VEHICLE INFRASTRUCTURE INTEGRATION (VII)

U.S. DOT DAY-1 APPLICATION DEVELOPMENT PLANS

U.S. Department of Transportation
Federal Highway Administration

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VERSION 1.2

Booz | Allen | Hamilton

REVISION HISTORY

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July 2006	1.0	Initial Draft
August 2006	1.1	Revised after receiving comments from U.S. DOT
November 2006	1.2	Revised after receiving comments from Mitretek

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1. EXECUTIVE SUMMARY

The purpose of this Application Development Plan (ADP) Report is to provide USDOT with guidance and suggestions on major program elements needed to support deployment of Day-1 public sector applications such that they would be "widely available" when the first generation of VII vehicles are introduced to the public (currently targeted for 2011). These program elements may include technical development activities such as fundamental research, proof of concept testing, and prototyping of applications—as well as deployment related tasks such as funding, quality control, programmatic oversight, and other support activities to state and local transportation agencies who will be involved in rolling out many of the public sector applications. Additional objectives of this report include:

– Identify key challenges and risk areas associated with developing and deploying each of the public sector applications,

– Highlight key cross-cutting application development issues that should be addressed by USDOT.

While a high level description of each application is provided (including *possible* schemas for the overall architecture and operation of the application), this Report is not intended to establish an initial baseline concept of operations for each of the applications. Such background information is provided only as an aid in describing activities/challenges that will need to be addressed in developing the public sector applications.

This Executive Summary is organized as follows:

- Background
- Overview of Application Development Process
- Cross-Cutting Issues
- Summary of Action Items

1.1. Background

VII represents a new paradigm for surface transportation—one that reflects a new spirit of cooperation between industry (i.e., automakers, suppliers, communication service providers) and government (i.e., federal, state and local). VII presents opportunities to advance surface transportation safety, mobility, and productivity through cost effective wireless communications between vehicles and the infrastructure.

Under direction of the VII National Working Group, several applications (or use cases) were selected for deployment during the initial rollout of the VII network and simultaneous introduction of VII vehicles—both of which are scheduled to occur in the 2011 to 2012 timeframe. Various stakeholders analyzed and prioritized these applications during the VII

Working Group Meeting held from June 28 to 29, 2005, and these applications continue to be the focus of development efforts. Table 1 shows the current set of Day-1 use cases[1].

Table 1 – Day-1 Use Cases

#	Day-1 Use Case	#	Day-1 Use Case
1	Emergency Brake Warning	11	Electronic Payment: Toll Roads
2	Traffic Signal Violation Warning	12	Traveler Information
3	Stop Sign Violation Warning	13	Ramp Metering
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5	Display Local Signage	15	Pothole Detection
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7	Present OEM Reroute Information	17	Corridor Management Planning Assistance
8	Present Traffic Information	18	Corridor Management Load Balancing
9	Electronic Payments: Parking / General	19	Weather Information: Traveler Notification
10	Electronic Payments: Gasoline	20	Weather Information: Improved Forecasting

The Day-1 applications were selected based on several factors including high-priority safety, mobility, and commerce needs; ability to be implemented during the timeframe of initial VII deployment; compatibility with low penetration of VII-equipped vehicles; and ability to test the system and inform decision making.

Application development responsibilities are spread among a variety of public and private entities. In Table 1, use cases numbered 1 through 10 were identified as "private sector" indicating that automakers and industry would have a lead role in developing these applications. For several applications, partnerships of federal, state, and local governments will sponsor overall development, prototyping, and deployment—and these applications are identified as "public sector" and are numbered 11 through 20 in Table 1. However, as will be discussed in the next section, it is clear that since the vehicle provides the raw input (via probe data) that powers all of the applications, and because government will be a stakeholder in safety and mobility applications, the development of all applications listed in Table 1 are very much a joint effort between the private and public sectors—particularly during early development phases.

The documentation of use cases was the first step in refining the Day-1 applications. The objective of the use case effort was to: (1) identify key stakeholders for the application, (2) describe the logical relationships between them, and (3) identify high-level functional requirements for key components of the VII system. The use cases for Day-1 applications were completed in April of 2006, and are available under separate documentation.

This Application Development Plan (September 2006) represents the next stage in the process, and is envisioned as only a starting point for moving forward. As application development

[1] VII Day-1 Application Descriptions as Agreed Upon at the June 28-29 VII Working Group Meeting, VII Working Group, published officially on August 23, 2005.

proceeds, technical challenges will be identified, new solutions will be proposed, and revised application architectures may be necessitated. This document is meant to outline the steps toward refining, implementing, and deploying these applications for Day-1.

In researching and developing these high-level application development plans, it became clear that some application pairings would involve very similar, or even identical, development tasks, and would likely be conducted by the same development teams (e.g., government entities, contractors, and supporting resources). Specifically, the Weather Information applications, (Traveler Notification and Improved Forecasting) have been combined into a single development plan, and, the Corridor Management applications (Planning Assistance and Load Balancing) have also been combined.

1.2. Overview of Application Development Process

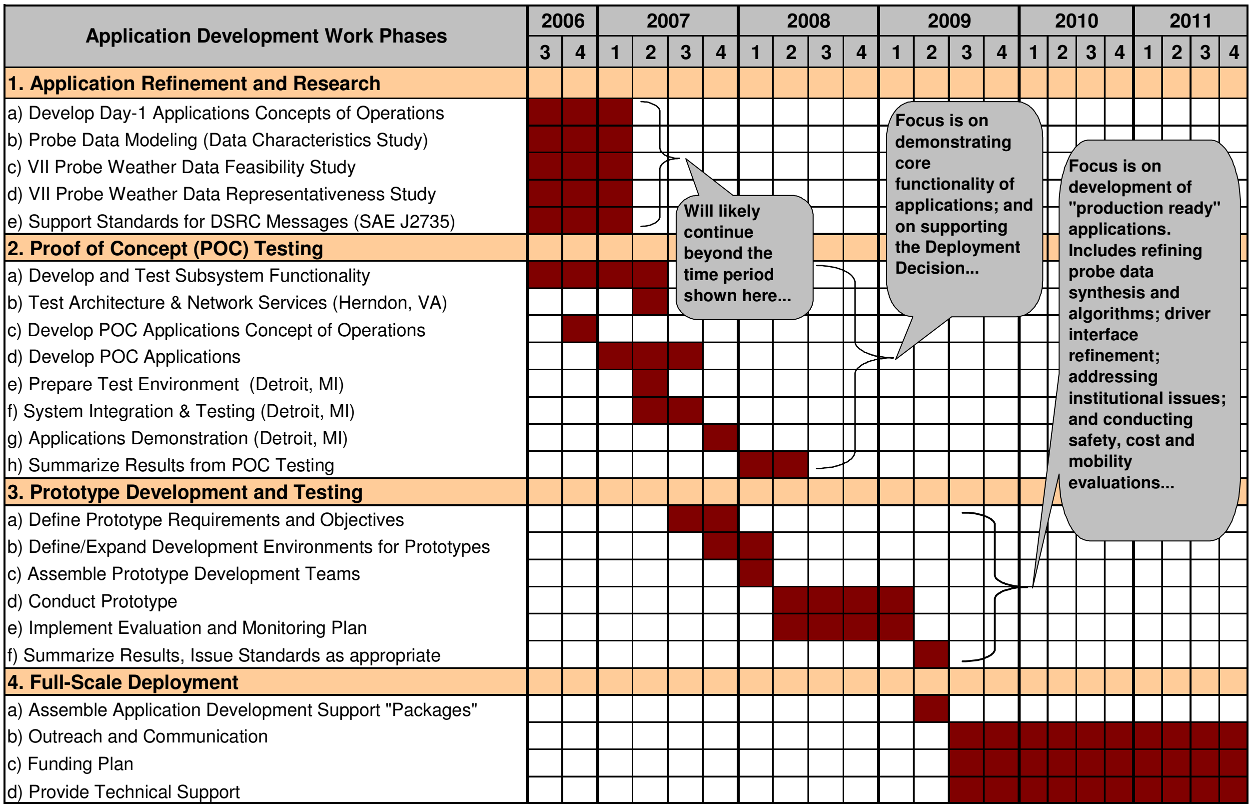
The development and deployment of the public sector Day-1 applications will generally consist of the key phases listed in Table 2.

Table 2 – Application Development Phases

Phase	Objective	Timeframe
Application Refinement and Research	• Develop application-specific concept of operations. • Perform fundamental research that will impact application development and deployment.	October, 2006 thru March, 2007 (and beyond)
Proof of Concept (POC) Testing	• Validate technical viability of VII concept including wireless communications, network design, and network services. • Implement a limited version of each Day-1 application to showcase functionality and demonstrate value-added features for motorists; Demonstrate that the VII system is capable of supporting the Day-1 applications.	October, 2006 thru June, 2008
Prototype Development and Testing	• Refine application software, address human factors issues, resolve institutional challenges, • Demonstrate actual safety and/or mobility benefits of the applications.	July 2007 thru June, 2009 (and beyond)
Full-Scale Deployment	• Assemble application support “packages” including best practices; core software modules; lessons learned, etc. • Establish “State VII Implementation Compliance Plans” and implement a USDOT project office to monitor progress of stat and local agencies.	June, 2009 thru Introduction of VII vehicles (and beyond)

Exhibit 1 provides a high-level schedule for the application development process. Each major application development phase is reviewed in more detail in the following sections.

Exhibit 1 – Generalized Day-1 Public Sector Applications Development Schedule



Public versus Private Sector Applications. The development efforts for both public and private sector applications will proceed along similar paths up through the Proof Of Concept (POC) testing phase—and the POC itself will very much be a jointly executed effort by industry and government (as discussed in the sections that follow).

In contrast, after POC testing has concluded, the development of the public and private sector applications will proceed along more separate paths. Commercial sector stakeholders will be independently responsible for development and deployment of their own “private sector” VII enabled applications—particularly those focused on convenience, customer services and/or electronic purse type of applications (with the notable exception of toll collection). The development of such private sector applications will however need to proceed along a path that is consistent with the overall technical, organizational and management structure of the VII network—and to this extent, private sector application development efforts are expected to be coordinated with the VII operating entity, of which the government (federal, state and local) will be a major constituent.

Additionally, the development of safety related private sector applications by each of the vehicle OEMs must also be coordinated with government (most likely NHTSA and FHWA) to ensure adequate consistency from a human factors perspective. NHTSA and USDOT will also likely have an oversight role to ensure that performance and functional parameters among the safety applications from various vehicle OEMs are adequately standardized so as to ensure that maximum safety benefits are indeed realized. While there is no direct oversight by NHTSA at this point in time, it is likely that post-POC, NHTSA will want to become more deeply involved with applications such as electronic brake light warning, collision avoidance enhancements, as well as general conveyance of roadway signage, weather, and traveler information to the driver.

While private sector applications will of course be led by commercial companies, the development and deployment of public sector Day-1 applications will be coordinated by government entities. The remainder of this Executive Summary (and entire Report) is focused on activities associated with development and deployment of the public sector applications.

1.2.1. Phase 1. Application Refinement and Research

The development of VII-enabled public sector applications is currently (October 2006) in the refinement and research stage. Key activities to be completed under this phase include the development of detailed concepts of operation of each application, as well as selected research activities related to vehicle probe data management and analyses.

Day-1 Concepts of Operation. The focus of these ConOps would be on describing the technical, operational, and organizational aspects of how the application will be implemented at Day-1. For each public sector application, there remains key technical, operational and/or architecture related issues that are either unresolved or not well understood. These key issues are outlined in the sections following this executive summary for each application—and are exactly they types of issues that would be addressed during the development of Day-1 ConOps, In addition, the development of the ConOps will likely provide important insight regarding the manner in which the applications should be demonstrated during the POC testing. The development of the ConOps should be led by USDOT, but be developed in full cooperation with those entities that will in fact be integral to the operation and execution of the application.

Fundamental Research Activities. The understanding and deployment of many of the public sector applications could benefit through fundamental research related to probe data generation and analyses. Specifically, such research is focused on how VII data streams from the vehicle would be used to supplement or replace existing traffic and traveler information related systems. Questions such as: what specific data elements should be included in probe data?: how many snapshots should be retained in a given probe message?: what should be the rules governing “ID persistence” between snapshots?; what level of market penetration is needed to support useful analyses for specific applications?, and, what are the benefits of allowing for localized control of probe data generation processes?—are all questions that can be initially explored through simulation, modeling and “soft” research activities. Therefore, it is recommended that such research be conducted in parallel with, and continuing beyond, the development of Day-1 ConOps for each application. The following are some of the key research activities identified as important to the development of the Day-1 applications:

- *Probe Data Modeling and Simulation (current Data Characteristics Study)*:
- *Signal Timing and Ramp Meter Research and Algorithm Development:*
- *Corridor Management and Load Balancing Research:*
- *Support of SAE J2735 Message Set Development:*

1.2.2. Phase 2. Proof of Concept (POC) Testing

The objective of the VII Systems Integration and Proof of Concept (POC) testing is to provide sufficient information to government and industry stakeholders about the viability of the VII technology, network architecture, and operations in order to support a "deployment decision". The focus is on a technical demonstration of the VII applications, as well as providing a preliminary but representative showcase of the value of the application to motorists, transportation agency officials, and the U.S. DOT. Thus, the POC is segmented into three distinct phases with differing objectives:

1. *Laboratory Development and Testing:* Test the VII system functionality and demonstrate that the architectural components and systems meet the specified requirements. This work will largely be completed at Booz Allen Hamilton's facilities in Herndon, Virginia, and will be begin during the last quarter of 2006. While most of this work will be completed by mid 2007 as shown in Exhibit 1, the laboratory testing facility will remain operational and can be leveraged for a variety of special tests as needed.
2. *Systems Integration and Testing:* Demonstrate that from a technical perspective, the network, on-board equipment (OBE), roadside equipment (RSE), and other VII system components are functionally integrated, can operate in a real-world environment, and can support the basic end-to-end services needed for the Day-1 applications. This systems integration work will be done in the Detroit Michigan development and test environment (DTE), and will proceed during the mid-2007 timeframe. (A more complete description of the DTE is available under separate cover.)
3. *Application Integration and Testing:* Demonstrate the value-added mobility and safety services that can be delivered to motorists by the public sector using broadcast type messages. This work is targeted to be completed during the later quarter of 2007 and into early 2008 as shown in Exhibit 1.

The later part of the POC will focus on demonstrating end-to-end functionality for several applications, and will be the first complete demonstration of the applications in a real-world environment. The focus of the POC is not to deliver production-ready software, processes, and component designs for the public sector applications, (this level of development is targeted for the prototype phase). Rather, because of the limited number of vehicles to be involved in the POC (between 50 and 75), and because of schedule considerations, the applications will be demonstrated using simplified probe data algorithms for analyses of traffic, weather and traveler information. In addition, much of the "content" of the messages to be broadcast to vehicles (whether it is traveler, traffic, incident, or weather related) will likely come from conventional sources of such information, or will be developed using special "work around" processes. Thus, the applications to be demonstrated during POC will represent application "stubs", or abbreviated versions of the applications that are likely to be available at Day-1.

The specific functionality and architecture for each of the public (and private) sector applications will be detailed in a POC Concept of Operations document that is jointly being crafted by the VIIC and USDOT. This document will list the performance and functional specifications for each application, as well as test conditions and demonstration scenarios to be used to verify performance of the applications.

"Deployment Decision". At the conclusion of the POC, (scheduled for mid 2008) a comprehensive Report will be developed that documents the performance and functionality of the VII components, system, and network. An assessment of the applications that were demonstrated will also be conducted that includes technical viability, driver acceptance, overall benefits and anticipated technical, economic, and institutional challenges associated with implementing the application on a national (large scale) basis. The POC Results Report will be jointly authored by USDOT and the VIIC. Based on the outcome of the POC Report, a decision will be made as to whether the VII concept is technically viable, economically feasible, and can be implemented in an effective and efficient manner. At this milestone, decisions about if and how to proceed with development of the VII concept will be jointly made by government and industry (including the VII Working Group), and if necessary, what significant changes in the concept or technology are needed before proceeding.

1.2.3. Phase 3. Prototype Development and Testing

Once a decision to proceed with the VII program has been made, the application development effort will focus on building prototypes of each public sector application. The intention of this phase would be to produce near "production ready", or fully functional designs that would be representative of an application that could be deployed on Day-1. The specific objectives for the applications prototype effort would include:

- development of large scale data analyses methodologies;
- create/capture such analyses and techniques in core software applications or "modules";
- develop a "working consensus" with the auto-industry on how the on-board application component will operate—including filtering and presentation of safety related information to the driver.
- refine interface specifications with various other entities involved in the application…including any third-party information providers that may be involved in the application;
- document management and business models needed to implement the public sector applications;
- and, synthesize various lessons learned during the prototype development.

These work products would then be assembled into a "support" packages such that transportation agencies could utilize the information to help them implement the applications on a local level. The application prototype development effort would proceed immediately after the POC, and it is estimated that such prototypes may take 1 to 2 years to fully develop and demonstrate—although there are many unknowns at this point and we suspect that knowledge gained during development of ConOps for individual applications, as well as testing during the POC will have a major impact on the manner in which the prototype development efforts take place.

To help accelerate widespread deployment of the public sector applications, it will be important that "core" software modules, database designs and analyses techniques be well documented during the application prototype development efforts. These "deliverables" would likely focus on software to support probe data analyses; syntheses and integration tools for leveraging non-VII transportation relevant data; and on tools for automating and managing the development and delivery of WAVE formatted traveler information messages.

In addition to the software modules and analytical support tools described above, an overall prototype "Results" Report would be developed. This report would describe and document lessons learned throughout the development effort relative to both technical and operational issues surrounding the applications, as well as programmatic and management issues. Such management issues might include for example: handling of jurisdictional conflicts; handling of network failures; and/or management of customer (or public) interface issues.

1.2.4. Phase 4. Full-Scale Deployment

At this point in time, it is assumed that State and local agencies will assume a leadership role in the deployment of VII public sector applications—including traveler and traffic information, weather and road condition advisories, corridor management, and traffic signal system optimization. This would seem appropriate since much of the public sector roadway related information that would be useful to motorists would originate at the local level. While it is still unclear exactly what level of probe data processing will be done at a national, (or centralized) level versus at a local (decentralized) level, it is still hypothesized that the state and local agencies will have a pivotal role in controlling the message content, and the administration, of the public sector applications within local regions.

At the same time, the expectations of the motoring public will be that the public sector applications will be widely available as soon as VII equipped vehicles become available in the marketplace. Since VII vehicles will be distributed more or less evenly throughout the country, this means that the public sector applications must be implemented and operating in essentially all metropolitan areas throughout the US in the 2011 to 2012 timeframe (to coincide with the introduction of the VII vehicles). It is therefore important that USDOT, together with State and local partners, implement a highly structured approach for deploying the VII applications. In other words, historical approaches that would allow for states to gradually implement new transportation services over a long time period will probably not be acceptable to the motoring public, or to the vehicle OEMs.

Develop "State VII Implementation Compliance Plans"

One possible approach would be for USDOT to develop and monitor state-based "VII Compliance Plans" that would require States to pursue a path toward deployment. The USDOT would develop an overall template for States to follow in developing their VII Compliance Plans—and would include key milestone dates that would need to be met.

The USDOT, (likely in cooperation with the Operating Entity), would then set up a "*VII State Compliance Project Office*" which would be responsible for monitoring the progress of states (and likely of major metropolitan areas) in meeting the milestones and other activities outlined in their State VII Compliance Plans. Various sub teams within this Federal office would likely be developed to focus on specific geographic areas—and/or perhaps on certain types of operating environments; for example; a " State Compliance Team; an MSA Compliance Team; a "Rural Area Compliance Team". All of these Teams may in turn be subdivided based on geographies within the country.

The USDOT VII *State Compliance Project Office* would also provide an array of technical products and services to support the States and local transportation agencies in deploying the public sector applications within their state. At the conclusion of the prototype development and testing, a comprehensive "Application Development Support Package would be assembled. This package would include the results from the Prototype testing, but would also include various background materials (ConOps), information about the "Operating Entity", VII contractors and resource references. Such support packages would constitute an important tool in helping to spur widespread deployment of the applications.

1.3. Cross-Cutting Issues

There are selected issues and tasks related to VII implementation which, depending on they are resolved, may impact the manner in which public sector applications are designed and implemented—and/or may impact overall VII network and operational features. Such issues and tasks include:

- Centralized versus Decentralized Application Hosting,
- VII "Operating Entity" Structure,
- Overall VII Network Operating Costs
- Alternatives Analyses

These issues and tasks can be addressed in parallel with development of the public sector applications so as to help support the "Deployment Decision" and ensure that application development is proceeding under the appropriate assumptions about how the VII network will operate.

1.4. Summary of Action Items

The U.S. DOT should consider moving forward with the following activities in the near-term to support nationwide deployment of the public sector applications:

- Continue to support fundamental research activities related to probe data analyses:
  - Expand simulation and modeling studies to explore how probe data could be used to measure the effectiveness of traffic signal control systems—and thus help with" fine tuning" of timing plans.
  - Conduct fundamental research related to corridor management including; development of algorithms for analyzing roadway network performance from probe data; modeling and simulation to understand how opt-in origin/destination data could be utilized for corridor planning assistance; and, research to address how broadcast messaging capability could best be leveraged to influence driver behavior.
  - Continue to fund research related to synthesis of weather related probe data with conventional weather information sources.
  - Continue to support the development of ongoing and new standards and protocols such as SAE J2735 and the Electronic Payment Systems National Interoperability Specification (EPSNIS).

- Initiate development of more robust Concepts of Operation for each of the Day-1 public sector applications. Involve key State, local, vehicle OEM, and other private sector stakeholders in the development of the Concepts of Operation. Focus initially on the Traveler Information and Electronic Toll Payment applications.
- Analyze additional "Day-2" use cases to determine if the current VII architecture, components and services can support their requirements—or whether modifications to the VII concept are needed.
- Develop a detailed "Applications POC Concept of Operations" that describes the performance and functional specifications for each application to be implemented during the POC, as well as test conditions and demonstration scenarios to be used to verify performance of the applications.
- Conduct POC testing to demonstrate the viability of the VII concept and technology, and to ensure that it is capable of supporting the final Day-1 applications.

Some of the longer-term actions that the U.S. DOT should consider include:

- Begin to craft high level plans for development of prototype Day-1 public sector applications. Consider the following: when prototype work can begin and whether it could overlap with POC testing; what resources and capabilities are needed of contractor teams; what application prototype development efforts might logically be grouped together to reduce redundancy; what, if any, additional development and test environments will be needed (in addition to the Michigan based DTE) to support prototype development; how many vehicles would likely be needed to support these additional test environments—and will vehicle OEMs be supportive of multiple DTEs. Also prepare a plan for monitoring the prototype efforts, and evaluating the costs and benefits of the public sector applications.
- Consider when and how NHTSA should become involved with developing "best practices" or guidelines for how safety related information is conveyed to the driver. Initiate human factors research related to conveyance of public sector safety and mobility messaging.
- Initiate an investigation of trade-offs involved in centralized (network level) versus decentralized (local level) processing of probe data to support various public sector applications. Evaluate and inventory the current capabilities of State and local TOCs/TMCs for executing their role in the public sector applications. Explore possible hybrid approaches to probe data analyses.
- Together with the VIIC and the Working Group, define a "strawman" structure for the VII "Operating Entity" that would be charged with the management and operations of the VII network and services.
- Initiate a more robust analyses of total implementation and operating costs for the VII infrastructure—and begin to consider long term cost allocation and funding models that would support on-going operations.
- Begin to document a more formal "alternatives analyses" that explores other technological approaches (in place of the VII/DSRC concept) for achieving the desired safety and mobility benefits. Review costs, benefits and ease of implementation issues for these other alternatives.

