) and by supporting significantly improved use of the gap-out feature in traffic signal systems.

A report prepared for the Federal Highway Administration placed the national estimate for delay caused by inefficient traffic signal timing at 5% of total delay (Cambridge Systematics, Inc., 2005). The most recent update to the Texas Transportation Institute Urban Mobility Report estimated total delay on the Richmond area road network at 10,081,000 person-hours in 2005 (Lomax and Schrank, 2007). Applying the 5% from the former report results in 504,050 person-hours of delay attributable to inefficient signal timing. The Texas Transportation Institute report used a value of $14.60 per hour as the value of travel delay. To be conservative, one can assume that only a fraction of the overall signal delay can be mitigated by VII data applications. Assuming 25% of 504,050 person-hours and a value of $14.60 per hour yields a benefit of more than $1.8 million per year for this one application. Further, other operations applications not yet examined will also likely benefit from VII. Of course, the potential costs of deploying and operating a VII network are significant. Thus, further research is essential to provide a foundation (the simulation environment) to conduct more sophisticated cost/benefit analyses as VII matures.

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