- Begin to consider how USDOT would work with State and local partners to implement the Day-1 applications on a large scale basis so as to coincide with the availability of production VII vehicles. Evaluate issues related to development of “State VII Compliance Plans”, and, the formation of a USDOT “VII State Compliance Project Office” that would be responsible for assisting States with implementation and monitoring progress.

2. INTRODUCTION

The purpose of this Application Development Plan (ADP) Report is to provide USDOT with guidance and suggestions on major program elements needed to support deployment of Day-1 public sector applications such that they would be "widely available" when the first generation of VII vehicles are introduced to the public (currently targeted for 2011). These program elements may include technical development activities such as fundamental research, proof of concept testing, and prototyping of applications—as well as deployment related tasks such as funding, quality control, programmatic oversight, and other support activities to state and local transportation agencies who will be involved in rolling out many of the public sector applications. Additional objectives of this report include:

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This Application Development Plans document (September 2006) represents the next stage in the process, and is envisioned as only a starting point for moving forward. As application development proceeds, technical challenges will be identified, new solutions will be proposed, and revised application architectures may be necessitated. This document is meant to outline the steps toward refining, implementing, and deploying these applications for Day-1.

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2.2. Overview of Application Development Process

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Table 4 – Application Development Phases

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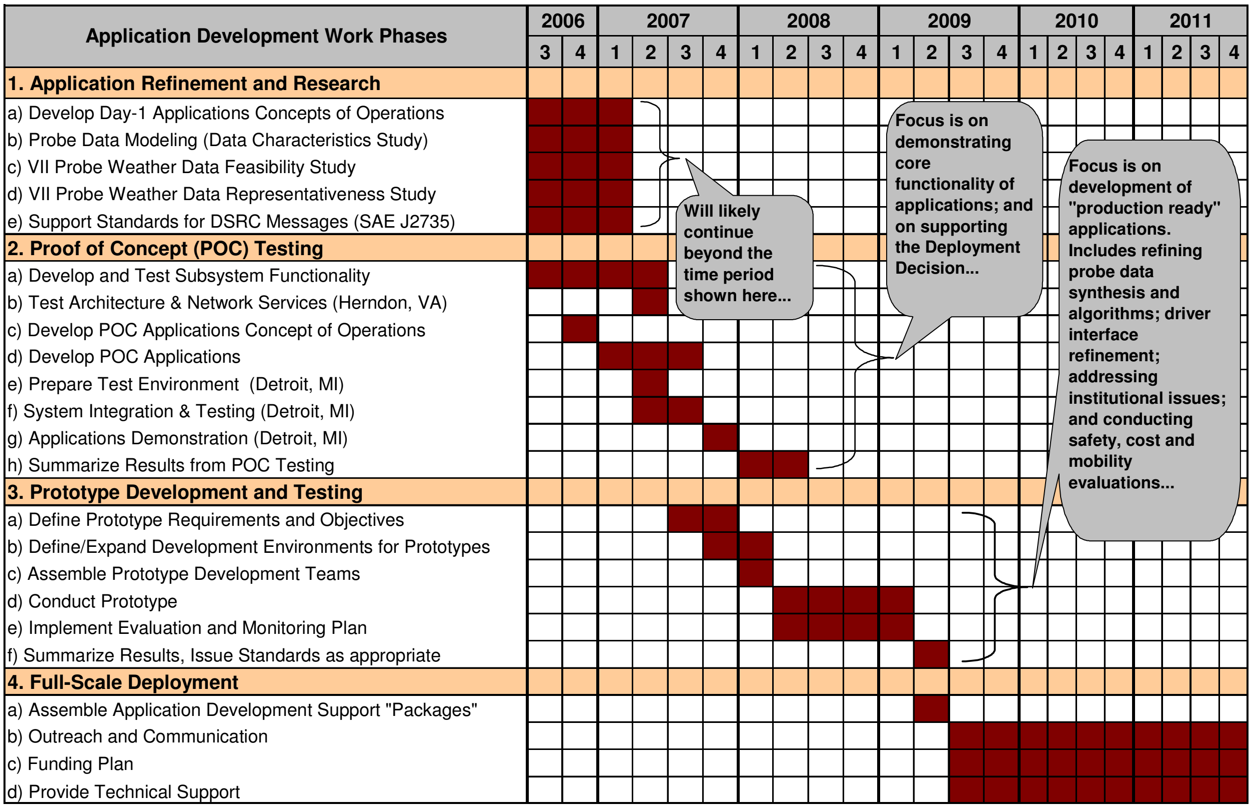

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2.3. Phase 1. Application Refinement and Research

The development of VII-enabled public sector applications is currently (October 2006) in the refinement and research stage. Key activities to be completed under this phase include the development of detailed concepts of operation of each application, as well as selected research activities related to vehicle probe data management and analyses.

2.3.1. Develop Application Concepts of Operation

As noted, work related to the development of individual public sector applications has thus far been limited largely to the development of the Day-1 use case documentation. However, the use cases were "VII system centric" and narrowly focused on identifying required network services as well as the high-level interfaces with the VII system. The processes, data analyses, and interfaces outside of the VII network were defined only to the extent necessary to ensure the VII system architecture met the requirements of those use cases. Thus, an important first step in moving forward with the public sector application development process will be to expand the existing application descriptions (use cases), and to develop more comprehensive Concepts of Operations (ConOps) for each of the applications.

The focus of these ConOps would be on describing the technical, operational, and organizational aspects of how the application will be implemented at Day-1. For each public sector application, there remains key technical, operational and/or architecture related issues that are either unresolved or not well understood. These key issues are outlined in the sections following this executive summary for each application—and are exactly they types of issues that would be addressed during the development of Day-1 ConOps, In addition, the development of the ConOps will likely provide important insight regarding the manner in which the applications should be demonstrated during the POC testing.

The development of the ConOps should be led by USDOT, but be developed in full cooperation with those entities that will in fact be integral to the operation and execution of the application. Participants in the application ConOps development process should therefore include: vehicle OEMs, state and local transportation system managers, the VII network design team, as well as engineering firms with domain specific expertise in traffic, traveler and/or weather systems as appropriate for each application. It is anticipated that a robust ConOps for each application could be developed within six months, and as noted would be developed with the full support of and input from both private and public sector stakeholders.

While developing the application ConOps for all of the Day-1 applications is useful, the two highest-priority applications from the perspective of supporting the POC appear to be the Traveler Information and Electronic Toll Payment applications. The traveler information application is central to the VII concept in that it will provide a foundation for both safety (incident notifications, in-vehicle signage) and mobility (traffic and weather information) applications. Additionally, the traveler information application exercises key network services including probe data dissemination and advisory message delivery functions (see Section 2 for more information on the Traveler Information application). It is also important to refine the ConOps for the Electronic Toll Payment application—principally, because the manner in which the on-board electronic payment service is executed could have significant technical and business model implications for toll authorities, and could impact the manner in which the tolling application is demonstrated during POC. (see Section 8 for more information on the Electronic Toll Payment application).

2.3.2. Fundamental Research Activities

The understanding and deployment of many of the public sector applications could benefit through fundamental research related to probe data generation and analyses. Specifically, such research is focused on how VII data streams from the vehicle would be used to supplement or replace existing traffic and traveler information related systems. Questions such as: what specific data elements should be included in probe data?: how many snapshots should be retained in a given probe message?: what should be the rules governing "ID persistence" between snapshots?; what level of market penetration is needed to support useful analyses for specific applications?, and, what are the benefits of allowing for localized control of probe data generation processes?—are all questions that can be initially explored through simulation, modeling and "soft" research activities. Therefore, it is recommended that such research be conducted in parallel with, and continuing beyond, the development of Day-1 ConOps for each application. The following are some of the key research activities identified as important to the development of the Day-1 applications:

- ***Probe Data Modeling and Simulation (current Data Characteristics Study)*: ** An initial study, being conducted by Mitretek Systems, is focused on developing a better understanding of how probe data can be used to support various public sector mobility and safety applications—most notably, the traveler information, optimized signal timing, ramp metering, and corridor management applications. Using efficient modeling and simulation techniques, the Data Characteristics Study will continue to explore issues related to the design and analysis of probe data. Results of such simulations might then be tested on actual vehicles in the POC (by reprogramming the probe data collection algorithms on selected vehicles). The two efforts would effectively compliment each other. Further, the insights gained through that the Data Characteristics Study related to market penetration rates could have an impact on application deployment planning strategies and schedules.
- ***VII Probe Weather Data Feasibility Study:*** The National Center for Atmospheric Research (NCAR) in Boulder, CO is under contract with FHWA to study and report on the feasibility of using vehicles as mobile weather probes. Weather and pavement information from vehicles can come from direct measurement (such as windshield wiper state or outside air temperature) or can be derived from indirect observations from devices such as vehicle traction control or anti-lock breaking system. A feasibility study white paper will be

produced during the fall 2006 and will (1) provide a basic understanding of current and future vehicle data elements that have the potential to be used directly or indirectly to sense weather and road conditions, (2) examine the potential contribution of VII derived atmospheric and road condition information in the analysis and prediction of weather-related hazards, (3) identify technical issues and barriers that may impact the development and implementation of weather-related VII applications, (4) outline research topics that need to be addressed to fully utilize vehicle data in improving road weather products and services, and (5) summarize the viability of using VII-enabled data in weather and road condition applications designed to improve surface transportation safety, mobility, and efficiency.

- ***VII Probe Weather Data Accuracy Study:*** Mitretek Systems of Falls Church, VA is under contract with FHWA to study the extent to which weather observations from vehicles compare with in-situ environmental sensors under different weather conditions. The study is seeking to answer the following questions: How does the outside air temperature as measured by OEM sensors compares with actual atmospheric conditions? Does time of day (sun angle), wind speed, or precipitation affect the readings from the vehicle? Or do vehicle speed, engine heat and heat from surrounding vehicles under congested conditions produce a bias that could make vehicle temperature observations not representative of actual conditions? These and many other combinations of factors are presented and studied to provide a foundation upon which discussions can begin regarding the practicality and representativeness of using weather observations from vehicles.
- ***Signal Timing and Ramp Meter Research and Algorithm Development:*** Specific research (beyond what is currently under the scope of the Data Characteristics Study) is needed to understand how VII probe data can support the objectives of signal timing and ramp metering optimization. Such research is needed is vehicle probe data, while a potentially rich source of traffic flow information, will yield different types of information than traditional signal system practitioners are accustomed to. A significant research effort is needed to characterize these differences; determine new alternative algorithms using VII data; and understand how current systems and methods can be updated, replaced, and/or used in conjunction with VII-based applications. Such research (including simulation and modeling work) is only being completed in a very limited fashion under the current scope of the Data Characteristics Study.
- ***Corridor Management and Load Balancing Research:*** The corridor management application requires fundamental research to develop algorithms for analyzing roadway network performance from probe data, and to understand how opt-in origin/destination data could be utilized for corridor planning assistance. Corridor management research should also determine how best to utilize the VII system for disseminating data directly to vehicles, address questions regarding the types, frequency, and geographic distribution area of broadcast messages, and specifically understanding driver behavior in response to broadcast messages. The research could also address how the VII network (and associated capabilities) could best be leveraged to facilitate/coordinate interagency actions in order to achieve load balancing across jurisdictional borders. Essentially, the VII concept could supplement or replace 511 systems, variable message signs, highway radio, and other means of conveying traffic and traveler information to the driver. Research related to how such capability can best be leveraged could begin in parallel with the POC. We suspect that "lessons learned" from private sector (commercial) implementations of traveler information systems (such as

XM radio or On-star) could be useful in such research. Clearly, experience gained with 511, highway message signs and other traditional information channels would also prove useful in assessing how VII could be best be leveraged to influence driver behavior. Research done to facilitate corridor management and load balancing should be coordinated with the US DOT's Integrated Corridor Management (ICM) initiative, and focus research efforts on how to use VII-specific technologies to support a corridor management application.

- ***Support of SAE J2735 Message Set Development:*** The work of this standards committee includes developing standards for probe data messages, as well as other advanced messages to support safety, mobility, and electronic commerce applications. USDOT's support for such standardization efforts should continue.

2.4. Phase 2. Proof of Concept (POC) Testing

The objective of the VII Systems Integration and Proof of Concept (POC) testing is to provide sufficient information to government and industry stakeholders about the viability of the VII technology, network architecture, and operations in order to support a "deployment decision". The focus is on a technical demonstration of the VII applications, as well as providing a preliminary but representative showcase of the value of the application to motorists, transportation agency officials, and the U.S. DOT. Thus, the POC is segmented into three distinct phases with differing objectives:

4. *Laboratory Development and Testing:* Test the VII system functionality and demonstrate that the architectural components and systems meet the specified requirements. This work will largely be completed at Booz Allen Hamilton's facilities in Herndon, Virginia, and will be begin during the last quarter of 2006. While most of this work will be completed by mid 2007 as shown in Exhibit 1, the laboratory testing facility will remain operational and can be leveraged for a variety of special tests as needed.
5. *Systems Integration and Testing:* Demonstrate that from a technical perspective, the network, on-board equipment (OBE), roadside equipment (RSE), and other VII system components are functionally integrated, can operate in a real-world environment, and can support the basic end-to-end services needed for the Day-1 applications. This systems integration work will be done in the Detroit Michigan development and test environment (DTE), and will proceed during the mid-2007 timeframe. (A more complete description of the DTE is available under separate cover.)
6. *Application Integration and Testing:* Demonstrate the value-added mobility and safety services that can be delivered to motorists by the public sector using broadcast type messages. This work is targeted to be completed during the later quarter of 2007 and into early 2008 as shown in Exhibit 1.

The later part of the POC will focus on demonstrating end-to-end functionality for several applications, and will be the first complete demonstration of the applications in a real-world environment. The focus of the POC is not to deliver production-ready software, processes, and component designs for the public sector applications, (this level of development is targeted for the prototype phase). Rather, because of the limited number of vehicles to be involved in the POC (between 50 and 75), and because of schedule considerations, the applications will be demonstrated using simplified probe data algorithms for analyses of traffic, weather and traveler information. In addition, much of the "content" of the messages to be broadcast to vehicles (whether it is traveler, traffic, incident, or weather related) will likely come from conventional sources of such information, or will be developed using special "work around" processes. Thus, the applications to be demonstrated during POC will represent application "stubs", or abbreviated versions of the applications that are likely to be available at Day-1.

The specific functionality and architecture for each of the public (and private) sector applications will be detailed in a ***POC Concept of Operations*** document that is jointly being crafted by the VIIC and USDOT. This document will list the performance and functional specifications for each application, as well as test conditions and demonstration scenarios to be used to verify performance of the applications.

Public Sector application development during POC will in part be influenced by Michigan DOT's Data Use and Analyses Program (DUOP). This is a separate and distinct effort to explore how "VII-like" probe data can be used to support traditional state DOT highway maintenance and operations responsibilities. Under the DUOP program, there will be nearly 3000 "probe data drone" vehicles deployed during the period in which the POC will take place. These vehicles will not be equipped with VII compatible OBEs and will thus not be part of the "core" VII POC testing. However, these vehicles will be capable of recording and storing probe data such that it could be downloaded and analyzed in a non-real time fashion. Such data could therefore be useful in developing analyses techniques and algorithms for processing probe data to determine traffic, traveler, and roadway weather conditions. In other words, the data from this test fleet could augment the probe data gathered from the 50 to 75 core VII test vehicles that will be equipped with VII compatible OBEs.

"Deployment Decision". At the conclusion of the POC, (scheduled for mid 2008) a comprehensive Report will be developed that documents the performance and functionality of the VII components, system, and network. An assessment of the applications that were demonstrated will also be conducted that includes technical viability, driver acceptance, overall benefits and anticipated technical, economic, and institutional challenges associated with implementing the application on a national (large scale) basis. The POC Results Report will be jointly authored by USDOT and the VIIC. Based on the outcome of the POC Report, a decision will be made as to whether the VII concept is technically viable, economically feasible, and can be implemented in an effective and efficient manner. At this milestone, decisions about if and how to proceed with development of the VII concept will be jointly made by government and industry (including the VII Working Group), and if necessary, what significant changes in the concept or technology are needed before proceeding.

2.5. Phase 3. Prototype Development and Testing

Once a decision to proceed with the VII program has been made, the application development effort will focus on building prototypes of each public sector application. The intention of this phase would be to produce near "production ready", or fully functional designs that would be representative of an application that could be deployed on Day-1. The specific objectives for the applications prototype effort would include:

- development of large scale data analyses methodologies;
- create/capture such analyses and techniques in core software applications or "modules";
- develop a "working consensus" with the auto-industry on how the on-board application component will operate—including filtering and presentation of safety related information to the driver.
- refine interface specifications with various other entities involved in the application…including any third-party information providers that may be involved in the application;
- document management and business models needed to implement the public sector applications;
- and, synthesize various lessons learned during the prototype development.

These work products would then be assembled into a "support" packages such that transportation agencies could utilize the information to help them implement the applications on a local level. The application prototype development effort would proceed immediately after the POC, and it is estimated that such prototypes may take 1 to 2 years to fully develop and demonstrate—although there are many unknowns at this point and we suspect that knowledge gained during development of ConOps for individual application, as well as testing during the POC will have a major impact on the manner in which the prototype development efforts take place.

While the POC effort is currently the subject of considerable effort—and a detailed work plan for the POC is being developed as part of the POC ConOps—only limited discussions of post-POC development activities have occurred, and there has been little documentation of such efforts. For these reasons, a somewhat more detailed, but still generalized review of post-POC application development activities (i.e., application prototypes) is presented in the following sections.

2.5.1. Resources and Location(s) for Development of Prototype Applications

Detroit Development Environment. At the conclusion of the POC, a very capable development and test environment (DTE) will have been established in the Detroit, MI, area. Further, the participating entities involved in the POC will have accumulated substantial experience in all areas of the VII concept including:

– network architecture and supporting network services,
– probe data analysis, and synthesis of probe data with other traffic information;
– advisory message generation, and broadcast delivery strategies and techniques;
– and, the on-board applications and interfaces needed to support the public sector applications.

It will clearly be efficient and effective to continue application refinement in the Detroit area. The DTE put in place for the POC might be expanded for the application prototype development in the following ways:

- Additional RSEs to increase the coverage area.
- Implementation of alternative backhaul communications methods (that were not included in the POC),

- Inclusion of multiple jurisdictions within the state,
- Additional test vehicles from multiple manufacturers,
- Integrated, proprietary human machine interface (HMI) platforms from each original equipment manufacturer (OEM).

At this point, it is difficult to estimate the overall scope of the application prototype development effort in terms of number of test vehicles needed, number of RSEs to be installed, geographic "footprint" of the DTE, and the proposed length of the test period. Nevertheless, each of these scope-related issues is discussed as follows:

- ***Number of test vehicles*:** The POC is targeting only about 50 to 75 fully functional VII vehicles. While it will likely be impractical for the application prototypes to include a sufficient number of vehicles to support robust and exhaustive probe data analyses, a significantly larger fleet population will likely be needed to support effective evaluations of public acceptance, reliability assessments, and HMI refinements, and to support individualized OEM product development. However, there is a practical limit on the size of the test fleet—at this stage (prototype development), the vehicles will be built with considerable experimental hardware and software including integrated OBE units, antennas, and HMI units that are integrated into the vehicle dash. These vehicles will be expensive and unable to be sold to the public. Further, it is unclear to whom the vehicles will be assigned and how they will be utilized. Most of the vehicles will likely be driven by employees of the car companies, or employees of the key stakeholders involved in the prototype effort. Some of the vehicles may be used to support more public demonstrations and customer "clinics." On balance, we suspect the test fleet will be limited to perhaps 50 to 100 vehicles per OEM, even during prototype application development stages.
- ***Geographic "footprint" and number of RSEs*:** The initial POC DTE is to be focused in a moderately dense suburban/urban environment (Northwest Detroit/Oakland County). While this environment includes diverse operating characteristics, intersection configurations, and roadway types, it does not include conditions that would be encountered in a central business district (CBD) or in rural areas. While more discussion is required, the prototype DTE should include areas that are representative of traffic conditions, roadway designs, and other features that would be found in CBD and rural route settings.
- ***Test period:*** While each application will be unique, and details related to the Day-1 concept of operations remain to be developed, it is estimated that the development and demonstration of prototype applications could be completed within a 12- to 24-month timeframe after the conclusion of the POC. Some applications, like winter and pothole maintenance may be able to be developed rather expediently since core algorithms and process for utilizing vehicle probe data have already been anticipated and incorporated into the development of Federally funded Maintenance Decision Support System (MDSS). Most of the applications however will involve considerable original research and inventiveness for leveraging VII probe data and the associated communications infrastructure (i.e.,VII network) in creating the public sector applications. Prototype development timeframes are therefore more difficult to predict.

Additional Prototype Development Environments. The POC in Detroit could clearly transition into an application prototype development environment with support, funding, and guidance from the U.S. DOT. *However, it should be understood that a Michigan-based prototype development environment would not alone be sufficient to support development of all of the applications.* For example, to fully develop the electronic toll collection application, several types of tolling environments will be needed including “open, fixed toll”, “closed, variable toll”, as well as High Occupancy Toll (HOT) facilities. All of these facilities do not exist in the Detroit area.

Similarly, the single test environment in Michigan cannot capture the diversity of traffic signaling systems, ramp meters, and/or existing types of roadway and ITS infrastructure that exists in the US today. The ability to leverage transportation network information gathered through existing intelligent transportation system (ITS) resources and programs will likely be important during early stages of VII deployment. This is the case since, at low market penetration levels, probe data alone will likely not support reliable and comprehensive estimates of travel times and traffic volumes throughout a particular metropolitan area. The integration of transportation-relevant information sources is the process followed by existing 511 traveler information systems. State and local transportation agencies that already have programs in place that integrate these disparate data sources (i.e., 511 type of programs) will benefit from implementing several of the Day-1 applications—traveler information, corridor management, ramp metering, and even perhaps signal timing.

Arguably, there are benefits in having multiple state and local partners involved in the VII prototype development to help foster creativity and diversity in how VII capability can be leveraged, and to ensure that the VII prototypes are applicable to an appropriately large cross-section of transportation and roadway environments. However, the key challenge to having multiple prototype locations is the availability of VII-equipped vehicles at all these locations. Therefore, it is highly likely that the number of potential prototype locations will be limited—with the Detroit Michigan DTE representing a key focal point for developing the work products that would support a national rollout of the public sector applications.

2.5.2. Roles and Responsibilities for Application Prototype Development

The resources and capabilities needed to support the prototyping of public sector applications are considerable. The following provides an overview of possible roles and responsibilities of key participants in the prototype efforts:

- ***U.S. DOT:*** USDOT would have a leadership role on all prototype development efforts including: supplying technical oversight; ensuring interoperability and conformance with other ITS architecture standards; managing all contractor teams; reviewing milestones and deliverable; and coordinating with state and local partners involved in the prototype effort. USDOT would also continue to be the lead interface agency with the auto industry concerning vehicle functionality and specifications that are needed to enable the public sector applications. As noted earlier, we suspect that during the prototype stage, NHTSA may wish to become involved with the manner in which safety related messages are conveyed to the driver to ensure adequate interoperability. USDOT would also provide the primary funding for the prototyping efforts, and it is recommended that a special VII prototype programs office within the ITS JPO be created to concentrate on the prototype efforts.

- ***State and Local Transportation Agencies:*** State and local transportation agencies will be the "host site operator" for the VII prototype development efforts. They will be responsible for providing the appropriate access to necessary infrastructure to install the VII equipment (RSEs and backhaul communications), and for cooperating with the prototype development team (i.e. "contractor team") to integrate existing transportation or traffic operations centers with the VII network and application components. The state and/or local agencies will also need to help with obtaining any special permits, and/or working with USDOT and the Contractor on provisions for limiting liability of participating vehicle manufactures or other commercial entities that may be involved with the prototype effort. As necessary, the State and/or local agency will also need to make available other ITS related assets that may be needed to augment the VII network or applications.
- ***ITS Engineering Firms:*** Engineering firms with specific domain knowledge in the targeted application area would be contracted to lead the overall prototyping efforts. For example, a Systems Integration/ITS firm with experience in 511 programs might lead work related to developing the traveler information prototype. In contrast, a firm with experience in integrating Maintenance Decision Support System (MDSS) software into a transportation agency's overall maintenance management system might be contracted to lead the Winter and Pothole Maintenance applications. These System Integration/Engineering firms would lead the overall technical development efforts for each of the prototypes, coordinate with VII network specialists and vehicle OEMs, and would work with local transportation agencies and the USDOT in executing the prototypes.
- ***Vehicle OEMs:*** The vehicle OEMs would supply the test fleets, and would build the on-board application components necessary to support each of the public sector applications.
- ***VII Network and Architecture Specialists:*** These specialists would lead communications trade-off analyses, support message delivery strategy development, and support development of any new network services required for the public sector applications.
- ***Academic/Research Institutions:*** These institutions would perform fundamental and applied research in various application areas. The subject of such work could include probe data analyses, traffic modeling, as well as cross-cutting human factors research. Such work would likely focus on simulation and modeling efforts that would complement the testing being conducted during the prototype phase. While such fundamental research is currently be contracted directly by USDOT (e.g., the Data Characteristics Study), such work could be folded into the prototype development phase at the appropriate point in time, (and thus be coordinated by the Systems Integration contractor leading the application development effort).
- ***Industry Associations:*** These associations would coordinate and foster public, private, and academic partnerships; build consensus among stakeholders; help establish testing priorities; and develop applications-related standards. During the prototype phase, the involvement of such associations, and indeed of the large community of stakeholders, could be structured as a task under the contract with the primary application Systems Integrator/ITS Engineering firm, or it could be a separately executed scope of work that USDOT would coordinated directly

- ***Industry and Technology Suppliers:*** There are selected areas of expertise, as well as certain technologies that cut across several applications. For example, GIS, roadway mapping, and navigation specialty firms would help with building map databases and developing roadway information synthesis tools. Similarly, independent service providers (ISPs) that specialize in weather forecasting may become involved with development of both the winter maintenance and weather information applications, but would not likely lead either of those prototype development efforts. Like the role of academic and research institutions described above, such technologies suppliers might support prototype development efforts as a subcontractor to the overall Systems Integration contractor, or alternatively could be retained directly by USDOT. If the later path were chosen, work products from such suppliers could be made available to multiple Systems Integration contractors leading the various prototype application development efforts. The most appropriate contracting arrangement will depend on if and how prototype development efforts are integrated across the various applications.

2.5.3. Integration of Public Sector Prototype Application Development Efforts

Selected groupings of public sector applications have similarities with regard to the types of skills and domain expertise needed to support, and in some cases even lead, prototype development. For example, the traveler information and corridor management applications both involve collection and analyses of probe data in order to assess road link traffic conditions, and both will involve generating broadcast messages in order to influence driver behavior. While there are clearly differences in the temporal use of the probe data, and in the content and manner in which the messages are developed and broadcast, the traveler information and corridor management applications will both require the lead Systems Integration contractor to have specialists in transportation planning, traffic engineering, and conventional traveler information systems (such as 511 services). In addition, (and as noted earlier), both would require the support of specialists in roadway mapping, GIS, and information display disciplines. It would be inefficient to retain unique development teams, and execute separate and distinct contracting efforts for these two applications. The fact that the same vehicle and infrastructure assets (i.e., the Michigan DTE) would be leveraged for both prototypes reinforces the notion that the development efforts be led by a single Contractor team (or Systems Integrator). This same logic applies to other groupings of public sector applications including:

- Ramp Metering and Signal Timing Optimization,
- Winter and Pothole Maintenance, and,
- Weather Information applications (Traveler Notification and Improved Forecasting).

The advantages and disadvantages of integrating selected public sector application development efforts will likely become more apparent after Day-1 Concepts of Operation are complete, and after conclusion of the POC testing.

2.5.4. Evaluation and Monitoring

For all of the application prototypes, it will be important to implement a *performance monitoring and reporting system* to help evaluate and manage the prototype development. A set of performance measurement tools will help determine the cost, benefits, and performance of the application from the perspective of different stakeholders including the U.S. DOT, the host-site agency, and the motoring public. Key areas of evaluation for the prototypes are as follows:

Public Acceptance: As part of the prototype each OEM will undoubtedly conduct their own market research and proprietary customer clinics regarding the performance and features of their vehicle applications, and of the VII concept in general. It will be important for the USDOT to make arrangements with OEMs to share or acquire non-proprietary portions of the research. Or, alternatively, to work with the OEMs in executing pre-competitive types of research to determine both general and specific evaluations of the performance and features of the public sector traveler information application. An assessment methodology would need to be clearly mapped that first assessed the test subject's driving habits and needs for traveler information, and then introduced the test subject to various features and driving situations in a controlled fashion. This might be followed perhaps by a more "free form" evaluation of the application and technology over a longer period of time.

Application Accuracy. Several of the applications are focused on assessing and reporting conditions along specified road segments including for example: average speed, travel times, surface conditions, weather conditions, presence of an incident, special speed enforcement provisions, etc. It will be important during the various prototypes to establish a means of periodically (perhaps randomly) determining actual "ground truth" relative to such conditions along various routes and at various times. The ground truth (say relative to congestion and weather conditions) can then be compared to the assessment developed by the VII application using probe data (as well as other conventional sources). Application accuracy and reliability over the course of the prototype development can then be measured.

Failure Mode Testing: While some failure mode testing will take place during the POC, additional testing involving unauthorized broadcast messages, errors in the management of messages at the RSE (either in sequencing, priority, or repeat rates), errors in the delivery instructions attached to "envelopes" that might cause messages to be broadcast in too small, too large, or overlapping geographic region; and, various failure modes in the OBE and HMI should be investigated.

Safety and Mobility Benefits Assessment: Because of the limited size and scope of the application prototypes, observable, macro level changes in road safety and mobility measures is probably not possible, (i.e. changes in average travel times or speeds along a roadway segment, or changes in crash rates over the prototype test period will likely not be observed). Rather, safety and mobility benefits will need to be assessed at a micro-level, and essentially be part of the overall public acceptance evaluation plan. For example, individual participants involved in the prototypes could report if and by how much travel times for various commutes are shortened (or otherwise may easier). This might be done for both scheduled peak hour trips as well as off peak ad-hoc trips. Similarly, they could report if and how various types of incident notifications and/or in-vehicle signage helped them avoid potentially dangerous situations or otherwise improve the safety of their commute.

Performance, Reliability and Maintainability Assessment: An important outcome of the prototypes will be a better, more robust assessment of the performance, reliability and maintainability of the overall VII network and subsystem components. This would include an evaluation of utilization and availability of RSEs, backhaul networks, SDN equipment and software, as well as vehicle OBE and HMI systems. Both scheduled and unscheduled maintenance actions would be tracked, and the resources and processes for maintaining operations would be logged. Overall uptime (or percent availability) for the end-to-end application functionality would be monitored and reported.

Capital and Operating Cost Estimates: For all of the prototypes, the total implementation and capital costs for: RSEs; backhaul communications links; SDN and NAP equipment; and, costs for other components associated with prototype application implementation will be tracked. On-going maintenance and operating costs must also be tracked. .

The monitoring and evaluation tools developed and implemented will provide the feedback necessary to raise awareness of VII's impact, and report on whether VII-enabled applications are meeting intended goals and objectives.

2.5.5. Summarize Results

To help accelerate widespread deployment of the public sector applications, it will be important that "core" software modules, database designs and analyses techniques be well documented during the application prototype development efforts. These "deliverables" would likely focus on software to support probe data analyses; syntheses and integration tools for leveraging non-VII transportation relevant data; and on tools for automating and managing the development and delivery of WAVE formatted traveler information messages.

In addition to the software modules and analytical support tools described above, an overall prototype "Results" Report would be developed. This report would describe and document lessons learned throughout the development effort relative to both technical and operational issues surrounding the applications, as well as programmatic and management issues. Such management issues might include for example: handling of jurisdictional conflicts; handling of network failures; and/or management of customer (or public) interface issues.

The Prototype Results Report would also include sections on the evaluations of cost, benefits and overall performance of the application and network. This would include summaries of public acceptance evaluations, failure mode testing, safety and mobility benefits, as well as performance, reliability and maintainability measures.

2.6. Phase 4. Full-Scale Deployment

2.6.1. Overview

The Deployment Plans for major USDOT sponsored programs involving new technologies, information systems or infrastructure designs (e.g., the "511" program, National ITS architecture, NG911, etc.) generally adhere to the following high level set of activities:

- Develop a Concept of Operations including Requirements, Objectives, and Evaluation Metrics,

- Conduct fundamental research, cost/benefits analyses and market studies to refine specific technical, operational, or institutional elements of the program.
- Select one or more States or local transportation agencies to develop and implement a proof of concept "showcase" of the technologies, systems or designs that form the core of the program,
- Conduct one or more Prototype Tests to fully develop and demonstrate the project or program in a "real world" operational setting,
- Assuming the Prototype Tests yield positive results, develop and document core "tools", equipment designs, software products, specifications, and "best practices" that can be packaged together for other States/local agencies wishing to implement a similar project.
- Work with commercial organizations and associations to develop industry-sponsored standards,
- Implement an outreach program to communicate results of testing, and to generate enthusiasm for the project.
- If appropriate, work with various stakeholders to develop a "Deployment Coalition", "Task Force" or other advisory group that can provide resources and advice on how to implement the project or program. Encourage development of user-communities and support groups to exchange lessons learned, etc.
- Develop a website focused on supplying/referencing the above resources and tools…and to provide other "how to" guidelines. As appropriate for the particular project, provide a listing of key risk areas, critical dependencies, do's and don'ts, as well as tools for calculating deployment costs and benefits.
- If appropriate for the project, develop a full-time USDOT project office to provide on-going support to States and local agencies,
- If appropriate, provide funding incentives for implementing the project or program,
- If appropriate, initiate regulatory actions, mandates, or financial disincentives for not adopting the program or project.

While these tactics and strategies are generally successful in the long-run, history has demonstrated that States are often slow to adopt new programs, processes or technologies—even when benefits can be clearly demonstrated. It can be decades before a new transportation technology, design, or process are actually fully implemented throughout the country—even when the technology or design is fundamentally advantaged.

2.6.2. Infrastructure Deployment Rate versus Application Deployment Rate

Because of this history, and the inherent variability of individual State priorities, funding and commitment to any new transportation program, a "business as usual" deployment plan for VII may not be acceptable to the vehicle OEMs or to the motoring public. OEM's will be reluctant to build in the additional costs of VII technology on every car they make if only a portion of their customers can enjoy the benefits. Individual motorists for their part will also be understandably disappointed if they are paying "extra" for a feature they cannot extract full value from. A deployment plan that allows for an unprecedented and accelerated adoption of the VII technology must be considered.

The deployment plan is further challenged by the fact that VII vehicles, even in the first year of introduction (say 2011), will be distributed widely throughout the country. It is impractical and inconsistent with OEM's business model to concentrate the delivery of those vehicles to, for example, the West Coast. Therefore, even though the penetration rate will be low for the first few years, essentially every urbanized area in the country will be host to thousands of VII equipped cars. If all goes as planned, the vehicle OEMs will offer VII on all newly designed models that debut after 2011/2012. On average, an all new design is introduced about every 6 years for a particular model line. This means that about 17 percent of production vehicles (or about 3 million vehicles) will be VII equipped when the technology is first introduced (presumably in 2011/2012). If these 3 million vehicles are apportioned in urban areas based on population, a large city such as New York would have almost 200,000 VII vehicles in the very first year as shown in the Exhibit 3, and over 1 million vehicles after just 3 years.

Exhibit 3 - VII Vehicle Population in Major US Cities During Initial Introduction

Urban Area	Population	VII Vehicle Population	
		Year 1	Year 3
New York--Newark, NY--NJ--CT	17,799,861	194,180	1,165,082
Los Angeles--Long Beach, CA	11,789,487	128,613	771,676
Chicago, IL--IN	8,307,904	90,632	543,790
Philadelphia, PA--NJ--DE--MD	5,149,079	56,172	337,031
Miami, FL	4,919,036	53,662	321,973
Dallas--Fort Worth--Arlington, TX	4,145,659	45,225	271,352
Boston, MA--NH--RI	4,032,484	43,991	263,944
Washington, DC--VA--MD	3,933,920	42,915	257,493
Detroit, MI	3,903,377	42,582	255,494
Houston, TX	3,822,509	41,700	250,201

This means that a VII deployment plan cannot proceed in an incremental fashion on a state by state basis, but rather must be operational in essentially all urban areas within a very short timeframe. For example, a plan that called for VII to be operational (including the availability of public sector applications) in say the top 50 cities in the US by 2012, the top 200 cities by 2015, and all 454 urbanized areas by say 2018, may not be acceptable to OEMs or motorists. Such a plan would mean that thousands of owners of VII vehicles who purchased their vehicle in the first year would not be able to take advantage of VII for 3 to 6 years later.

If however the VII infrastructure was in place throughout the US on "Day-1" (even if not fully deployed in terms of density of RSEs), and , assuming that vehicle OEMs would begin offering value-added private sector mobility and convenience applications immediately at Day-1, then consumers would still benefit from the VII technology and may be willing to "wait awhile" for the state or local transportation agency to begin implementing public sector VII applications. In other words, the vehicle OEM's would create a value-proposition for their customers (even at Day-1) that would not be critically dependant on the widespread deployment of public sector applications. For example, vehicle OEMs would likely offer the following services at Day-1:

- navigation assistance and for-fee traveler information services,
- various e-payment applications negotiated with other commercial entities (parking, gasoline payments, fast food),
- various customer relationship management services (remote vehicle diagnostics, warranty management, etc.)
- select "concierge" services: unlock doors, emergency assistance, availability of commercial services (next exit services), etc
- vehicle-to-vehicle safety services and collision avoidance applications (although consumers would recognize that because of the initial low penetration rates, it may take several years before they would begin to extract value from this capability).

Having acknowledged the above commercial realities, it will nevertheless be critically important that the public sector applications be introduced in an expeditious fashion—particularly if the public sector (and not the vehicle OEMs) paid for the infrastructure to be implemented. The public may tolerate some delay in widespread deployment of public sector applications, but they will not want to have paid for the infrastructure, paid a higher price for their vehicles, and then have to pay a monthly fee to vehicle OEMs in order to extract value from VII.

2.6.3. Assemble Application Development Support "Package"

At the conclusion of the prototype development and testing, a comprehensive "Application Development Support Package would be assembled. This package would include the results from the Prototype testing as described in section 1.5.4 (including software), but would also include various background materials (ConOps), information about the "Operating Entity", VII contractors and resource references.

2.6.4. Develop "State VII Implementation Compliance Plans"

Central to the overall national Deployment Plan (relative to development of the public sector applications) would be for USDOT to develop state-based "VII Compliance Plans" that would require States to pursue a path toward deployment. Milestones in such a plan might include:

- initiate certain planning activities;
- document current resources and capabilities related to gathering traveler information,
- submit draft and final plans for how the application is to be developed and delivered; (roles and responsibilities of state DOT versus local agencies?; what services and components of the application will be done "in-house" versus contracted out to commercial firms? Locations and functionality of all TOCs (or similar entities) that would deliver the application; plans for how the State DOT would provide oversight and/or otherwise monitor progress of local transportation agencies; etc.)
- issuing of RFPs for supporting services,
- procurement and installation of related resources and equipment,
- initiation and completion of a test plan,

- Other compliance requirements that would be issued, monitored and approved by the VII "Operating Entity"

The USDOT would develop an overall template for States to follow in developing their VII Compliance Plan—and would include key milestone dates that would need to be met.

2.6.5. Monitor Compliance Submittals, Provide Technical Support and Manage Grants

The USDOT, (likely in cooperation with the Operating Entity), would then set up a "*VII State Compliance Project Office*" which would be responsible for monitoring the progress of states (and likely of major metropolitan areas) in meeting the milestones and other activities outlined in their State VII Compliance Plans. Various sub teams within this Federal office would likely be developed to focus on specific geographic areas—and/or perhaps on certain types of operating environments; for example; a " State Compliance Team; an MSA Compliance Team; a "Rural Area Compliance Team". All of these Teams may in turn be subdivided based on geographies within the country.

The USDOT *VII State Compliance Project Office* would also provide an array of technical products and services to support the States and local transportation agencies in deploying the traveler application within their state (and likely all the other applications). Such support could range from provisioning of standardized software and probe data analyses tools that were developed during the prototypes, as well as information about applicable standards, equipment needs and other resources.

3. CROSS-CUTTING ISSUES

There are selected issues and tasks related to VII implementation which, depending on they are resolved, may impact the manner in which public sector applications are designed and implemented—and/or may impact overall VII network and operational features. Such issues and tasks include:

- Centralized versus Decentralized Application Hosting,
- Examination of "Day-2" Use Cases
- VII "Operating Entity" Structure,
- Overall VII Network Operating Costs
- Alternatives Analyses

These issues and tasks can be addressed in parallel with development of the public sector applications so as to help support the "Deployment Decision" and ensure that application development is proceeding under the appropriate overall assumptions about how the VII network will operate.

3.1. Centralized versus Decentralized Application Hosting

For essentially all of the public sector applications, a notional Transportation Operations Center (TOC) or transportation management center (TMC) has been defined as a key entity responsible for implementing and operating the public section applications at the local level. Conceptually, this notional TOC will subscribe to probe data from the VII network; combine it with other (traditional) traffic, incident, event and weather data; and then generate value-added safety and mobility messages for travelers. In reality, however, the overall resources, capabilities, and even the existence of such notional TOCs throughout the U.S. must be examined—and strategies and tactics for accommodating widely varying levels of involvement and sophistication from the local and state transportation agencies must be considered.

Additionally, even those local and state transportation agencies that do have considerable capability and resources will nevertheless be unfamiliar with VII probe data. While the VII network will be capable of delivering probe data to local users in a convenient and timely manner (essentially real time), each agency will be responsible for analyzing the data in order to estimate travel times, volumes, speeds, and incidents over various road segments within their jurisdiction.

To address the diversity of public sector end users of VII data, research is needed to determine the pros and cons of centralizing and automating probe data analyses to generate traffic, congestion, and weather information. For example, the VII operating entity (or a commercial firm contracted by the Operating entity) could provide for a centralized "traffic analyses, weather, and incident reporting" service. This service would collect probe data, analyze the data to determine road link traffic and road conditions, and then deliver these "default" traveler information messages to the local or state transportation agency. The transportation agency could then either simply "approve" the messages such that they would be automatically delivered to the appropriate local RSEs, or, the local agency could use the “enhanced” probe data (meaning the information has been enhanced compared to raw probe data) as input for generating their own traveler information messages.

An alternative approach to addressing this issue would be for USDOT to sponsor development of common software modules or libraries for analyzing probe data that could be given to local transportation agencies. The local transportation agency (or some authority having jurisdiction) would still need to subscribe to the probe data, implement the software and deliver the messages. While from the USDOT perspective this latter approach is programmatically simpler (i.e., another network service would not need to be created), it is less “hands-off” from the perspective of the local transportation agency, and, it may be more costly since each and every TOC or transportation agency would be required to implement their own analyses (or probe data translator) programs.

While the impact of this issue (i.e., diversity of resources and capabilities among TOCs) on VII application implementation will become more clear as the Day-1 ConOps are completed, and as POC testing proceeds, USDOT may wish to consider a separate research effort that identifies and inventories the TOC and TMC resources that are available at the local level. The research could also explore the trade-offs involved in centralized versus decentralized probe data processing including: “freshness” and turnaround times on probe data analyses; quality of the analyses; flexibility for accommodating localized message content and updates; and, overall costs, safety, and mobility implications. The research might also explore pros and cons of a hybrid approach (i.e., centralized and decentralized) to probe data analyses.

3.2. Examination of “Day-2” Use Cases.

The VII network architecture and associated services were largely developed based on requirements as defined by the private and public “Day-1’ use cases. While these use cases represent a broad cross section of functional needs, it is acknowledged that requirements from additional “Day-2” use cases could impact VII component and system designs—which in turn could impact how the Day-1 applications are implemented. It is therefore important that Day-2 use cases be examined in a fashion sufficient to determine if the current VII network, services, and components are capable of supporting the use cases. The Day-2 use cases should be analyzed and tested against the architecture to identify if any deficiencies in the architecture exist. USDOT is currently proceeding with this work .

3.3. Establish the VII Operating Entity Structure

The manner in which public sector applications are deployed and operated could be profoundly impacted by baseline assumptions regarding the overall governance and operating model for the VII network, infrastructure, and supporting services. It is therefore important that at least a high-level definition be established for how key stakeholder groups (government and vehicle OEMs) will interact with each other, and with outside stakeholders, in order to:

- – share information extracted from probe data,
- – accommodate “third-party” applications (i.e., applications not developed by vehicles OEMs or government agencies);
- – manage liability;
- – rationalize network capacity, (how do publishers and subscribers get charged for using the network)
- – ensure quality of service,
- – establish adequate security measures,
- – fund and maintain ongoing VII network services and applications.

It is envisioned that some type of joint public-private “operating entity” will be responsible for managing the operations of the VII network and services. While it is premature to define the detailed organizational, management, financial, and operational constructs for such an entity (since the manner in which stakeholders will interact will likely become more clear as the ConOps for each application are detailed, and after the POC testing is completed), it is nevertheless appropriate to develop a “strawman” management and operating model for the “operating entity”. Such a strawman could be based on current knowledge and assumptions about the network architecture, services, and applications. The roles, responsibilities and overall governance structure of the operating entity should be developed with input from all affected stakeholders including: vehicle OEMs, USDOT, state government, communication infrastructure and systems suppliers; as well as other stakeholders that have been involved in developing the VII concept thus far. The definition of the operating entity would not only begin to clarify how government and industry would interact with each other to manage and use the VII assets, but also how state and federal government would interact.

The output of this work will be important for both crafting application development plans, and for supporting the overall Deployment Decision.

3.4. VII Operating Cost Analysis

The costs associated with on-going operations, maintenance and utilization of the VII network are not well understood or documented, yet could have a profound impact on how applications are executed—as well as impact the overall Deployment Decision. An analyses of communications costs has already been developed based on very preliminary assumptions about the volume of “traffic” on the network as well as the mix of alternative backhaul communication links. However, these communication costs are only part of the total operating costs for the VII systems and network. Additional costs will include: the on-going maintenance and replacement of the physical VII infrastructure (including RSEs, VII servers and network hardware); costs associated with the “operating entity” including managing certificates of authority; executing any and all network services including probe data dissemination and message delivery ; managing overall quality of service; issuing and receiving payments for various services; managing conflicts and resolving capacity and authority issues; and costs associated with interfaces that might be established with other public entities such as emergency management services; public service points; etc. In short, the total on-going operating costs for maintaining and operating the VII network and services needs to begin to be assessed. The output of this effort is needed so that both government and industry can begin to develop strategies for how such costs will be paid for—and if they are indeed reasonable given the anticipated benefits from VII public and private sector applications. At this point, vehicle manufactures for example do not know what will be their annual costs will be for utilizing the VII network and services. As assessment of the total operating costs for VII network operations and maintenance is an important first step in crafting strategies about how to allocate costs and fund operations.

3.5. Alternatives Analyses

USDOT and industry have already invested considerable effort in examining the overall "value proposition" of the VII technological approach for executing various safety, mobility and convenience applications. The results of such efforts were summarized in a petition to the FCC for allocation of the 5.850 to 5.925 frequency band to be used exclusively for short range vehicular applications—with the priority given to safety applications. It was concluded by the FCC, as well as by USDOT and a majority of the vehicle manufacturers, that the overall VII technological approach was sound and offered advantages over other means of vehicle to vehicle and vehicle to infrastructure communications. Nevertheless, the issue of whether the short range communications/VII approach is the most cost effective means for achieving safety and mobility benefits will resurface as the Deployment Decision draws near, and as more details related to the overall design and costs of the VII concept become available. Not all of the major car companies are fully supportive of the VII concept, and other parts of the world are taking a different approach. For example, the European model seems to focus on standardized short range vehicle-to-vehicle communications (similar to the VII concept) for executing a variety of safety applications, but then would rely on more conventional cellular, WiMax, and/or satellite communications for vehicle-to-infrastructure communications. While there are good economic and political reasons for why different approaches might make sense in different world markets, the question of whether the safety and mobility applications can be executed in a fashion that would require less government involvement, and at lower capital costs will no doubt arise. To this extent, USDOT should consider beginning to assemble a formal "alternatives analyses" that examines if and how other communications and on-board technologies could be leveraged to achieve the same or similar safety benefits. The alternative analyses would examine the applicability of new cellular services (4G); new WiMax technologies; mesh network concepts; and other leading edge approaches that might facilitate vehicle-to-vehicle and vehicle-to-infrastructure communications and applications. Each alternative would be examined relative to capital cost, operating costs, performance, security, privacy, and ease of implementation trade-offs.

4. TRAVELER INFORMATION

4.1. Application Description

The objective of the Public Sector Traveler Information application is to provide location and situation-relevant information to travelers while in their vehicles using the VII network and WAVE communications standards. Traveler information would be delivered to vehicles based on a standardized "language" consisting of message sets, data frames, and date elements. The public sector traveler information application is to be differentiated from private sector traveler and navigation assistance applications in that the information (messages) are delivered un-encrypted via the open-standard WAVE short message format as currently outlined in SAE J2735. In contrast, private sector traveler information applications would be encrypted and likely delivered via a propriety language. Additionally, unlike the private sector application, it is not envisioned that the public sector traveler information application would provide for maintaining a communications session as the vehicle moves from RSE to RSE (i.e., the application would not utilize "session management" network services with individual vehicles). Rather, all messages from a particular RSE would be broadcast to all vehicles within range of that RSE.

Within the scope of traveler information application, public entities (both state and local) collect information derived from vehicle probe data as well as from traditional traffic monitoring systems, and provide geographically-relevant information to vehicles. While not directly in the scope of the traveler information application, this same information content might be reformatted and delivered to traditional traveler advisory systems such as web sites, dynamic messages signs (DMS), 511 systems, and highway advisory radio (HAR).

The public sector traveler information application is at this point scoped to include the following message categories:

- Traffic Information
- Incident Information
- Local Signage.

Each of these message categories is discussed in more detail in the following sections.

Traffic Information. The application would include provisions for broadcasting basic traffic information on defined roadway links within proximity to the RSE. Examples of traffic information would include average travel speeds, travel time, and other measures of traffic density (e.g., "percent utilization"). The roadway link descriptive information would be generated both through analyses of probe data as well as through more traditional sources of traffic conditions (e.g., CCTV, loop detectors, etc.). The OBE in the vehicle would then store and "assemble" the roadway link data to convey the "local" roadway traffic conditions to the driver. While OEMs will employ different strategies to this end, it is envisioned that the roadway link information might be overlaid on a GIS map database and displayed to the driver. Alternative methods of conveying traveler information to the driver could be envisioned that are based on predefined threshold events or incidents, combined with voice annunciation (i.e., exception-based reporting).

There are, however, several significant design issues that must be addressed:

- How will roadway "links" be defined (e.g., beginning and ending latitude/longitude together with "link name")? Will digital map notations available from commercial GIS databases be used for the "link name"? Conventions and standards remain to be finalized.
- How is "proximity" to be defined (i.e., what is the geographic coverage for a particular RSE)? How will coverage requirements vary for different RSE location environments (e.g., CBD, suburban, rural settings)?
- Some RSEs in adjacent jurisdictions will likely have overlapping coverage. How will messages from different jurisdictions be coordinated so that vehicles do not receive conflicting data?
- What is the appropriate resolution for a link (i.e., what should be the length of a travel link as reported in a single WAVE traveler information message)? Can this vary with each reported roadway, and by jurisdiction, or is standardization needed?
- What is an appropriate cycle time for repeating traffic information messages? What are the implications for the number of roadway links (i.e., individual J2735 traveler information messages) for which traffic information can be reported from a particular RSE?

Incident Information. The public sector traveler information application would also provide for incident reporting, and would include event-driven messages relevant to a particular point location or roadway segment. Examples include location of an accident, blocked lane, and other types of localized traffic disruptions. Incident information may also include more widespread broadcasts related to emergency events.

Local Signage. It should be noted that in previous documentation describing VII applications, local signage was often treated as a separate application. If local signage however is defined as the in-vehicle equivalent of roadside signage that is generally implemented and controlled by local and state governments, then the source of the local signage is in fact the public sector—and this application is arguably a subset of the public sector traveler information application. Local signage messages are intended to convey information that is temporary or periodic (i.e., may vary with time of day, day of week, etc.). Examples would include school zone warning and associated speed limits, work zone warnings/speed limits, cautionary warnings in place due to special events or conditions such as reduced speed due to surface conditions or fog. Detour information and road closures are also examples of local signage.

4.1.1. Relationship to Other VII Applications

The public sector traveler information application is central to the VII concept in that it will support both safety (incident notifications, in-vehicle signage) and mobility (traffic information) functions. In addition to supporting these message categories, it is envisioned that *weather advisory* and *corridor management* applications (discussed later in this document) will evolve into subsets of the public sector traveler information application. Further, it would be inefficient to implement unique prototype development efforts targeted at separately demonstrating the functionality implied by the three different applications (traveler information, weather advisory, and corridor management). While the data sources and analyses needed to support message development for these three applications may not be the same, all are focused on delivering standardized public sector generated messages through targeted RSEs. They differ primarily by the content of the message, and perhaps by strategies related to when and where the messages get disseminated.

4.1.2. Overview of Application Development Roadmap

At this point in the VII program, the high-level public sector traveler information use case has already been developed, and feedback has been received from public sector end users including state and local transportation agencies. This feedback focused on the overall flow of information (logical architecture), the anticipated roles of various entities, and high-level assumptions regarding data sources and traveler information message content. However, resolution of the technical issues previously noted as well as other design details remains to be completed, and could have a significant impact on the OBE and RSE, as well as other network components and services.

It should also be recognized that the traveler information application will be “breaking new ground” in many areas including providing detailed, near real-time traffic information to motorists, in their vehicles, and by a public sector entity. For these reasons, it is important that government and industry reach consensus on these more detailed technical requirements, as well as on the objectives and scope of the public sector traveler information application. It is also important that a prototype application be built and demonstrated so as to provide an opportunity to refine technical details, and to address programmatic and institutional issues associated with implementation.

The technical and programmatic work products from the prototype could then be “packaged” and a plan for disseminating the information to other transportation agencies could be developed. Such work products would likely include technical software designs, data analysis methodologies, and WAVE message generation processes. Also, important lessons learned would be documented regarding the roles of local and state transportation agencies, the network operating entity (network services), and vehicle OEMs. Guidelines for managing jurisdictional issues would also hopefully result from the prototype testing.

The deployment plan would also need to address the role of the U.S. DOT in assisting local and state agencies in preparation for offering the traveler information application in their jurisdiction. With this background, the proposed public sector application development plan consists of the following major steps:

- Application Refinement and Research
- Proof of Concept Testing:
  - Laboratory Development and Testing
  - System Integration and Testing
  - Application Integration and Testing
- Prototype Development and Testing

- Full-Scale Deployment

While from a contractual perspective, the above work might be grouped and awarded in varying ways, it is recommended that the current Booz Allen, VII Consortium (VIIC), and U.S. DOT team members involved in the VII program be tasked with completing all work up through POC testing. At that point, the U.S. DOT could issue a Request for Application to engage one or more teams, each anchored by a state DOT to provide a host site(s) for further developing the traveler information application. These teams would be charged with developing prototype traveler information applications that were appropriate for their particular coverage age. This work would include developing core software modules, lessons learned, and best practices for implementing a VII traveler information application. The U.S. DOT would then leverage the work from the prototype test(s) to develop guidelines and technical work products to assist other state and local transportation agencies with readying themselves for supplying traveler information messaging over the VII network when the first production vehicles begin to enter the market in around 2011.

4.2. Application Refinement and Research

4.2.1. Fundamental Research

Fundamental modeling and simulation research related to how probe data can be used to estimate travel times, speed profiles, and traffic conditions along roadway segments should continue in parallel with the POC testing efforts described in the next section. The research should include an analyses of various probe data generation strategies, probe data “association” rules, and alternative “opt in” strategies. Such modeling and simulation work is already being sponsored by USDOT under the Data Use Characteristics Study, (described more fully in section.2.3.2).

Additional, human factors research related to how traveler information can be safely conveyed to the driver will also be needed. Such research however would not need to begin in earnest until the prototype development stage since it is at this stage that “production like” displays and proprietary human machine interfaces from individual OEM’s will begin to emerge. NHTSA has been, and will continue to conduct substantial research related to driver distraction caused by in-vehicle systems. Such research includes the “100 car Naturalistic Driving Study”, the joint industry-government “SAVE-IT” prototype vehicle development effort; and, the publication of general guidelines and principals to be used by automakers and aftermarket suppliers in designing and implementing in-vehicle information systems.

4.2.2. Concept of Operation

The next step of the development process for the Traveler Information application is to develop a detailed Concept of Operation for the Day-1 implementation. This would help define the coordination that will be required between the vehicle OEMs and the U.S. DOT, and what the role of state and local transportation agencies will be in executing the traveler information application. For example, issues that would be refined/addressed during this effort would include:

- ***Traffic information broadcast strategies:***

- Consensus on how to define roadway links so that the on-board application can properly interpret the traffic flow information. Currently, the SAE J2735 committee is working on standardized formats for defining links that would include specifying the "name" of the link along with beginning and ending latitudes and longitudes for the link. This "header" information would then be followed by the descriptive traffic, incident, or signage information about that link. However, the "link name" must be referenced to a pre-defined digital map database so that the exact roadway segment is understood by the sender and receiver of the information. For example, in 2005, the Illinois Department of Transportation (IDOT) selected a commercial consortium (NAVTEQ, GIS Solutions, and ESRI) to develop and implement a statewide comprehensive digital road network database. A similar database might be implemented on a national scale to refine/simplify the link definition. The naming conventions and details related to link definition require continued discussion and development.
- Link resolution (i.e., the length of a link) and geographic coverage of traffic information messages from particular RSEs. Discussions of if/how traffic information delivery protocols would be tailored for RSEs operating in different environments (e.g., rural routes, CBD).
- Discussion of the "optimal" delivery rate (or density) of public sector traffic messages from RSEs—and the impact such rates may have on network bandwidth requirements and on OBE requirements for storing, assembling, and conveying the information to drivers. In other words, the level of traffic information detail that will be targeted for the public sector traveler information application requires discussion and consensus.

- ***Conveyance of public sector traveler information messages to the driver.*** While each OEM will develop unique and proprietary ways of prioritizing, filtering, and displaying the public sector traveler information, safety–related, in-vehicle signage and incident messages should have some level of standardization or consistency relative to driver conveyance methods (this is in addition to the overall message priorities that will be defined by the Operating Entity and coded as part of the Application Class ID). For example, it may be appropriate to have some minimum standards for how information about lane blockages, inoperative traffic signals, etc. is communicated to the driver approaching the incident. These types of issues should be addressed at least at a high level in the ConOps, and in a more detailed fashion in the Prototype (see Fundamental Research above).
- ***Proposed methodologies and guidelines for how traffic information from different jurisdictions would be handled at the "boundaries"*** (where there could be overlap in RSE coverage). The ConOps should address possible strategies and tactics for how this issue can be handled in a consistent and efficient manner.
- ***Discussion of the scope of "local signage" that should be included in the application.*** Some have suggested that local signage go beyond temporary or periodic signage—and include signage such as "do not enter," "trucks only," "turn lights on in tunnel," etc. Similarly, electronic signage related to parking restrictions could be broadcast. The scope of local signage (for the Day-1 application) would be refined in this phase.

The ConOps would also address the following requirement for the Traveler Information application:

- Functional requirements
- Performance requirements
- Interface requirements
- Data requirements
- Security requirements
- Safety requirements

The overall development of the application, including refinement of the ConOps is appropriately led by the U.S. DOT and its support contractors since the core off-board application as well as the data to support it will be developed and managed by the public sector. However, this is clearly an application that requires a strong industry-government partnership since the on-board application component is also likely to be complex and will be critical for the success and market acceptance of the application. The refinement of the ConOps will therefore be a joint effort between the U.S. DOT and the VIIC. A draft of the ConOps should be targeted for completion by early 2007.

Upon completion of the draft ConOps, an industry workshop(s) would be held to provide feedback as well as obtain input into prototype development and application deployment strategies. The industry workshop(s) would include stakeholders from state DOTs, local transportation agencies, ITS engineering firms who specialize in traffic and transportation management and information systems (e.g., 511 systems), and vehicle OEMs. The industry workshop could be held in late 2006. Based on feedback from this broader community, a revised ConOps would be issued by early 2007.

4.3. POC Testing

As noted in section 2.4, “VII Systems Integration and Proof of Concept (POC)”, the POC will focus on demonstrating end-to-end functionality for several applications, including the traveler information application, and is divided into three phases. ***Laboratory Development and Testing: Systems Integration and Testing:*** and ***Application Integration and Testing:***

The focus of the POC is not necessarily to deliver production-ready software, processes, and component designs for either the analyses of probe data or the generation of traveler information messages. This level of development is targeted for the Prototype Test(s).

The POC in Detroit is scheduled to begin in the first quarter of 2007. However, technical requirements as well as programmatic issues related to executing the traveler information application remain to be addressed—and an overall ***POC Applications Concept of Operation*** must be developed. While the POC Applications ConOps will detail activities to be completed in each phase as well as provide for a detailed Test Plan, Organizational Responsibilities Matrix, Schedule, and Resource Requirements Plan, the following overview of these is provided as a starting point for work to be completed during the POC.

4.3.1. Laboratory Development and Testing

Laboratory development and testing of the VII network and services will begin in the last quarter of 2006. Relevant to the traveler information application will be the development of the probe data dissemination service, the message delivery/advisory service (or broadcast service), as well as other basic security and provisioning services that will allow the network to be monitored, and for updates in software to be executed. The application components and services developed and tested during this phase will be common to essentially all of the public sector applications

4.3.2. Systems Integration and Testing

POC Systems Integration work will begin in the second quarter of 2007, including end-to-end testing of the public sector traveler information application. The focus in this development phase (within the POC) is to demonstrate that:

- An authenticated entity (e.g., a local public transportation agency) can subscribe to location-specific probe data, and collect specific types or subsets of probe data,
- Traveler information messages can be published, or delivered to, specific RSEs
- RSEs can receive, manage, and broadcast the messages as instructed, and,
- Vehicles can receive the messages and convey the information.

During this phase, actual probe data from the VII test fleet will be collected by RSUs, delivered to the SDN, and forwarded to authenticated entities subscribing to the data. While the Detroit DTE is comparatively small and would normally be managed by a single Transportation Operations Center, the test plan will call for possibly two to three “virtual” TOCs to subscribe to probe data collected from RSEs that align with the virtual TOC jurisdictions. In other words, the DTE will be artificially segmented into multiple jurisdictions so that probe data collection (and message delivery) services can be appropriately tested.

Because the content of the messages themselves is not critically important during this phase of development work, traveler information messages will be fabricated (or emulated) and delivered to the SDN “manually”. At least three “types” of messages will be simulated:

- Basic traffic information (e.g., link speeds, travel times)
- Incident information (e.g., lane blockage, accident notifications)
- Signage (e.g., work zones, school zones).

These advisory messages will be coded to simulate origination from different virtual TOCs with different jurisdictions and certificates of authority. The messages will include appropriate delivery instructions relative to broadcast location.

The RSEs will receive and deliver these “canned” messages to the VII test fleet. The vehicles will then display the messages in a simplified fashion—perhaps as a simple listing of messages received. The overall test objectives will be to monitor and verify that probe data can be appropriately collected, parsed, and delivered to the correct entities; and that authenticated messages are delivered to the correct locations and can be interpreted by VII test vehicles. The testing will also show that conflicts related to overlapping messages, jurisdictions, and/or probe data dissemination can be managed and controlled.

The System Integration phase of the POC is targeted to conclude in mid 2007. At that point, the basic network services needed to support the traveler information application would have been demonstrated, RSE design for managing broadcast messages solidified, and OBE basic functionality for receiving and displaying public sector information verified.

4.3.3. Application Integration and Testing

During the application demonstration phase of the POC, development work on the traveler information application will focus on the following capabilities and features:

- Analyze vehicle probe data to determine traffic and incident information (limited analyses however due to limited number of vehicles),
- Combine probe data with "traditional" sources of traffic, incident, and signage information to develop a consolidated roadway network view,
- Generate WAVE-formatted traveler information advisory messages,
- Deliver messages to targeted RSE locations, at appropriate time and with appropriate broadcast instructions,
- OBE application "intelligently" prioritizes and conveys messages,
- On-board probe data generation and delivery protocols modified "locally" to support unique circumstances. (this feature still being debated).

The overall objectives of the Application Demonstration phase are to:

- Further refine technical aspects related to probe data generation, probe data distribution services, and advisory message delivery services to ensure the performance and scalability of the application,
- Provide a demonstration of the value of the application to motorists using real-world data and operational situations.

Each of the key activities to be completed in this development phase are discussed in the following sections.

Analyze Probe Data to Determine Traveler Information: Probe data from the “core” VII test fleet, as well as the 2800 probe data drone vehicles, will be collected and analyzed to determine traffic flow operational data as well as incident information. However, based on early results from the Data Characteristic Study, we suspect that this volume of data will be insufficient on its own to yield reliable information about traffic conditions. To address this situation, test fleet vehicles may be modified such that probe data is generated at much higher frequencies, and stored on-board for longer periods before being purged, than is required by design standards. Such a strategy would effectively simulate a much larger number of probe vehicles such that useable analyses of probe data might be facilitated. The focus of this effort will be to show that probe data can be successfully utilized to report traffic and congestion conditions.

***Probe Data and Traditional Traffic Information Integration and Analysis Service*:** During the Application Demonstration phase of the POC, it will also be important to demonstrate that probe data can be combined with "traditional" sources of traffic, incident, and signage information to develop a consolidated roadway network view. Traditional sources for traffic flow data might include loop detectors, digital video imaging, cell phone tracking, and other means. For many years (and until a majority population of in-use vehicles are VII capable), such data fusion capability will be needed to develop the most complete picture of traffic conditions. Traditional sources of incident information would include roadway maintenance and related scheduled events from the local or state DOT, and/or incident data supplied by the local police, fire, or utility agencies. Such data is often consolidated by a public service access provider. Probe data will be analyzed and fused with such information to determine relevant traveler information (e.g., link travel times, link speeds, incident information). *The overall breadth and depth of this "data fusion" effort will in part dependant on how MDOT's Data Use Analysis and Processing (DUAP) program can be leveraged during the POC to support VII applications*.

VII Advisory Message Generation and Delivery Service: After probe data and traditional traffic information have been integrated, it will still be necessary to convert this information into a format that can be broadcast over the VII network. This process will include the following major steps:

- ***Defining roadway links***. This includes parsing each roadway in the DTE into discrete segments such that descriptive information about that segment can be included in individual advisory messages.
- ***Compiling message content***. Initially, traveler information will be in a variety of traditional electronic and non-electronic formats. This information must be converted into discrete WAVE (J2735 compatible) messages the match the defined roadway segments. Both automated and manual processes for generating WAVE traveler information messages will be developed. For example, the process must allow for a local transportation manager to compile a message manually for delivery to specific locations. We suspect this will often be the process followed for certain types of incident-related messages. Basic message configuration tools for assisting the managers would be provided including, for example, a "WAVE message input data form." More automated processes for generating messages, including perhaps a "WAVE message compiler" that is linked to conventional traffic information databases, might also be investigated.
- ***Defining delivery instructions for WAVE messages***. While not yet finalized, the proposed traveler information message formats for traffic, incident, and signage information include provisions for defining valid message deliver times. However, this information, which is embedded in the message itself, is only meant to assist the OBE with in-vehicle conveyance strategies—and is not used for controlling how message broadcasts are managed by the SDN and the RSE. Rather, it is envisioned that individual messages will be packaged into "envelopes" by the TOC (or by any entity authorized to publish information on the network). The "envelope" would contain instructions on geographic locations for the messages to be broadcast and valid broadcast times and dates, as well as repeat rate and possibly other instructions related to "triggers" for broadcasting the messages. Envelopes could contain a single message or perhaps several hundred.

While a technical construct for managing message delivery has been broadly outlined, rules and strategies for determining from which specific RSEs various types of messages should be broadcast, as well as broadcast frequency, must be developed. For example, how large of a coverage area should be defined for particular types of incidents? If the information is broadcast in a very large coverage area, bandwidth capacity may be jeopardized, and OBE message processing and storage requirements would be increased to handle the large volume of messages received. However, if the messages are only broadcast by the RSE that is nearest the incident (or the defined roadway link), then the information may arrive too late for the motorist to act on. For example, if there is congestion at a particular roadway link, the motorist will want this information far enough in advance to take another route. Absent a provision for allowing drivers to enter their intended destination, the strategies for broadcasting messages and subsequent interpretation by OBEs becomes a significant design challenge. (It should be noted that if the OBE application knew the intended destination, this would allow for precise filtering of the public sector messages. But, this is also a capability that is envisioned only for private sector navigation applications.) During the Application Demonstration phase, such issues will begin to be addressed.

After traveler information messages have been generated with the appropriate "envelope" instructions, the messages would then be published to the SDN. The SDN would then decode the instructions; look up the specific RSEs that messages should be delivered to; and then deliver those messages along with instructions about when the messages should be broadcast, repeat rates, and termination time/date. The RSEs would then broadcast the messages per delivery instructions. Compared to the work completed during the Systems Integration phase, the Application Demonstration phase of the POC would include the delivery of actual, near real-time traveler information messages along with more detailed "envelope" instructions regarding when, where, and how the messages are broadcast.

On-board Message Management: During the Systems Integration phase, the goal would be simply to demonstrate that messages could be received and displayed by the OBE. In the Application Demonstration phase, more sophisticated strategies and tactics for storage and conveyance of messages to the driver will be demonstrated.

While the formats and strategies for conveying public sector traveler information will vary by OEM for production vehicles, pre-competitive formats will need to be built to demonstrate the capability of the application and the value to the customer. For example, if a message about revised speed limits in a work zone is broadcast, the on-board application might receive the message, check the location of the vehicle to determine whether it is in the work zone, check to determine whether the speed limit is being exceeded (and perhaps by how much), and then issue a warning to the driver if they are exceeding the speed limit by some threshold. If the vehicle is not exceeding the speed limit, no message would be displayed. Similarly, messages that might be applicable only for vehicles operating in a particular lane, or traveling in a particular direction, could be analyzed and only displayed if/when appropriate.

Essentially, OBE refinement in the Application Demonstration phase would focus on more sophisticated filtering, analyses, and conveyance of messages so that "nuisance" and/or non-relevant messages were suppressed, while relevant messages were delivered in a manner and at a point in time that was useful to the motorist. A "stretch" goal for the Application Demonstration phase might be to show that the on-board unit could "piece together" public-sector-provided traffic messages for consecutive roadway links in order to develop a map of the local area showing travel speeds (perhaps using the "red, yellow, green" convention). Public-sector-provided messages about incidents or signage might also be overlaid on the map.

***Localized Probe Data Generation Management*:** Early work from the Data Characteristics Study suggests that proposed design standards for the collection, storage, and transmission of vehicle snapshots may be insufficient to support some applications—particularly those that require traffic flow and volume data. A potential solution would be to have the local authority having jurisdiction make a request (through the network SDN and RSE) for vehicles in a particular vicinity to modify the manner in which the vehicle generates, stores, and transmits probe date. Such modifications may include increasing the frequency of snapshots, holding the temporary vehicle ID for longer distances or timeframes, and/or storing additional snapshots in each probe message packet. During the Application Demonstration, the capability of the infrastructure to request changes in the manner in which probe data is generated and broadcast in specific locations, and of the vehicles to respond appropriately, will be targeted for demonstration.

4.3.4. Summarize Results from POC Testing

The traveler information application demonstration phase of the POC is expected to be concluded in early 2008. At that point, an Application Development Report will be assembled that summarizes the performance and functionality features that were demonstrated, documents how technical issues were resolved, and reports on issues that require additional test and refinement (including technical, organizational, and programmatic challenges).

In summary, the purpose of the POC is to provide a compelling but abbreviated demonstration of the traveler information application (as well as other applications). The work to be completed during this phase involves a combination of capabilities and experience including:

- Collection, analysis, and synthesis of multiple traffic and incident data sources to generate useful messages to motorists (e.g., traditional ITS acumen)
- Continued refinement of network services and subsystem component functionality (e.g., VII network, architecture, and communications familiarity)
- On-board vehicle systems, driver interface designs, and human factors considerations (e.g., vehicle design expertise).

4.4. Prototype Development and Testing

4.4.1. Refine Prototype Requirements and Objectives

While the focus of the Proof Of Concept phase is to support the Deployment Decision, the focus of Prototype phase is to fully develop the Traveler Information Application such that the work products from the prototype(s) can be packaged and distributed to other state and local transportation agencies across the country. Such work products might include core software modules for analyzing probe data and for generating WAVE-formatted messages; best practices and lessons learned related to integrating non-VII traveler information sources; guidelines for managing jurisdictional and institutional issues (e.g., privacy, security); integration of the VII-generated information with other advisory media (e.g., DMS, HAR, 511); and potentially, experience working with third parties who wish to provide traveler information content to motorists. Other transportation agencies across the country could then initiate their own programs for deploying similar traveler information applications that were tailored to their service areas. Key technically focused development tasks to be completed during the prototype(s) include:

- Enhancement of probe data analyses techniques, and process for integration with traditional transportation network monitoring and reporting data
- Refinements in advisory message delivery services and strategies
- OEM specific tailoring of OBE applications and interfaces
- Development of recommended practices for conveyance of safety related messages
- Integration with existing traveler information systems (e.g., DMS, HAR, 511)
- Integration with third-party information service providers.

Each of these development tasks related to the traveler information application is briefly discussed in Section 4.4.4 “Conduct the Prototype Development and Testing.”

4.4.2. Expand/Create the Prototype Development Test Environment(s)

As discussed in section 2.5.1, it will clearly be efficient and effective to continue application refinement in the Detroit area—and the DTE put in place for the POC could be expanded to support application prototype development. Issues related to an expansion of the VII test fleet, number and location of RSEs, as well as coverage area are discussed in section 2.5.1.

Complimentary Test Environments: Also as discussed in section 2.5.1, there may be advantages related to implementing multiple Development and Test Environments (DTEs)—and this could be particularly true for the Traveler Information Applications.

The ability to leverage transportation network information gathered through existing ITS resources and programs will be important during early stages of VII deployment. This is the case since, at low market penetration levels, probe data alone will likely not support reliable and comprehensive estimates of travel times and traffic volumes throughout a particular metropolitan area. Information collected through conventional ITS equipment such as loop detectors, CCTV, cell phones, and toll tag monitoring could be analyzed and integrated with the probe data to achieve better and more expansive estimates of traffic conditions than could be achieved through probe data alone. Further, even in the long run (when a majority of vehicles are VII-enabled), much of the incident and signage data (that would be converted to VII messages) will still originate from the State DOT, local transportation agency, and/or local public service answering point (PSAP). For example, information about work zones, detours, roadway maintenance, police actions, and other planned “incidents” will be originated through conventional means and (ideally) integrated with probe data as well as conventional ITS traffic monitoring systems to form a more complete picture of the travel times, incidents, and signage information on particular roadway links.

Essentially, the integration of transportation relevant information sources described above is the process followed by existing 511 traveler information systems (absent of course the information that could be gleaned from the probe data). State and local transportation agencies that already have programs in place that integrate these disparate data sources (i.e., 511 type of programs) will benefit from implementing the VII traveler information application in two ways:

1. The VII traveler information application will provide more immediate value to motorists since a more comprehensive database of relevant information will be available for supporting the development of WAVE-formatted messages.
2. Challenges related to integrating multiple (conventional) data sources will have already been solved so that the only new challenge will be to integrate the probe data information.

Based on the above arguments, the U.S. DOT may wish to consider supporting a second traveler information prototype development effort in an area that already has a state-of-the-art 511 traveler information system in place. To initiate a second development test environment, the following key minimum steps would be required:

- VII-compatible RSEs would need to be sourced and installed.
- A network access point and service delivery node would need to be established for the DTE.
- Approved/validated software for executing network services would be installed.
- Vehicles with approved/validated OBEs would need to be operated.
- Communication standards governing probe data generation (SAE J2735) would need to be adhered to.
- Advisory messages (from the TOC) would need to follow the WAVE convention standards as well as standards for the "envelope" delivery instructions.

Based on the above requirements, it would seem inefficient to immediately establish a second DTE in parallel with the Detroit effort since basic network software and subsystem components will not yet have been developed. However, it is feasible that a second DTE for supporting the traveler information application could be established at a point when the initial Systems Integration phase of the POC is concluding, or about mid 2007. At that point, the basic network services needed to support the traveler information application would have been developed, and the basic end-to-end functionality would have been demonstrated. Also, additional RSEs should be available at that point in the program including any refinements in software or designs as a result of the POC Systems Integration testing. There are advantages and disadvantages, however, to initiating/supporting a second prototype effort at this early stage (i.e. mid way through the POC in Detroit):

- ***Advantages:*** The more effort and resources that can be applied to developing the traveler information application, the more likely that important technical challenges will be identified and resolved expediently. Also, because the second prototype effort would be targeted for a region with advanced traveler information synthesis and reporting capabilities, it is more likely that timely, accurate, comprehensive and useful messages could be delivered to motorists using the VII network. This would help generate early enthusiasm and support for the project, and would allow for an "early success story." The traveler information application development would not be contingent upon (or mired in) building basic systems for integration and synthesis of non-VII sources of travel, incident, and signage data.

- ***Disadvantages:*** The POC will not yet be complete, and during the Application Demonstration Phase of the POC there will be continued refinement of network services, as well as likely modifications and improvements to other VII subsystem components (including the RSE, OBE, SDN specifications and other components). It will be a technical and management challenge to maintain configuration control in both test environments during this period of likely rapid and progressive development of the VII concept and components. Additionally (and obviously), there will be additional resources needed to support a second test environment and development team. If a Prototype development effort were to begin prior to the conclusion of the POC in Detroit, the "Deployment Decision" will not yet have been made—and it is conceivable that the VII concept could be changed radically, or even cancelled. Thus, the effort will have been wasted.

It should also be noted that a second DTE would not necessarily need to be architecturally and logically linked to the DTE in Detroit (via a backbone network as described in the National Architecture Specifications). The second DTE could operate autonomously so long as it followed all applicable VII standards and utilized approved network software that was developed by the U.S. DOT/Booz Allen/VIIC team. While there would be advantages in linking the two DTEs in a manner that represents a scaled-down version of the national architecture, the costs and operational issues associated with doing so would need to be further investigated.

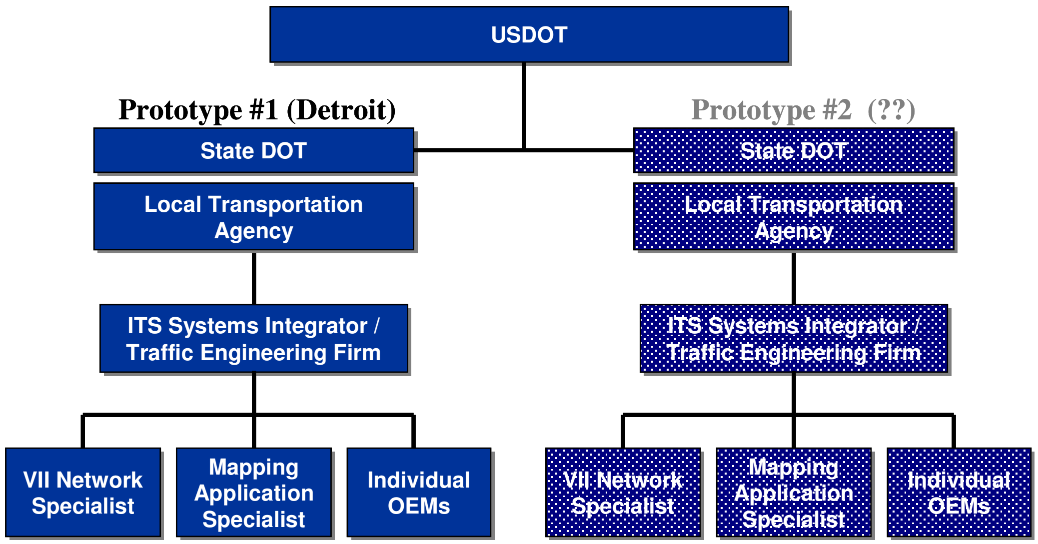
4.4.3. Prototype Development Team(s)

The resources and capabilities needed to support Prototype development and testing are considerable. Core team members would include:

- U.S. DOT (JPO) to oversee and help fund the effort.
- A State DOT partner to co-sponsor the prototype
- A local transportation agency (or more likely, an interagency organization) that would have jurisdiction over the region in which the development test environment would be implemented (e.g., a host-site operator)
- An ITS/traffic engineering and systems integration firm to lead the technical development effort
- Vehicle OEMs to supply the test fleets and build the on-board application components
- VII network and architecture specialists to lead communications trade-off analyses, support message delivery strategy development, and support development of any new network services required
- A GIS, roadway mapping, and navigation specialty firm to help with defining roadway links, building databases and applications for managing WAVE-formatted messages, and developing roadway information synthesis tools.

Exhibit 4 presents a hypothetical organization chart for the prototype development team .

Exhibit 4 – Team Organization for the Traveler Information Prototype Development



4.4.4. Conduct the Prototype Development and Testing

The traveler information prototype development effort in Detroit would begin at the conclusion of the POC (or in early 2008). Key application development activities that would be targeted for the prototype phase are briefly discussed in the following sections.

- ***Enhancement of Probe Data Analyses and Integration with Traditional Transportation Network Monitoring:*** As previously discussed, the task of analyzing probe data and integrating it with more conventional traffic monitoring sensors and information will begin in the POC. However, the scope of the POC will be limited to possibly 50 vehicles and less than 100 RSEs. During the Prototype, the DTE would be expanded to include multiple jurisdictions and a greater variety of operating environments—including perhaps some portion of rural route coverage. Refinements in traffic information analyses would likely include more automated synthesis of probe data with conventional roadway measurements, identifying and correcting for possible sampling biases and data anomalies, fusing probe data from different manufacturers that contain different data elements, and using the probe data to forecast rather than just report traffic conditions.
- ***Refinements in Advisory Message Delivery Services and Strategies:*** Continued research into tradeoffs surrounding the frequency, resolution, and "reach" of broadcast traveler information messages will need to be conducted. Such tradeoffs will involve bandwidth usage (communications costs), the required "freshness" of information, on-board memory and processing requirements, and required resolution of information by the driving public. For example, the following development tasks related to message management could be advanced during the prototype:
  - Experimentation concerning the appropriate broadcast region (or coverage area) will continue to be refined.
  - Alternative (and pre-competitive) strategies for intelligently storing and filtering messages to the driver will continue to be refined during Prototype development,

particularly to the extent that the filtering/display solutions themselves would impact the viability of alternative broadcast strategies being considered (i.e., an iterative and cooperative approach with the vehicle OEMs will need to be implemented to determine "optimal" public sector message broadcast methods).

- Methods for managing message delivery schemes at the RSE level will be refined (e.g., message broadcast sequencing algorithms that maximize bandwidth utilization while retaining fundamental messaging priority requirements).
- There will be additional refinement of the "envelope" concept for packaging messages together with delivery instructions. Such refinement might focus on "envelop" packaging strategies that would minimize the necessary communications between the TOC and the SDN, and between the SDN and individual RSEs.

- While these and other issues related to improving communications efficiency within the VII network will begin to be explored in the POC, they will be studied and refined during the prototype—and where possible, best practices and standards will be developed.
- S***eparate OBE Applications/Interfaces for Each OEM:*** During the Prototype, individual OEMs would refine their own proprietary OBE applications for supporting traveler information messages that are broadcast by public sector entities. In contrast, during the POC, a common (VIIC-developed) traveler information application would be utilized during the testing. We suspect that these POC-designed vehicles would continue to operate during the Prototype, and might serve as a reference fleet that could be used to support U.S. DOT-sponsored research related to filtering and display of public sector traveler information messages.
- ***Recommended HMI Practices for Conveyance of Safety-Related Messages:*** As noted in the Overview section, it may be appropriate to develop standards around driver conveyance (or presentation) practices for selected safety-related messages that would be provided as part of the traveler information application. For example, there may be benefits to motorists for having similar (or the same) presentation formats for messages that contain information about lane blockages, hazardous pavement conditions, traffic signal failures, and other selected safety-related messages. Although the "priority" of such messages will be defined elsewhere (by the operating entity), the specific manner in which these messages are presented to the driver (whether through audible tones, voice annunciation, visual displays, or a combination of these) will have an impact on driver response. If the presentation methods are substantially different between vehicle makes and models, there is the potential for drivers' response times to be less optimal than if the presentation formats were standardized. If the presentation methods are standardized along at least some dimensions (minimum standards that remain consistent), then the driving public will develop a better, more ingrained knowledge of the meaning of a particular safety message alert—and therefore appropriate response actions and response times will benefit. A task focused on identifying the pros and cons of implementing presentation guidelines for safety-related messages should be implemented during the Prototype, along with a research plan for developing such guidelines.
- ***Integration with Existing Traveler Information Systems (DMS, HAR, 511):*** The analyses of probe data along with the enhanced traveler information databases that will be developed

to support VII advisory message generation could also be leveraged to support the delivery of better information through more conventional media including 511 programs, dynamic message signs, highway advisory radio, public web sites, and other means. Such integration would help to build public support for the VII program, and motorists that do not have VII-equipped cars would still benefit from the improved traffic information that they generate. During the prototype, a development task would be to integrate probe data collection and analyses efforts with existing traveler information systems and networks.

- ***Integration with Third-Party Information Service Providers:*** It is currently unclear whether third-party applications that would reside on the OBE will be supported by vehicle OEMs. If supported, such applications might combine for-fee, third-party services with public sector provided data to offer motorists additional navigation and traveler information options. Essentially, third-party service providers may wish to work cooperatively with the public sector to offer enhanced functionality. If the vehicle OEMs and OBE architecture permit third-party applications, then development work related to refining such applications could proceed as a development task (or work stream) under the prototype phase.

4.4.5. Evaluation and Monitoring

Whether one or two prototype development efforts are established, it will be important to implement a *Performance Monitoring and Reporting System* to help evaluate and manage the prototype testing. A set of performance measurement tools will need to be carefully crafted and implemented to help determine the cost, benefits, and performance of the traveler information application from the perspective of different entities including the U.S. DOT, the host-site agency, and the motoring public. Key areas of evaluation for the Prototype testing and development are as follows:

- Public acceptance evaluation
- Failure mode evaluation
- Safety and mobility benefits assessment
- Performance, reliability, and maintainability of network and supporting components
- Capital and operating cost estimates.

For all of the evaluation criteria, it will be important to establish various baseline measurements related to the traffic conditions within the DTE, the test subject's driving performance and habits, and the overall DTE operating environment. Such measurements should be taken before the prototype phase begins. These tests and evaluation criteria were reviewed in section 2.5.4, Evaluation and Monitoring.

4.5. Full-Scale Deployment

Full-Scale deployment tasks and strategies for all of the VII public sector applications are discussed in section 2.6 "Full Scale Deployment", and, general cross-cutting issues affecting full-scale deployment are also discussed in section 3.0, "Cross-cutting issues. However, the following are selected deployment and institutional risk issues that are particularly associated with the traveler information application.

4.5.1. Policy, Liability, and Institutional Issues

Key policy and institutional issues associated with this application include:

- ***Vehicle Tracking***. The current default probe data snapshot scheme calls for some degree of "association" of consecutive snapshots to improve analysts' ability to estimate variables such as speed, volume, turning movements, etc. In addition, there is consideration of public sector "opt-in" programs that would ask for the motorists' permission to anonymously track their vehicle as a means of enhancing the traveler information services that the public sector would provide. While there would be assurances from the U.S. DOT, the vehicle OEM community, and others that such tracking could not be linked to a specific vehicle, or vehicle owner, there will still be considerable controversy and debate surrounding probe data "association" as the project moves forward.
- ***Information Accuracy***. Any public agency broadcasting traveler information (including messages that may have safety implications) will likely be held to high standards for ensuring the accuracy of the information. For example, if the weather and surface condition broadcast information is erroneous or excessively "old," and a motorist is involved in a collision after having acted on weather information received from the public entity (e.g., the motorist proceeded along a road based on information about the reported roadway conditions, but then encountered conditions that were much different or worse), then it is conceivable that the motorist would hold the public agency liable for the collision. The general issue of "information accuracy" is a pervasive issue for several VII applications, and this issue will need to be addressed during deployment.

4.5.2. Key Risk Areas

The following are selected key risk areas associated with the development of the Traveler Information application:

- ***Vehicle OEM support for Public Sector Traveler Information Application:*** A key challenge and risk to the development of the public sector Traveler Information application is to what extent vehicle OEMs will leverage the messages provided by public sector agencies relative to presentation of the information to the driver. It is likely, especially on high-end models, that vehicle OEMs will provide advanced and tailored traffic and traveler information to subscribing customers. However, the extent to which customers who do not wish to subscribe to for-free services will have access to publicly provided traveler information on these models is yet to be determined. Additionally, lower-end models, which may not have sophisticated HMIs or navigation systems, may rely on publicly available traveler information messages as their primary source of data, specifically as the market demographics suggest that owners of those vehicles are less likely to pay a reoccurring subscription fee to the OEMS. A risk is that OEMs choose not to build in robust features or capabilities for utilizing the public sector information.
- ***Capabilities and Resources of Local and State Transportation Operating and Management Centers:*** There is a broad range of capabilities and resources among TOCs and TMCs for pulling together local traffic, incident, and signage information, and developing appropriate

traveler information messages. The analysis of probe data to extract traffic-related information will add to this burden. While it is expected that “standard” software modules and analytical tools for analyzing probe data will be developed by traffic and transportation engineering firms, local agencies will still need to configure, implement, and manage such software and systems. Vehicle OEMs may be skeptical about the ability of local transportation agencies nationwide to develop and implement systems for delivering value-added traveler information systems in an expedient and effective fashion. An alternative, “default” approach would be to centralize some degree of probe data analysis at the national level, and to generate standardized messages based on this analysis. How this issue is “played out” will impact the on-board application design, network design, roles of local agencies, and other important design issues.

5. SIGNAL TIMING OPTIMIZATION

5.1. Application Description

Overview. At Day-1, VII will provide the ability to gather traffic related information necessary to monitor and refine the operation of traffic signals. When combined with other existing traffic data sets, more effective timing plans could be produced for both isolated and coordinated signal systems. VII data will provide detailed vehicle snapshots, including timestamp, position and speed, as well as the vehicle's trajectory through the intersection. These data will be archived and analyzed to identify when a range of negative conditions occurs that currently cannot be efficiently measured using conventional traffic detection technologies. Automatic identification of these negative conditions will provide support for developing signal timings and daily schedules for coordinated signal systems.

In the future (beyond "Day-1"), as higher penetrations of VII equipped vehicles enter the market, traffic responsive (TRSP) and fully adaptive traffic signal control based on vehicle probe data could also be enabled. However, signaling systems that are capable of responding to real time traffic flow measurements do not have a high deployment rate in the U.S. Therefore VII-augmented TRSP applications would likely not see high deployment rates. Additionally the TRSP application would require significant penetration rates of VII vehicles, along with a familiarization and confidence in VII data by practitioners. In addition, fully Adaptive traffic signal control is a very new concept that is not governed by any standard practices or technologies. Utilizing VII data to implement adaptive signal control may require partial or total revision of basic signal control concepts and architecture. Adaptive signal control that is enabled by VII technology is therefore not a Day-1 application and is not covered in this Application Development Plan.

For a more detailed discussion of traditional traffic signal control systems, see Appendix B.

Background: Signal Timing Optimization Goals

There is no general consensus on what constitutes good traffic signal operation. Some optimization tools are based on reducing stops and delay in various combinations, others on maximizing capacity. Still others are based on some surrogate performance measure such as progression. In practice, most agencies desire to please their motorists in order to minimize citizen complaints. Because the motoring public in a given region has been conditioned by the operation of that region, basing success on citizen complaints allows wide regional divergence. For example, some regions routinely use cycle lengths in the range of two to four minutes, while other agencies with equally congested networks would never implement a cycle over two minutes. Motorist opinion in congested areas is usually strongly held and vigorously expressed, and drivers accustomed to one system might find the operation of another system intolerable.

Despite these regional effects, motorists generally complain when they are forced to stop unexpectedly or for a longer period than they believe is "fair." They often complain when forced to wait through more than one green period. Finally, they complain when queue lengths block access to intermediate intersections and driveways, or force turning lanes to spill out into through lanes. Thus, most skilled practitioners seek signal timings that minimize the following: queuing, unexpected and unexpectedly long stops, cycle failures, and queue spillover

Implementation and Operation of Traffic Signal Systems

Traditionally, traffic signal timings are developed on the basis of the volume of vehicles making each movement at each intersection. These counts are usually collected manually; although, during peak periods, some can be collected using a system of vehicle detectors if they are favorably configured. However, most agencies do not configure detectors for counting vehicles because such configurations are not necessarily the most effective arrangement for normal “calling” and “extending” functions that are part of actuated signal control. (see Appendix B for explanation of signal phasing, calling, and extending functions).

Data collected for signal timing plans also usually includes 24-hour vehicle counts made with temporarily located automatic traffic counters. These provide traffic volume data to support the initial development of signal timing (or phasing) plans for various periods throughout the day (i.e. daily schedules).

These data are programmed into signal timing optimization software that use volume-based delay and saturation equations, or volume-based macroscopic simulation, to optimize operation according to the objective function associated with the particular tool.

The signal timings as calculated by the optimization software are then scrutinized by the practitioners, refined as needed, and then installed into the local signal controllers. Daily schedules (i.e., the distinct periods throughout the day for which signal timing plans are changed) are typically implemented based on a visual review of 24-hour count data.

Thus, the operation of most traffic signal systems is based on a limited sample of data collected days, weeks, or months before timing implementation, and they remain in operation potentially for years thereafter.

Once installed, the signal timings are observed in the field for effective operation. Signal timing professionals will determine whether traffic is behaving as expected and therefore achieving the desired optimal operation. Inevitably, adjustments are made to fine-tune both the timing plans and the daily schedule, based on observation over a period of one or more days. The objective of those adjustments is to achieve operation that is visually effective from the perspective of the agency practitioner. That effectiveness is usually based on achieving *smooth flow* and *minimizing queue formation* and congestion. Both are visual manifestations of reduced delay and stops. Those objectives are generally not measurable using traditional traffic detectors (which only measure vehicle presence in a predetermined detection zone).

Opportunities for Leveraging VII Probe data

As noted, a critical activity is fine-tuning the signal timings when they are implemented, calibrating the daily schedule, and then evaluating the signal timing patterns over time. Currently, most agencies depend on direct field observations for all these activities which presents a resource challenge to many agencies.

VII probe data can be used to evaluate signal system operation in support of fine-tuning and evaluating signal timing patterns, and in support of calibrating the daily schedule to achieve the desired operation.

In particular, agencies fine-tune their signal timings to:

- Minimize unexpected stops and starts of the traffic stream
- Minimize intersection delay (and thus travel time)
- Minimize cycle failures
- Minimize queue spillover.

Depending on the manner in which probe data is coded, generated, and collected, it could, theoretically, support measuring time-in-queue by movement, deceleration, start of queue position, and unserved queues. These measurements could then be used to support control strategies that would fine-tune the signaling system. VII probe data can also be used to support the ability to supplement detector data in response to detector faults, even if providing an improvement on normal fail-on detector failure modes. Essentially, the probe data would offer a much more efficient means of measuring the effectiveness of the existing signal timing plans compared to manual counts and labor intensive observation by signal timing professionals.

It is possible that offline optimization algorithms can be crafted to use probe-based measures of effectiveness directly, rather than manually collected turning-movement counts. This would require extensive experimentation to develop optimization approaches that would be competitive with traditional methods. In practice, making the probe data available might attract support from the research and software community who have developed these optimization approaches.

Probe data can also evaluate whether progression is working properly by identifying approaches where large platoons arrive while the light is red. This can be used both to evaluate offset values and also to select a pattern that uses offsets more suited to progression in the direction of the problem.

Supporting Traffic Responsive Signal Plans (TRSP). Most practitioners will try to optimize operations using conventional signal timing and daily schedule dimensions before developing traffic-responsive capability. Those agencies that have the resources and face the situations that allow for traffic-responsive operation will use appropriately designed systems to collect a range of volume and occupancy data from the designated system detectors. This historical data will be used to develop thresholds and/or traffic pattern profiles (depending on the system software), to which real-time detection data will be compared for pattern selection during normal operation. These thresholds (for changing signal timing patterns) will be fine-tuned in the same way that daily schedules are fine-tuned—so as to achieve pattern transitions at appropriate times to track the changes in demand patterns throughout the day.

Another opportunity for VII is to provide an alternative to the use of volumes and detector occupancies for traffic-responsive pattern selection. For example, queue spillover is usually a sign of a capacity issue, which is often addressed by engaging a pattern with a longer cycle (up to a point) to increase the capacity. Queue spillover may be detected as increases in occupancy on system detectors, but only if the system detector is ideally placed. The spatial perspective of VII likely makes evaluating the size of the queue far easier.

Given that the objective of most practitioners is to achieve smooth flow and minimal queuing, selecting patterns on the basis of direct measurements of those parameters might be more effective and easier to implement. It is likely that doing so will require significant “on-the-ground” experience with VII data before practitioners and researchers will be able to devise new pattern selection algorithms to take advantage of the probe data. For this reason, the opportunity for improved traffic-responsive operation based on VII is largely not attainable for Day-1.

Clearance intervals provide another opportunity for VII. Timing professionals calculate clearance intervals on the basis of the approach speed and grade. Wet roads are assumed, and this assumption may be unnecessarily conservative during dry conditions and not conservative enough during wet conditions. Existing literature includes research on the necessary clearance intervals under various conditions, but measuring those conditions requires expensive environmental sensing at a wide variety of locations. Such data are not currently available to operating agencies. However, probe data from VII vehicles could be used to pinpoint when deceleration rates declined at certain intersections (in conditions of poor traction) and increase when conditions improve. VII vehicles could also yield useful data such as anti-lock brake actuation, the use of windshield wipers, and/or temperature data which might be used to support changing clearance intervals to track current environmental conditions.

Supporting Adaptive Signal Systems. Adaptive signal algorithms based on the ability to detect queue formation have been developed in the past, but were never implemented because queue data have been unavailable. VII probe data can be incorporated directly into adaptive algorithms to address this issue, but it requires designing the adaptive algorithm in light of the available data. Measuring queue lengths consistently and reliably enough to support adaptive control may require a higher penetration of VII-equipped vehicles than is anticipated for Day-1 implementation or demonstration. Moreover, at Day-1, traffic volume estimates using probe data will not be practical due to the limited, as well as fluctuating, number of VII vehicles within the total vehicle population. It is not envisioned that VII data would replace the traditional processes for developing signal timings initially. Traffic volume requires a predictable penetration, which assumes high penetration rates to minimize error.

5.1.1. Relationships to other VII Applications

This application will utilize “basic” VII network functions such as probe data dissemination and advisory message delivery. Also, the roadway weather and surface condition data will likely be reported using the same roadway “link” definitions that are to be defined as part of the traveler information application. Otherwise, this application is not linked to any other Day-1 application.

5.1.2. Overview of Application Development Roadmap

Based on these assumptions and background information, the Deployment Plan for the signal timing optimization is organized as follows:

- Application Refinement and Research
- Proof of Concept Testing
- Prototype Development and Testing
- Full-Scale Deployment

During concept refinement, the roles of various entities involved in the application will be clarified and more details related to the overall architecture will be developed. The development of a ConOps for signal timing optimization will be an important step in bringing together the signal system industry and VII developers to help frame how VII will be leveraged both at Day-1 and beyond to assist in improved and cost-effective signal systems. Additionally, early on in the application development, specific research into how VII data might be used to generate the necessary information (cycle failures, stops, delays, etc.) to produce measures of effectiveness (MOEs) will be needed. Such research could also include how VII might be leveraged for more advanced traffic-responsive, traffic-adaptive, and signal re-timing applications.

During POC testing, basic functionality will be demonstrated including the ability to collect and analyze probe data to determine fundamental MOEs (e.g., cycle failures, stops, delays). Specific staged tests would be performed with POC vehicles to generate probe data during varying traffic conditions. The data would then be analyzed offline to determine whether data can be extracted (particularly queue data) to evaluate the effectiveness of the current signal timing plans. Additionally, the data would be analyzed to determine whether indicators or “flags” can be derived that might be used to fine-tune signal timing plans.

After the POC and the research into potential algorithms is will underway, an Application Development Team would be selected to build prototype support tools for practitioners using VII probe data. The focus of the Development Team would be to develop tools that would automate the collection and analyses of probe data to determine MOEs that would assist in the fine-tuning of signal timing plans. The Prototype would focus on implementing complete end-to-end functionality including collecting VII probe data, analyzing it real-time using revised and fully researched algorithms, and providing an interface for practitioners to use this data. It is assumed for purposes of this Application Development Plan that the Prototype, as well as the POC, would take place at the Michigan DTE.

It is unlikely that a complete TRSP system would be implemented during the Prototype as there is significant algorithm and system development and research required. Additionally, while TRSP is a widely known concept, it has not been widely accepted and implemented. Therefore, it is unrealistic to assume that the nationwide deployment of a TRSP system would occur by Day-1. However, as practitioners become increasingly familiar with utilizing VII probe data (to determine MOEs and fine-tune signal timing plans) and research advances, development of a TRSP, and/or traffic-adaptive control algorithms that leverage VII probe data is possible—but is beyond Day-1.

5.2. Application Refinement and Research

5.2.1. Fundamental Research

The signal timing optimization application requires the development of techniques and algorithms for extracting relevant signal timing information from probe data. Research is needed to determine how to characterize probe data in support of this objective and to understand the statistical quality of the data. For example, cycle failures (where the green time is insufficient to clear the queue) are currently evaluated on the basis of tracking whether signal controllers too frequently do not terminate on the basis of gaps. However, it would be much more accurate to measure cycle failures directly by noting that some probe vehicles were not accommodated by the first green period presented to them. Intersection delay, which cannot be measured directly by conventional detectors, can also be directly measured from probes. The U.S. DOT is currently directing a "Data Characteristics Study" (being led by MitreTek) that to a significant degree is evaluating how probe data can be used to support a variety of analyses and measurement of traffic flow through signalized intersections. Using modeling and simulation techniques, this work will help determine at what level of market penetration probe data will begin to reliably support analyses for the evaluation and improvement of traffic signal systems operations. However, additional research will be necessary to understand how to fine-tune signal timing plans from probe data and provide practitioners with useful information to understand the effectiveness of their current signal timing plans.

5.2.2. Concept of Operation

The first step of the application development process for signal timing optimization is to refine and further develop the signal timing optimization use case and develop a more detailed Concept of Operation for Day-1 signal timing optimization.

The ConOps would, in particular, define the activities of agencies who conduct signal timing optimization as they relate to the data that can be received from the VII infrastructure. The Concepts would refine how the following objectives and tasks related to signal optimization could be accomplished at Day-1:

- Speed, braking, and acceleration information from the VII infrastructure would be used to derive delay and queuing information to identify intersections with operational problems.
- Speed and delay information could be used to support fine tuning of daily schedules for coordination and to support the development (including fine-tuning) of timing patterns.
- Speed and brake application data can be used to support pattern selection algorithms in traffic responsive operation.
- Probe data can be used to identify conditions under which the clearance intervals should be modified, such as under conditions of ice and snow.

Next, application requirements based upon the ConOps would need to be developed and would include the following:

- Functional requirements

- Performance requirements
- Interface requirements
- Data requirements
- Security requirements
- Safety requirements.

Upon completion of the ConOps and requirements, an industry workshop would be held to provide feedback, as well as obtain input into prototype development and application deployment strategies. While this document provides a starting point for recommendations relative to prototype development and deployment strategies, the results from industry-focused workshops would yield a complete and agreed upon concept of the signal timing optimization, a defined set of requirements, a more detailed approach for development of prototype applications, as well as thoughts on deployment strategies.

5.3. POC Testing

The POC for the traffic signal optimization application will take place in Detroit DTE. It is envisioned that a U.S. DOT-sponsored team would lead the effort.

- The team would collect and analyze the probe data from the approximately 50 "core" VII test vehicles to see how they might support signal timing optimization. We would also take advantage of the 2800 DCX probe data "drone" vehicles, although the probe data from those vehicles would be collected in a non-real time fashion using a Wifi type of collection system. Such data could however still be used to assess the operation of the timing plans that were in place at the time the data was collected. Since the plan for Day-1 is to use the VII probe data in an "off-line" operation to measure the effectiveness of the signal timing plans, the data from the 2800 DCX vehicles should prove almost equally as useful as the data from the 50 VII vehicles for this particular application.
- While we could not likely get volume or turning movement data during POC due to the limited amount of vehicles, we would be able to develop speed profiles. The speed measurement information may be used to refine some signal control and timing parameters, and additional analysis could be performed on the limited volume and turning movement data to refine the Data Characteristics Study. (Note: special staged or pre-arranged experiments with numerous vehicles at a single intersection might allow for analysis of volumes and/or turning movements during the POC).
- The team would experiment with alternative probe data generation and association schemes to evaluate which ones best support the signal timing optimization.
- The team would examine incoming probe data, perhaps in near real time, to determine when/if existing alternative signal timing plans might be implemented (i.e., simulate switching of signal timing plans using received probe data from POC vehicles).

As noted earlier, a separate document (i.e., "POC Application ConOPs") is being developed that will guide application functionality and demonstration during the POC. This document will contain additional details on the manner in which the Signal Timing Optimization application will be executed during POC.

5.4. Prototype Development and Testing

This section is organized as follows:

- Refine Requirements and Objectives
- Expand/Create the Prototype Test Environment
- Prototype Development Team
- Conduct the Prototype Development and Testing.

5.4.1. Refine Prototype Requirements and Objectives

Following a successful POC test in Detroit, a more expansive Prototype could be initiated. The focus of the Prototype development effort would be to:

- Refine the probe data generation, association, and collection processes
- Refine strategies for RSE placement and probe message management
- Experiment with various “opt-in” probe data schemes
- Work with one or more traffic engineering firms that specialize in the development and implementation of signal timing plans and signal control systems to demonstrate how VII probe data could be leveraged to improve traffic flow through a series of signalized intersections.
- Demonstrate complete end-to-end functionality of a local signalized corridor that is “optimized” using VII data. Compare costs and benefits of utilizing VII data versus conventional fine tuning.

The requirements and objectives for the Prototype would be based on industry consensus viewpoints that were solicited and documented during the development of the Concept of Operation for Day-1, as well as on the results of the POC testing.

5.4.2. Expand/Create the Prototype Develop Test Environment

Infrastructure. It is envisioned that the Prototype effort would be completed in the Detroit area and would continue to leverage the VII equipped vehicles, as well as the 2800 Chrysler probe vehicles. The focus of the Prototype would be to create a complete, integrated corridor of signalized intersections that were all equipped with RSEs. The signal system would need to be sufficiently complex to promote confidence in the results but simple enough to be broadly applicable to other signaling systems around the country It is anticipated that a system with 10 to 20 signals in an arterial coordinated system would fit this requirement. (At this point in time, only 3 to 4 intersections will be equipped with RSEs during the prototype, so the test environment would need to be significantly expanded.)

The traffic signals need to be operated using either a centralized control system or a field master (or both), that is available for enhancement by the software engineers on the team. A site with signal timings that are not necessarily current would provide the best opportunity to demonstrate the application since the focus will be on how probe data can be efficiently collected and analyzed to improve overall operation. If the traffic signaling system in that particular corridor were already "optimized", then the Prototype might only show that data useful in validating performance could be efficiently collected, but no improvement in traffic flow performance would be realized. The demonstration would therefore be less compelling.

n addition to expanding the Detroit test environment, it is also recommended that the Prototype development effort be augmented by using a hardware-in-the-loop simulation test bed. Field data would be collected at the field site to provide the basis for simulation in the lab. The field data would include traffic counts, both turning movement counts and 24-hour automated counts, intersection geometry, traffic signal operation, and vehicle trajectories using a commercial GPS travel-time data collection tool. (Additional discussion of how the hardware-in-the-loop laboratory would be leveraged to augment the Prototype development is discussed in section 5.4.4.

Test Vehicles. It should be noted that some key questions must be resolved as to the degree of penetration of VII-equipped vehicles that would be required to support the Prototype. Various levels of penetration could be tested in the experiment, starting with minimal penetration and increasing the level until the provided data achieves sufficient reliability to support the activity. The simulation test bed in particular would facilitate those iterations. Based on previous research, penetrations of 3 to 10 percent are expected to be effective, although the research on which this is based was concerned with travel time measurement, which is a different objective. A typical peak period of two hours might carry, say, 18 percent of the daily traffic. Assuming a moderately heavy arterial street carrying 45,000 cars a day, the simulation might include about 10,000 cars (including the initial period before data is collected where the simulation achieves equilibrium as the network is filled). As noted earlier, since the focus of the prototype is to use probe data in a non-real-time fashion to measure system effectiveness, the data to be provided by the 2800 Chrysler "drone" vehicles will prove nearly as useful as the data from the much smaller VII test fleet. The Chrysler test fleet however would not be useful for supporting development of a traffic responsive prototype application. For a TRSP system, it is imperative that traffic data be collected near real-time so that it can be quickly analyzed, and new signal time plans "called" if necessary. The probe data from the Chrysler test fleet will not be available in a near real-time fashion and therefore would not support such an effort.

5.4.3. Prototype Development Team

Much of the development of the probe data analysis "service" requires understanding how traffic information must be presented to practitioners to provide for effective decision making. This requires domain expertise in traffic signal operations at the agency practitioner level.

Also, properly documenting the needs and requirements and demonstrating traceability requires systems engineering expertise. Traffic researchers are needed to explore how to characterize probe data such that it is statistically valid in addition to being expressed usefully to satisfy the requirements. Traffic researchers will also work with the operations experts and signaling software supplier to develop probe-based traffic responsive pattern selection algorithms. Software engineers will be required to develop the probe data analysis service and the performance monitoring capability.

Evaluation of the VII-enabled signal optimization application requires implementation with a cooperative operating agency willing to allow the consultant team to assist them with demonstrating end-to-end functionality. Evaluation also requires statistical skills to test the stochastic results for statistical validity.

Thus, the ideal team would include personnel with expertise in:

- Traffic signal system operations
- Traffic signal timing in coordinated systems and in traffic responsive coordinated systems
- Field data collection, including turning movement counts, 24-hour counts, and vehicle trajectory data
- Systems engineering
- Software engineering for developing the VII-based services
- Traffic research and statistics
- Hardware-in-the-loop simulation.
- Cooperative local transportation agencies. (presumably RCOC and/or other local transportation agencies in Michigan.

Many of these skills overlap so that careful selection of team members can minimize the cost and complexity of the team. The U.S. DOT will provide overall programmatic support for the demonstration, and will supply the VII elements needed to perform the demonstration. The public agencies to be included in Prototype effort will provide access to their traffic control systems, and will help with coordinating the work of other team members for necessary field work. The local agency professional will also provide review of signal timing plans developed for the demonstration and supervision of their installation.

5.4.4. Conduct the Prototype Development and Testing

The signal timing optimization Prototype would require the development of the following high-level components:

- ***Probe Data Analysis Service:*** Would need to be developed to characterize measures of effectiveness using alternative probe data collection schemes in support of offline optimization and evaluation of coordinated traffic signals. Probe data would need to characterize intersection movement delay, unexpected stops, and excessive queuing.
- ***Performance Monitoring and Reporting Service:*** A set of performance measurement tools to automatically provide evaluation of performance gains of VII-enabled systems. These tools will provide the feedback necessary to raise awareness of VII's impact, and report on

whether VII-enabled traveler information systems may need additional work to realize predicted goals. While some of these metrics will be identical to those developed as part of the probe data analysis service, the metrics should also include more conventional, manually collected and observed measures in order to establish the before and after “ground truth” regarding traffic signal system performance. It may even be useful to implement some type of public survey instruments to determine if motorists have noticed any perceptible changes (improvements) in traffic flow, or in the operation of the signaling system.

The development of these components would be accomplished during the early part of the Prototype and would build on work done in the POC.

Probe Data Analysis Service. The process for developing the probe data analysis service includes developing core analytical techniques and algorithms, crafting useful display and output formats, and then coding such analyses and techniques into software modules. Such prototype software, along with appropriate documentation and instructions, would then be made available to the traffic single system practitioner who would then fine-tune the operation of the “corridor”. After the changes have been implemented, the practitioner would use the same probe data inputs and analyses software to validate improvements and determine whether the service has reached its goal.

Demonstrating the effectiveness of the program requires a comparison of two basic effects:

- What were the personnel resources needed to fine-tune the system remotely using probe data compared to the resources needed to fine-tune the system by observation on the ground?
- Were the resulting fine-tuning operations at least equally effective in terms of minimizing the negative effects described in preceding sections?

Initially, a typical field arterial system consisting of 8 to 12 intersections can be constructed in a hardware-in-the-loop laboratory environment, with controllers interfaced to a traffic simulation tool using CIDs. The traffic simulation tool would provide the vehicle-trajectory probe data with typically 100-millisecond resolution, which can be used as the basis for developing tool prototypes. The design effort for creating the laboratory operation under test would be similar to conditions on the ground, even including viewing animated displays of the intersections.

The hardware-in-the-loop test lab might, for example, include the following:

- 12 traffic signal controllers, with enough cabinetry to interface to CIDs
- 12 controller interfaces devices
- VISSIM simulation, equipped with hardware-in-the-loop interfacing to the CIDs
- Test traffic counts from a 12-intersection field site where on-the-ground testing might ultimately take place.

A signal timing practitioner of demonstrated experience but unrelated to the experiment would be made available to test the effectiveness of the service.

The evaluation and demonstration process would include the following steps:

- Developing a data input set for VISSIM to match the measurements from the potential field test site
- Simulating traffic signal operation and the simultaneous collection of probe results. The model would be considered valid when it produced similar probe information to what was measured at the field site.
- Programming the test-bed controllers for hardware-in-the-loop simulation
- Connecting the CIDs and interfacing the test-bed
- Conducting hardware-in-the-loop simulation of actual (existing) test cases
- Optimizing the signal timing using traditional methods (The exact method is not important because the purpose of the test is to evaluate the helpfulness of the service after optimization, not to compare the optimization to an objective standard)
- Implementing the optimized timings
- Using only the prototype probe data analysis service, fine-tune signal operation
- Implementing the refined operation
- Evaluating the effectiveness of the support for fine-tuning on the basis of observing the real-time simulation animations.

After refining the entire development, testing, and evaluation process in this laboratory environment, the new timing plans and daily schedules could then be implemented in the "real-world" test environment (i.e., the same system from which the probe data was originally gathered. The impacts on traffic flow would then be measured using both VII probe data, as well as conventional methods. The proposed approach would not require revisions to the software in the local signal controllers.

All of the software modules developed during the Prototype, as well as other best practices and lessons learned in implementing the signal timing optimization application would be summarized in a Prototype Final Report as described in section 2.5.4 (Evaluation and Monitoring) and section 2.5.5 (Summarize Prototype Results).

5.5. Full-Scale Deployment

Once the Prototype development and demonstration is complete, the results should be disseminated to the user community. This will include a guide on how to use VII probe data to fine-tune and monitor the operation of traffic signal systems, and white papers describing traffic responsive pattern selection algorithms that can be implemented by the private sector in its signal systems products. Additional full-scale deployment issues are reviewed in section 2.6, "Full Scale Deployment".

5.5.1. Policy, Liability, and Institutional Issues

Implementation of this application provides no known policy issues and requires no changes in basic agency jurisdiction. Traffic signal operation is safety-related and subject to severe scrutiny.

Given that the signal controller has constraints programmed both in software and hardware to prevent unsafe operation, and given that the proposal does not propose to modify these constraints, the risk of increased liability is minimal or negligible. In other words, basic phasing and other timing considerations that might impact safety would not be impacted.

Institutionally, the probe data analysis and monitoring services directly serve the practicing agency professional, and thus do not impose implementation within commercial products. Thus, there is no negative impact on the private sector as a result of providing these services.

The traffic responsive pattern selection service would be implemented in products supplied by the private sector. The algorithms developed during the Prototype would be published such that all suppliers would have free access to them for fair and competitive implementation.

5.5.2. Key Risk Areas

The following is a key risk area for the development of the signal timing optimization application:

- ***Penetration Rates at Day-1:*** An important risk in the development of the signal timing optimization application is the ability of the application to provide benefits during low penetration rates at Day-1. Given low market penetration, it will be a challenge to develop applications that can provide even modest benefits in improving the ability of a signal operator to retime signal systems. In the future, as higher penetrations of VII-equipped vehicles are realized, fully adaptive traffic signal control can also be enabled. Adaptive control is not, however, a conventional operation governed by de facto standards, and therefore may require partial or total revision of basic signal control concepts and architecture.

6. RAMP METERING

6.1. Application Description

Like many signal systems, most ramp metering systems operate on a time-of-day basis. Some systems use detector data from the freeway to determine metering on/off times during peak periods and check for an unacceptably long queue with a single detector upstream on the ramp, but otherwise do not respond to changing traffic conditions in real time. VII data can eventually provide sufficient data to offer more responsive ramp metering systems, and in the short term can simplify the setting of optimal ramp metering rates. Also, by providing more comprehensive data it will enable the generation of effective ramp metering plans without the need to manually collect data in the field. Some sophisticated ramp metering systems adjust metering rates as often as twice per minute. VII may eventually provide advantages to these systems, but likely not until full market penetration is achieved. VII integration with advanced ramp metering systems is not considered for Day-1 as part of this use case.

At Day-1, VII probe data will provide detailed vehicle snapshots, including timestamp, vehicle position, speed, braking and acceleration information, as well as the vehicle's trajectory through the ramp and merge area(s). Eventually, the probe data will also allow for aggregated flow profiles of vehicles between ramps on a per-lane basis. From this data, other measures including link travel time, mainline speed, mainline delay, ramp queue delay and average ramp queue length (over time intervals, non-real time) information can be derived. These data will be archived and subsequently fused with other data from non-VII sources, and analyzed to generate new ramp metering plans, and at which times of the day to activate those plans.

Finally, at Day-1, VII will incorporate a set of performance measurement tools to automatically provide evaluation of performance gains of VII-affected systems. These tools will provide the feedback necessary to raise awareness of VII's impact, report on the performance of VII-enabled ramp metering systems, and determine whether additional work is required to realize predicted goals.

In the future, as higher penetrations of OBU-equipped vehicles are realized, more responsive algorithms may be employed to take advantage of the ability to determine queue length in real time with VII data. Additionally, VII may provide a simpler installation paradigm for future deployments, as agencies would not need to install mainline or even ramp detectors, instead relying on VII to provide required detection.

Note: During the development of the Day-1 use cases, a separate use case for ramp metering and signal timing optimization were established. While these two use cases are significantly different technically, and provide significantly different functionality, the development plans for these two use cases follow essentially the same approach.

6.2. Application Refinement and Research

The Ramp Metering application requires the development of techniques and algorithms for extracting relevant ramp metering information from probe data. Fundamental research is needed to determine how to characterize probe data in support of the objectives of this application, and to understand the statistical quality of the data. The U.S. DOT is currently directing a "Data Characteristics Study" (being led by MitreTek) that to a significant degree is evaluating how probe data can be used to support a variety of analyses and measurement of traffic flow through freeways utilizing ramp meters. Using modeling and simulation techniques, this work will help determine at what level of market penetration probe data will begin to reliably support analyses for the evaluation and improvement of ramp metering operations.

6.3. POC Testing

The POC testing will be utilized to:

- Analyze the probe data from the VII-equipped vehicles and the DCX probe vehicles to see how they might support the determination of ramp metering information (e.g., link travel times, mainline delay, queue length, vehicle trajectories)
- Experiment with alternative probe data generation and association schemes to evaluate which ones best support the ramp metering
- Examine incoming probe data, perhaps in near real time, to determine when/if existing alternative ramp metering schemes might be implemented (i.e., simulate switching of ramp metering schemes using received probe data from POC vehicles and/or DCX probe vehicles).

As noted earlier, a separate document (i.e., "POC Application ConOPs") is being developed that will guide application functionality and demonstration during the POC. This document will contain additional details on the manner in which the Ramp Metering application will be executed during POC.

6.4. Prototype Development and Testing

An application Prototype development effort would follow the POC and would:

- Refine the probe data generation, association, and collection processes
- Refine strategies for RSE placement and probe message management
- Involve one or more traffic engineering firms that specialize in the development and implementation of ramp metering control systems to demonstrate how VII probe data could be leveraged to improve traffic flow through a freeway corridor using ramp meters.
- As appropriate, the Ramp Metering application would be linked to the corridor management, load balancing application.

Because the Detroit DTE does not include existing ramp meters, an alternative location for conducting the ramp metering prototype would need to be identified. As discussed in section 11 (Corridor Planning), it may be advantageous to implement that application in a locality that already has a mature and capable traveler information systems (i.e., a 511 system and associated data collection and analysis processes). The same Prototype develop and test environment identified for the Corridor Planning application might also be leveraged for the Ramp Metering Prototype.

6.5. Full-Scale Deployment

Once the Prototype demonstration is complete, the results should be disseminated to the user community. This will include a guide on how to use VII probe data to fine-tune and monitor the operation of ramp metering systems, and white papers describing traffic responsive pattern selection algorithms that can be implemented by the private sector in its ramp metering products. Additional full-scale deployment issues are reviewed in section 2.6, “Full Scale Deployment”.

6.5.1. Policy, Liability, and Institutional Issues

Implementation of this application provides no known policy issues and requires no changes in basic agency jurisdiction. Ramp metering operation is safety-related and subject to severe scrutiny. Given that the signal controller has constraints programmed both in software and hardware to prevent unsafe operation, and given that the proposal does not propose to modify these constraints, the risk of increased liability is minimal or negligible.

6.5.2. Key Risk Areas

The following is a key risk area for the development of the signal timing optimization application:

- ***Penetration Rates at Day-1:*** An important risk in the development of the Ramp Metering optimization application is the ability of the application to provide benefits during low penetration rates at Day-1. Given low market penetration, it will be a challenge to develop applications that can provide even modest benefits in improving the ability of a ramp meter operator to retime systems. In the future, as higher penetrations of VII-equipped vehicles are realized, fully adaptive ramp meter control can also be enabled.

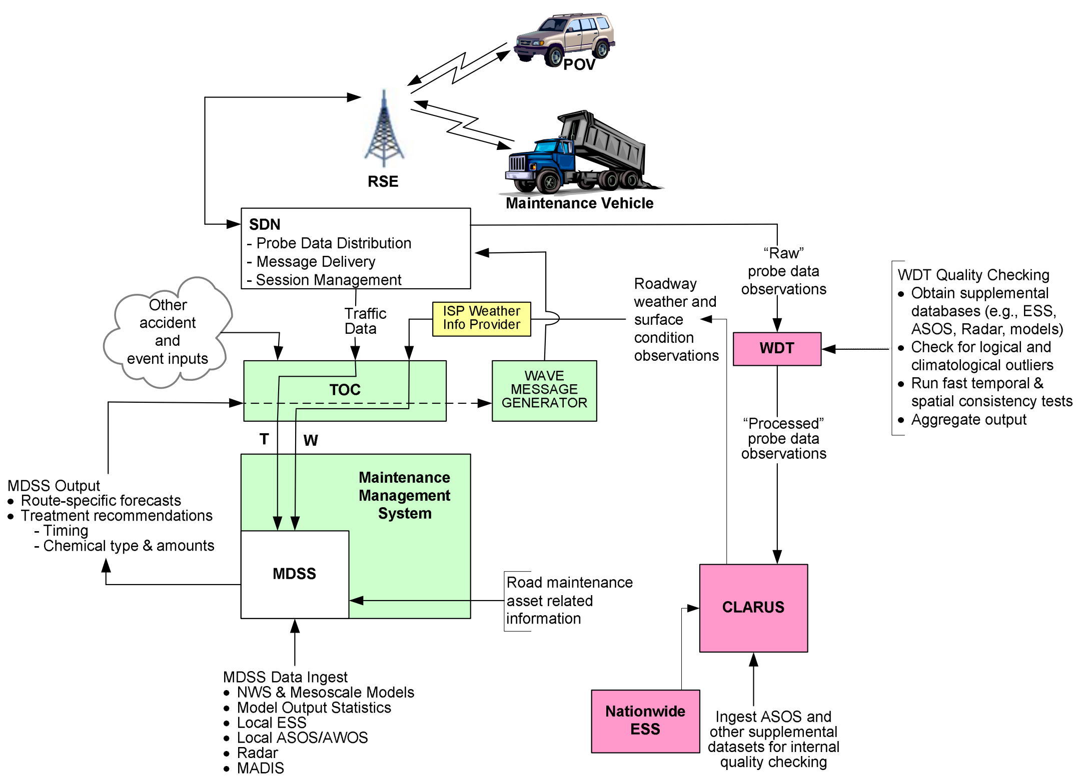
7. WINTER MAINTENANCE

7.1. Application Description

The Winter Maintenance application integrates roadway weather and environmental conditions data from "traditional" sources, with vehicle-based sensor data from VII-equipped vehicles — both privately owned vehicles (i.e. OBEs) as well as roadway maintenance vehicles (i.e. PSOBEs) — to support decisions on surface treatments, and to communicate that treatment information to maintenance vehicles in an expeditious and efficient manner.

At this point in the VII program, the high-level public sector winter maintenance use case has already been developed, and feedback has been received from public sector end users including state and local transportation agencies. Exhibit 5 provides an overview of the information flow as well as key entities involved in the application.

Exhibit 5 – Winter Maintenance Application Architecture Diagram



7.1.1. Overview

The overall application would operate as follows:

- VII-equipped privately owned vehicles (POVs), as well as selected roadway maintenance vehicles that have been properly equipped, will include in their probe messages a variety of data elements relevant to documenting current weather and roadway surface conditions. Such data elements might include outside temperature, wheel slip events (activation of traction or stability control functions if the vehicle is so-equipped), ABS braking events, windshield wiper status and wiper speed setting, status of exterior lights, and sun or rain sensors if the vehicle is equipped with such sensor. Maintenance vehicles might be configured with additional or more accurate sensors such as infrared detection of pavement temperature, humidity readings, and possibly even wind conditions (taken when the vehicle is at a standstill).

- This probe data will be forwarded to a "Weather Data Translator" (WDT). The role and processing capabilities of WDT have yet to be fully defined. However, the FHWA vision for the WDT is for a robust data quality checking system which makes use of numerous supplemental data sets (both in-situ and remotely sensed) and contains complex routines for evaluating bias and outliers. In addition, the WDT is expected to reduce the processing load of downstream systems by providing normalized, aggregated or formatted output. The WDT must be formally considered for design and implementation since it will play a significant role in all weather applications. Moreover, the WDT will likely touch many other VII applications since weather is a cross-cutting area for transportation. The idea for a WDT, which originated in the FHWA Road Weather Management Team, is currently under consideration by the National Center for Atmospheric Research (NCAR). A report on its feasibility and potential capabilities is expected in the fall of 2006.
- The "processed" probe data from WDT is then forwarded to USDOT's *Clarus* system (http://www.Clarusinitiative.org). *Clarus* ingests data from environmental sensor stations (ESS) across the nation, as well as ASOS and other supplemental datasets for internal quality checking. The roadway weather and surface condition observations from *Clarus* could then be forwarded to the TOC directly. Alternatively, a private sector Information Service Provider (ISP) that specializes in weather information could subscribe to *Clarus* to analyze the data to develop localized weather and surface condition reports for specific roadway segments, and then forward this "enhanced" information to the TOC.
- The weather and surface condition data for specific road segments is then forwarded by the TOC to a generalized maintenance management system (MMS). The TOC would also forward general traffic condition information (congestion and incident data) for these same segments, since it may impact roadway maintenance decisions. The MMS would house a more specialized maintenance decision support system (MDSS) module (or stand alone application) focused on providing decision support for roadway winter maintenance operations. This would include route-specific forecasts and recommendations related to when, where, and how to perform winter treatment actions in the region covered by the MDSS. The MDSS might also be integrated with maintenance vehicle dispatch and assignment management software. It should be noted that the MDSS functionality is central to the Winter Maintenance application in that it represents the leading-edge approach for collecting relevant roadway condition and weather observations, and then developing recommended maintenance actions that allows for optimizing equipment, people, and resources. The MDSSs in place today in states such as Iowa, Nebraska, and South Dakota rely on probe data from maintenance vehicles to augment weather data received from other sources. However, the MDSS concept was envisioned to leverage data from additional probe vehicles (i.e. POVs) if and when such data became available. To this end, VII and the MDSS

concept represent a natural "fit." For more information on MDSS, see the following link: http://www.rap.ucar.edu/projects/rdwx_mdss/index.html

- The MDSS would then determine optimal surface treatment plans, help modify maintenance vehicle dispatch and assignment schedules, and then forward the instructions to a "WAVE message generator." The messages would then be sent to the SDN for delivery to the maintenance vehicles via the VII network.

7.1.2. Relationship to Other VII Applications

This application presumes that the capabilities and functionality of the Weather Information application as described in Section 9.0 are in place. Specifically, it is presumed that VII weather-related probe data is being forwarded to *Clarus* and that a WDT has been integrated with *Clarus*. This application further presumes that the capabilities and functionality implied by the Traveler Information application as described in Section 4.0 is also in place. Specifically, it assumes that the ability to estimate travel times and congestion on roadway links is in place. It also assumes that all provisions for enabling the delivery of traveler and weather-related messages are also in place. This would likely include provisions for maintaining "sessions" with maintenance vehicles so that complete roadway maintenance and treatment instructions could be communicated.

7.1.3. Overview of Application Development Roadmap

Based on these assumptions and background information, the Deployment Plan for the Winter Maintenance application is organized as follows:

- Application Refinement and Research
- Proof of Concept Testing
- Prototype Development and Testing
- Full-Scale Deployment

The proposed application development plan is characterized by work phases that represent a progressive development of the application from concept refinement through full scale development. During concept refinement, the roles of various entities involved in the application will be clarified and more details related to the overall architecture will be developed. The overall Application Deployment plan proposed in this document will also be reviewed.

During POC testing, basic functionality will be demonstrated including the ability to maintain communication sessions with actual or emulated maintenance vehicles. Probe data related to surface conditions would be analyzed, and treatment instructions delivered to maintenance vehicles. However, it is unlikely that integration of *Clarus* and/or MDSS would be tested during POC.

Toward the end of the POC, a Winter Maintenance Application Development Team would be selected to build and test a full prototype application. The prototype application would focus on implementing complete end-to-end functionality including an MDSS and full integration with *Clarus*. It is assumed for purposes of this Application Development Plan that the prototype application development would take place at the POC DTE in Michigan.

7.2. Application Refinement and Research

7.2.1. Fundamental Research

Considerable fundamental research is required related to how probe data could be used to report on, and forecast, the weather and road condition surface information along roadway links or at specific roadway locations. Much of this research surrounds how the raw probe data from VII vehicles would be "translated" into more meaningful observations. As noted in the Overview section, this function could be performed by software and systems that are notionally termed a "Weather Data Translator". Some basic research related to the use of vehicle probe data to improve the reporting and forecasting of roadway weather conditions is already being done by NCAR (***VII Probe Weather Data Feasibility Study)***. Additionally, Mitretek, has been tasked with conducting empirical field studies related to assessing the accuracy and usefulness of weather related probe data acquired (or transmitted) from vehicles under varying speed and other operating conditions, (***VII Probe Weather Data Accuracy Study).*** This research is discussed **in** more detail in the Introduction (Section 2.3).

7.2.2. Develop Day-1 Concept of Operation

While the initial use case for the Winter Maintenance application has been developed, the logical links, exact roles of various entities, and the overall architecture including the components outside the VII network still require refinement. For example:

- Is this application critically linked with the capability implied by roadway MDSS? Or, can a limited or "baseline" version of this application be developed that would provide support for those agencies that are not implementing an MDSS? Based on preliminary research conducted for this Applications Development Plan, it would appear that the VII Winter Maintenance application and MDSS concept are tightly linked; however, this issue could be more fully explored in the ConOps.
- Should the ConOps include provisions for integrating conventional telematics services that are commonly used by roadway maintenance departments to assist with vehicle management operations (e.g., cellular, satellite communications and related services)? Or, should the VII network be relied on exclusively for communications with the maintenance vehicles? Other communications means may be needed beyond the VII network. In rural areas, maintenance trucks may have plow routes that don't include RSEs or do so infrequently. If this is the case, the truck probe data may not have a chance to be downloaded in reasonable amount of time. This will impact the performance of MDSS if it relies on vehicle-based treatment data.
- Should "off-the-shelf" vehicle routing, dispatch, and optimization software be integrated with the overall ConOps?
- How and where in the overall architecture should observed weather and road surface data be translated into more useable roadway link messages? Is this done by the TOC, the "Weather Enterprise," or an ISP? Also, how and where in the architecture will the roadway link surface condition information get converted into the WAVE message format before finally being published on to the VII network?
- For maintenance vehicles, what are the "baseline" assumptions about the additional data elements that these vehicles will include in their probe messages?

A first step in the application development process will be to clarify and embellish the overall ConOps, and to gain widespread consensus on the "boundaries" for the application (e.g., location of the WDT in the architecture, more details on role and integration of *Clarus*, ISP, MDSS, etc.).

It will also be important to gain consensus among key stakeholders (i.e., state and local agencies responsible for roadway maintenance, as well as the U.S. DOT, *Clarus*, MDSS, and VII team members involved in the respective projects) on the overall development plan for the Winter Maintenance application. This report presents an initial, high-level straw man for a development plan, but the plan will need some degree of "buy-in" from stakeholders before moving forward.

To this end, the U.S. DOT could consider engaging in an application scoping effort. The focus of the effort would be to develop a detailed ConOps for the Winter Maintenance application, and to refine the overall deployment plan. A winter maintenance application development "task force" could be assigned to lead this effort. It is recommended that the FHWA road weather management team should take the lead on this task force and create a balanced set of participants that would likely include members of the VII development team, staff at the FHWA Office of Operations, ITS JPO, and representatives from key states interested in this application and who have participated in winter maintenance decision support system activities. Finally, it would be important to include on the task force representatives from NCAR who are actively involved in the development of MDSS, as well as systems integrators who are currently involved in offering MDSS type applications and services.

7.3. POC Testing

As noted in Section 2.4, "VII Systems Integration and Proof of Concept (POC)", the POC will focus on demonstrating the VII concept through several applications, including the winter maintenance application, and is divided into three stages. *Laboratory Development and Testing; Systems Integration and Testing;* and *Application Integration and Testing*.

The focus of the POC is not necessarily to deliver production-ready software, processes, and component designs for either the analyses of probe data or the generation winter maintenance related messages. This level of development is targeted for the Prototype Application Development phase.

The POC in Detroit is scheduled to begin in the first quarter of 2007. However, technical requirements as well as programmatic issues related to executing the winter maintenance application remain to be addressed—and an overall ***POC Applications Concept of Operation*** must be developed. While the POC Applications ConOps will detail activities to be completed in each phase as well as provide for a detailed Test Plan, Organizational Responsibilities Matrix, Schedule, and Resource Requirements Plan, the following overview of these is provided as a starting point for work to be completed during the POC.

7.3.1. Laboratory Development and Testing

Laboratory development and testing of the VII network and services will begin in the last quarter of 2006. Relevant to the winter maintenance application will be the development of the probe data dissemination service, the message delivery/advisory service (or broadcast service), as well as other basic security and provisioning services that will allow the network to be monitored, and for updates in software to be executed. The application components and services developed and tested during this phase will be common to essentially all of the public sector applications.

7.3.2. Systems Integration and Testing

Before the Winter Maintenance application demonstration can begin in earnest, it will be necessary to have completed basic systems integration testing of the VII network—including the development and demonstration of various application "stubs." For the Winter Maintenance application, there are three key network services that must be developed and demonstrated. These include probe data dissemination, advisory message delivery, and session management. During the systems integration phase of the POC, all of these services would have been developed and tested in the Detroit DTE.

7.3.3. Application Integration and Testing

The POC testing in Detroit will be the first opportunity to demonstrate the ability to collect probe data useful in identifying and locating road surface conditions that might require snow removal, pre-conditioning treatments, or other maintenance actions. Prior to the initiation of the POC, it will be important to refine requirements and goals for demonstrating or otherwise supporting the development of the Winter Maintenance application at the Detroit test bed. Key issues to be addressed include:

- What specific sensor data that is useful in determining surface conditions could/should be available from the "core" VII test fleet (traction control events, actuation of stability control systems, temperature sensors, wiper system status, steering wheel rate of change, ABS events, vertical acceleration threshold events, sun sensor, rain sensor, etc.)? Which specific sensor data will be available from various sub-fleets within the test fleet?
- What specific sensor data related to weather and road conditions will be available from the 2800 Chrysler provided "drone" probe vehicles?
- What specific sensor data could/should be available from maintenance vehicles, in addition to the above (infrared surface temperature detection, status/position of snow plows, status of sand or salt application apparatus)?
- How will "ground truth" regarding the conditions of the roadways be determined so that sensor data can be analyzed to determine how to correlate readings with "ground truth"? What SCE or ESS already exists in the DTE area? Is this sufficient? How can it be augmented? Can the existing maintenance vehicles be used for "ground truth"?
- How are communications to the winter maintenance vehicles currently handled? What type of telematics system(s) are in place?
- Should an objective of the POC be to equip maintenance vehicles with a PSOBEs to support communications to/from the vehicle? If so, who will install and configure the maintenance vehicles with PSOBEs? Or should some of the test fleet vehicles be equipped to emulate maintenance vehicles with PSOBEs? If so, who will install and configure the test fleet vehicles with PSOBEs? Or, will it be sufficient to analyze the test fleet probe data to enhance

surface maintenance decisions, but then relay back the instructions to maintenance vehicles via an existing telematics service?

- What type of "simplified" WDT will need to be developed? In this context, the concept for a simplified WDT must fit into the larger scope of WDT engineering and development. FHWA is expected to work on this issue during the latter part of 2006.
- Perhaps most importantly, it will be necessary to determine if and how *Clarus* and the FHWA prototype MDSS should be included in the POC, or whether such an effort should more appropriately be targeted for Prototype Application Development phase.

Test Plan: In preparation for the POC, a test plan should be developed that details any "special" or contrived test situations that should be implemented to demonstrate functionality and/or test the overall application. For example:

- It may be appropriate to stage a specific number of traction loss events along a specific roadway link to see if all of the events were captured by the network and forwarded to the application. Similar staging of hard braking and/or high-rate steering maneuvers might also be considered.
- Additional tests related to the ability to accurately determine the lane(s) that have been plowed or treated (based on probe message location accuracy).
- Ability to manage vehicle-to-infrastructure communications with actual or emulated maintenance vehicles across multiple RSEs (session management).
- Testing of the overall application "processing time" (or delay) between generation of probe data by actual or emulated maintenance vehicles as well as regular test fleet vehicles, detection of adverse roadway conditions, processing of the conditions information to determine winter treatment actions, and the dissemination of treatment instructions to actual or emulated maintenance vehicles.
- Other tests related to determining the VII contribution to improving the functionality and performance of the MDSS, if an MDSS is included in the POC.

Resource Requirements: As part of preparing for the POC, the following high-level resources categories will need to be addressed.

- *Infrastructure:* As noted earlier, based on the requirements defined for the POC, it may be necessary to install additional "conventional" roadway sensors to establish the "ground truth" regarding roadway conditions and establish baseline data sets. This work could begin almost immediately.
- *Vehicles:* It may be worthwhile to equip a limited number of test vehicles (either the POC test fleet, the Chrysler drone vehicles, or the maintenance vehicles) with a particularly capable and advanced array of environmental sensors. Such sensors, for example, could include infrared temperature detection of the road, optical sensors (or even digital cameras) to determine if the road is covered with snow, and/or special rain and sun sensors to more precisely measure those conditions. Such data could be "over-sampled," and/or innovative strategies for capturing the data based on various triggers might be developed. Such vehicles would effectively serve to enhance knowledge of actual roadway conditions, and could be used in conjunction with the other infrastructure environmental sensors.

- Also, as noted earlier, if maintenance vehicles are going to be equipped with PSOBEs, this will be a parallel development effort that must begin several months before the start of the application demonstration—or in early 2007.

It is envisioned that development work focused on the Winter Maintenance application during the POC would be comparatively modest. This is primarily the case because at this point in time, neither MDOT nor RCOC have in place a roadway MDSS to accept and act on the probe data messages. In this context, it should be noted that the FHWA prototype MDSS could be configured to cover the roadways included in the DTE to support this Day-1 application. Additionally, it is unclear at this point whether roadway maintenance vehicles should actually be integrated with PSOBEs, or this functionality should be emulated using more conventional telematics services. Nevertheless, the Winter Maintenance application development work could proceed during the second half of 2007 and would include the tasks and activities listed in Table 5.

It should be noted that the tasks listed in Table 5 presume implementation of an MDSS is not within the scope of the POC. Should an MDSS be targeted for implementation during the POC, additional tasks for supporting the MDSS application would be added, and a public institution such as NCAR with MDSS experience would be engaged in executing majority of those additional tasks.

Table 5 – Winter Maintenance Application Development Task for POC

Task	Description
1. Generate application relevant probe data	This would focus on generating probe data from test fleet vehicles and/or actual/emulated maintenance vehicles.
2. Collect and provide probe data to application	This is one of the core functions provided by the VII network.
3. Analyze application relevant probe data	This would focus on analyzing selected “event-driven” probe data such as traction loss, stability control, and ABS actuation, as well as temperature, rain, or sun sensor data to determine the location (roadway link) and severity of snow, ice, or other adverse winter conditions.
4. Provide additional "traditional" application relevant data	This activity focuses on providing additional roadway condition data that may be gathered from a variety of non-VII sources.
5. Integrate probe data with “traditional” roadway condition data to determine conditions	Focuses on integrating the relevant vehicle generated probe data with roadway condition information gathered through SCE or ESS or other similar source to develop a consolidated picture of the weather and surface conditions on a roadway link.
6. Generate WAVE formatted messages	This task would focus on converting the consolidated roadway link conditions information to WAVE formatted message, packaging the messages into “envelopes” with delivery instructions, and publishing the messages on the VII Network.
7. Route messages to correct RSEs	This is one of the core functions provided by the VII network.
8. Interpret messages, prioritize, and display	The vehicles receiving these messages could be test fleet vehicles and/or actual/emulated maintenance vehicles.

In addition, the POC winter maintenance application may not include integration with the *Clarus* system. Integration with this system is addressed more fully in the Weather Information-Traveler Notification application development plan.

7.3.4. Summarize Results from POC Testing

The winter maintenance application demonstration phase of the POC is expected to be concluded at the end of 2007 or early 2008. At that point, a report will be developed that summarizes the performance and functionality features that were demonstrated for the application, documents how technical issues were resolved, and reports on development issues that require additional test and refinement (including technical, organizational, and programmatic challenges).

7.4. Prototype Development and Testing

7.4.1. Refine Prototype Requirements and Objectives

A first step in the prototype development effort would be to refine the overall objectives and scope. The focus of a Winter Application prototype development program would be to comprehensively demonstrate end-to-end functionality, including the integration with a fully operational winter MDSS, and multiple maintenance vehicles that were modified to include PSOBEs. The refinement and scoping effort would be a cooperative effort between the U.S. DOT and MDOT, and funding for the prototype would presumably be shared.

The prototype effort would operate for at least one full winter, and would include provisions for comparing "before" and "after" performance metrics related to winter maintenance operations. It is also envisioned that the prototype effort would include full integration with the *Clarus* system and with the Weather Information-Traveler Notification application.

A significant feature of the winter maintenance application is the integration of roadway condition relevant probe data with an MDSS. Without the MDSS, this application arguably degenerates to a subset of the Traveler Information-Weather Notification application. Specifically, without an MDSS, a consolidated picture of the road conditions (which is a key output of the Traveler Information-Weather Notification application) could simply be forwarded to roadway maintenance departments and used as an additional piece of information for planning their operations. While the VII network would/could still be utilized to send messages to maintenance vehicles, this is not a particularly new or innovative functionality as nearly all maintenance vehicles are equipped with some type of telematics service for communications with their central dispatcher.

7.4.2. Expand/Create the Prototype Development Test Environment(s)

Roadway maintenance decision support systems are comparatively new tools being experimented and tested by a number of state DOTs. The MDSS project is a multiyear effort sponsored by FHWA to prototype and field test advanced decision support for winter maintenance managers. The first federal MDSS prototype was demonstrated and tested in Iowa from February to April 2003 and was eventually moved to Colorado after 2004. There has been considerable investment in MDSS since then and several states are now involved in evaluating several different systems. This work has involved the integration of several key components including:

- The collection of “conventional” roadway condition information from existing ESS and SCE equipment
- The integration of roadway asset management models
- Integration of various local roadway condition data with national and regional weather forecast data.

To date, 49 states already have operating RWIS; 11 states either have or are in the process of implementing MDSS; and by 2010, MDSS is targeted to be installed in about 35 states. The focus of these systems will be to provide operational and tactical decision support for winter maintenance activities—focusing on a forecast period of 0 to 48 hours. Also, the functionality of MDSS is actually being expanded for other maintenance areas such as striping, sign installation, and mowing activities that are influenced by weather (but not necessarily winter weather), and hence should also provide benefit to those states that do not experience severe winters.

Interestingly, key lessons learned from the Iowa MDSS deployment would seem to suggest that weather and roadway condition information collected from VII-equipped vehicles could address some of the challenges facing MDSS. For example, lessons learned from the Iowa MDSS deployment as detailed in a summary report, "Winter MDSS; Demonstration Results and Future Plans” (Pisano, Stern, Mahoney), include:

- The availability and quantity of real-time precipitation rate data are very poor. (VII-equipped vehicles would not provide real-time precipitation rates but could provide highly detailed and localized information about precipitation, which could be very valuable.)
- During a winter storm, the DOT operators often do not have the time to enter actual treatments for each route. Therefore, the MDSS can lose track of actual road conditions. (VII-equipped maintenance vehicles would automatically forward information about which road links have been treated, and provide detailed information about the current road conditions.)
- Light snow events and intermittent, highly localized events are critical to DOT operations but are particularly hard to predict. (VII vehicles may be capable of detecting such events.)

Based on limited research, it would appear that several states already have invested considerable effort in developing winter MDSS. Since the MDSS is central to the VII-based Winter Maintenance application, it could be argued that the prototype application development should be conducted in a location with a working MDSS system. However, it appears that an investment in a VII DTE in one of these locations would be a challenge given the limited number of VII test vehicles that will be produced and supported by OEMs. Additionally, at the conclusion of the POC, a very capable DTE will have been established in the Detroit area. Further, the participating entities involved in the POC will have accumulated substantial experience in all areas of the VII concept including network architecture, supporting network services, advisory message generation and delivery, and the fundamental on-board applications and interfaces needed to support the winter maintenance application. It will clearly be efficient and effective to continue the Winter Maintenance application refinement in Michigan, and it is recommended that prototype application development be conducted in the Detroit area. However, it is also recommended that an MDSS be fully implemented and integrated within the Michigan DTE during the prototype so as to fully exploit the benefits of the VII probe data. A preliminary investigation suggests that the MDSS is relatively "portable" web-based application, and is in fact often hosted by the supplier at its facilities. Further, while MDSS will benefit from having multiple SCE and ESS inputs, such existing infrastructure is not necessarily a pre-requisite for implementing the systems. Hence, this preliminary investigation suggests that it would be easier and more efficient to implement MDSS in Michigan than to set up and operate a second VII DTE in a state that already has an MDSS.

The DTE put in place for the POC might be expanded for the prototype in the following ways:

- *Additional RSEs to increase the coverage area.* It may be advantageous to include areas to the west and north of Detroit that are less urbanized, and to also include the downtown CBD area (in addition to the initial DTE in the suburban Oakland county area). The winter maintenance prototype would therefore include a variety of operation and environmental conditions.
- *Additional roadway maintenance vehicles*. It may be useful to include the roadway maintenance activities from two different counties. The roadway maintenance in Michigan is controlled at the county level (similar to several other states), and therefore, the prototype would comprehend and address provisions for integrating such operations.
- *Additional POVs*. The POC is targeting only about 50 fully functional VII vehicles. While it will likely be impractical for the prototype to include a sufficient number of vehicles to support robust and exhaustive probe data analyses, a significantly larger fleet population will likely be needed to support effective evaluations of the winter maintenance application.
- *Additional SCE and ESS equipment*. Such assets would serve to improve operation of the MDSS.

7.4.3. Prototype Development Team

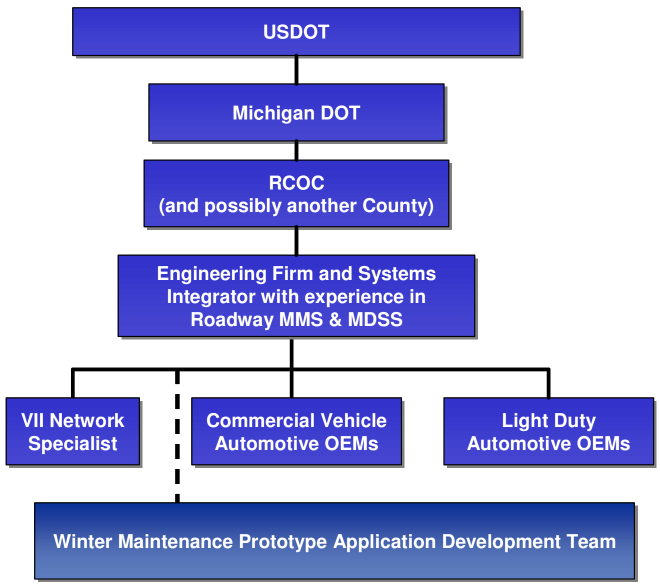
The resources and capabilities needed to support winter maintenance prototype development and testing are considerable. Core team members would include:

- U.S. DOT (JPO) and the FHWA Road Weather Management Team to oversee and help fund the effort
- Michigan DOT to co-sponsor the prototype
- Road Commission of Oakland County (RCOC) (as well as perhaps an additional county) that would have jurisdiction over the region in which the development test environment would be implemented (e.g., host-site operators)
- Firms with experience in designing, developing and implementing roadway maintenance management systems and MDSS to lead the technical development effort
- Vehicle OEMs to supply the test fleets and build the on-board application components—including a commercial vehicle OEM who would be interested in adapting and supporting a small fleet of vehicles with OBEs

- VII network and architecture specialists to lead communications trade-off analyses, support message delivery strategy development, and support development of any new network services required
- A GIS, roadway mapping, and navigation specialty firm to help with defining roadway links, building databases and applications for managing WAVE-formatted messages, and developing roadway information synthesis tools.

Exhibit 6 presents a hypothetical organization chart for the prototype development team. As shown in Exhibit 6, the Winter Maintenance Application Development Team would also need to work cooperatively with the Weather Information-Traveler Notification Application Development Team since that effort would be responsible for the collection and analyses of weather-related probe data, integration of that data with other weather information sources, and the generation of consolidated information about the weather conditions on roadway links.

Exhibit 6 – Team Organization for Winter Maintenance Prototype Application



7.4.4. Conduct the Prototype Development and Testing

The Prototype in Detroit would begin at the conclusion of the POC (or in mid 2008). The prototype test period should include at least one full winter season, which means that the prototype would continue through to mid 2009.

7.4.5. Evaluation and Monitoring

A rigorous evaluation and monitoring plan would need to be implemented throughout the prototype development effort and would include an assessment of the following:

- Impacts on response times for snow removal and treating roadways
- Impacts on winter roadway maintenance labor and material costs
- Impacts on total overtime
- Impacts on general safety and mobility measures during winter storms

- Impacts on complaints (or compliments) from the public
- Impacts on overall capital and operating cost estimates for implementing and operating the MDSS and Winter Maintenance application.

The monitoring and evaluation tools developed and implemented would provide the feedback necessary to raise awareness of the Winter Maintenance application's impact, and report on whether additional development work would be needed to realize predicted benefits.

For all of the evaluation criteria, it will be important to establish various baseline measurements related to the traffic conditions within the prototype DTE, the test subject's driving performance and habits, and the overall prototype DTE operating environment. Such measurements should be taken before the prototype phase begins. These tests and evaluation criteria were reviewed in section 2.5.4, Evaluation and Monitoring.

7.5. Full-Scale Deployment

To help accelerate widespread deployment of the Winter Maintenance application, it will be important that "core" software modules, database designs, and analysis techniques be thoroughly researched, developed, and documented during the Prototype development effort. These "deliverables" would likely focus on:

- Software to support the analyses of probe data elements to yield reliable observations of roadway surface conditions
- Software and techniques for integrating this probe data analyses with other, non-VII road surface condition data
- A working prototype of a winter MDSS that is integrated with VII probe data, and is linked with maintenance vehicle dispatch and assignment software
- A comprehensive report that summarizes all technical, programmatic, and institutional issues associated with the deployment of the Winter Maintenance application
- A summary of all capital and operating costs items, and a listing of resources and equipment needed to support the application.

Further, it is envisioned that as prototype software modules from these early deployments become available, private vendors and others will incorporate them into their product lines and develop applications tailored to the needs of state DOTs. Such customized decision support systems will ultimately increase the productivity of road maintenance agencies and result in safer roads during the winter.

Unlike the Traveler Information application, this application's primary user is the state and local DOTs (not the motoring public). The public, of course, will benefit from improved winter maintenance, but the general motoring public will not demand that, or directly care whether, the local roadway maintenance agency deploys the winter maintenance application—public just want the roads to be cleared in a timely fashion. To this extent, the nationwide rollout of this application will be very much voluntary on the part of state and local DOTs—and will likely depend on the success of the first prototype, as well as the overall ease with which the application can be implemented. The U.S. DOT's role will therefore be focused on supporting the prototype, documenting results, and engaging in a communications and outreach plan to help state and local agencies better understand costs, benefits, and implementation guidance.

7.5.1. Policy, Liability, and Institutional Issues

There does not appear to be any significant policy, liability, or institutional issues since this application is effectively a management and productivity improvement program for state and local DOTs.

7.5.2. Key Risk Areas

The risks areas associated with the application are primarily technical and resource related, and includes the following:

- ***Successful deployment of the Traveler and Weather Information Notification Applications:*** Both of these applications will provide core services and data needed to enable the Winter Maintenance application. This includes the ability to accurately report, and possibly forecast, localized roadway surface and weather conditions.
- ***Sufficient number of probe vehicles:*** Without a sufficient number of probe vehicles, the Winter Maintenance application, as well as the MDSS, will have to rely on conventional or traditional sources of weather and road surface condition reporting. However, our preliminary research indicates that the Detroit area has limited SCE or ESS equipment. Therefore, a pre-condition of the application development program may be to install additional equipment and systems to establish “ground truth” for roadway weather and surface conditions.
- ***Integration of PSOBE with maintenance vehicles:*** Thus far, the commercial vehicle community has not participated in the VII development program. A core component of the Winter Maintenance application will be integrating a VII-compliant PSOBE into commercial maintenance vehicles that are likely to be Class 7 or 8 trucks. To be effective, this integration will include a connection with the vehicle's CAN databus as well as direct links to various special sensors that the vehicle may have (infrared surface temperature detection, etc.). The installation and integration of the PSOBE will require the cooperation of truck OEMs and PSOBE application developers.
- ***Development of the MDSS:*** The MDSS deployment represents a separate development program in itself, which will significantly influence the full-scale deployment of the Winter Maintenance application. A closer examination of the resources, equipment, and infrastructure needed to support a VII-linked MDSS should be completed.
- ***Roadway maintenance is performed at the county level in Michigan:*** In many states, the maintenance on major roads is completed by local roadway crews that report to the state DOT. The implications of this regarding the scalability and applicability of the Winter Maintenance application to be developed should be examined.

8. POTHOLE DETECTION

8.1. Application Description

During the development of the Day-1 use cases, a separate use case for pothole detection was established. This use case was differentiated from the winter maintenance use case primarily because of the following reasons:

- Pothole detection application primarily uses OBEs and Winter Maintenance application primarily uses PSOBEs
- To detect potholes, the probe vehicles will need to include in their probe data message set two key data elements:
  - *Vertical acceleration*: The overall vertical acceleration of the vehicle as measured at the vehicle's center of gravity
  - *Wheel-based vertical acceleration threshold*: Recording an "event" whenever an individual wheel exceeded a pre-defined vertical acceleration threshold.
- Both of these data elements are defined in SAE J2735. However, they both are fairly specialized sensor data that would not be available on every car. Generally, cars that are equipped with automatic load leveling systems, air suspensions, and/or so-called "active" suspensions would be equipped with vertical accelerometers and thus able to generate such data elements fairly easily. Most other cars would not be able to provide these data elements unless vertical accelerometers were specially added to the vehicle.
- The vertical acceleration threshold data that would be generated by appropriately equipped vehicles, and then transmitted to the TOC (or local roadway maintenance department) would not be utilized to impact near real-time decisions about roadway maintenance (as is the case with the Winter Maintenance application), but rather would be collected and analyzed to help direct and plan maintenance actions (i.e., pothole repairs) that would take place over the following days, weeks, or months. In other words, there is a difference in the temporal use of the data.

In all other respects, however, these two applications operate identically. Specifically,

- Both call for the generation of data elements useful in assessing roadway weather and surface conditions. (It should be noted that vertical acceleration data is also used by the Winter Maintenance application as it would help in detecting general road roughness that may be linked to patchy snow or ice conditions.)
- Both collect the probe data and forward it to the TOC, WDT, or the roadway maintenance department (depending on how the application ConOps gets defined).
- Both could benefit from having "special" data elements available from maintenance vehicles.

Essentially, the Winter Maintenance and Pothole Detection applications are both focused on gathering probe data to better assess localized weather and road surface conditions, and both are focused on improving the roadway maintenance operation. With the Winter Maintenance application, the data is used in a near real-time fashion, while with Pothole Detection, the data is used for longer-term maintenance planning.

Because of the similarities of these two applications, it is recommended that the application development efforts essentially be combined, and that the Winter Maintenance Application Team also be charged with developing algorithms and processes for detecting potholes.

8.2. Application Refinement and Research

As with the other Day-1 public sector applications, it will be important to development a more detailed concept of operations for how the application would be implemented at Day-1. The Pothole Detection ConOps however will be largely influenced by design, operations, and other implementation details to be developed as part of the Winter Maintenance Application ConOps—and by the outcome of testing completed during the POC.

8.3. POC Testing

During the POC, it will be important to demonstrate that vertical acceleration data can be collected, and pothole locations identified. To this extent, at least some portion of the VII "core" test vehicle fleet should be capable of generating such data. It would also be extremely beneficial if some portion of the 2800 probe data "drone" vehicles also be capable of including vertical acceleration data as part of the probe data message. During the POC, such information could be collected and analyzed by the Winter Maintenance Application Development Team. How the Pothole Detection and Winter Maintenance Application will be combined during the POC and will be detailed as part of the POC Applications ConOps document.

8.4. Prototype Development and Testing

During the Winter Maintenance Application prototype development effort, it is presumed that an MDSS application will be developed and installed in the Michigan DTE (see Section 5.4). A "stretch goal" for this Prototype effort might be to expand the functionality of the MDSS to include identification and tracking of pothole locations and severity (based on VII data), and to offer recommendations for maintenance actions. If it is not practical to incorporate such functionality into the MDSS (perhaps because of the near real-time, operational focus of the MDSS application), then such functionality might be incorporated into a more traditional roadway maintenance management system.

8.5. Full-Scale Deployment

Because of the similarities of these two applications (Winter Maintenance and Pothole Detection), it is recommended that they be developed in parallel during POC and for prototype application development and testing. Specifically, the overall Team that is assembled to develop the Winter Maintenance application would also be tasked with developing a pothole maintenance application. Effectively, all development processes and entities involved in the two applications will be the same. To this extent, development of the pothole detection application might be thought of as an additional task within the overall winter maintenance application.

9. WEATHER INFORMATION

9.1. Application Description

When initially conceived by the VII Working Group, the applications identified as “Day-1” included a use case that would gather weather-related probe data gathered by VII vehicles, analyze the data, and send weather information back to vehicles about the localized conditions that the vehicle was traveling in. This generalized concept became the weather information use case. As the use case was being developed, however, it became clear that assumptions about temporal use of the data could significantly alter the manner in which the use case would be developed and deployed. The weather information use case was therefore split into two applications as follows:

- **Weather Information-Traveler Notification**: This Day-1 application is anchored by the requirement to provide localized weather information back to vehicles based on an integrated, near real-time analysis of probe data as well as other (conventional) sources of weather information. It essentially represents the initial intent of the weather information use case as described by the Working Group.
- **Weather Information-Improved Forecasting**: This application is focused on the longer-term use of probe data to improve the weather forecasting process. It does not have the requirement for providing weather-related information back to the vehicle.

The weather information-traveler notification use case was further refined/divided into two different use cases based on alternative assumptions about a major U.S. DOT weather-related initiative known as *Clarus*. The *Clarus* system, when it becomes operational, will provide for a national clearinghouse of roadway weather information. One use case was developed that assumed *Clarus* would not be available to support the Day-1 VII Weather Information application, while a second use case assumed that *Clarus* would be available. The weather information use case was split since the processes as well as the required entities for executing the application would be different. However, there was always general agreement that *Clarus* would eventually be integrated with the VII initiative. To this extent, this Weather Information-Traveler Notification Application Development Plan has been developed to address both the “with” and “with out” *Clarus* use cases. Essentially, it is assumed that during the POC testing, the Weather Information application will not leverage the *Clarus* initiative—and therefore represents a deployment process without *Clarus*. However, it is assumed that for the Prototype Development (that follows the POC testing), an explicit objective will be to integrate the *Clarus* and VII initiatives, thus representing the “with” *Clarus* use case.

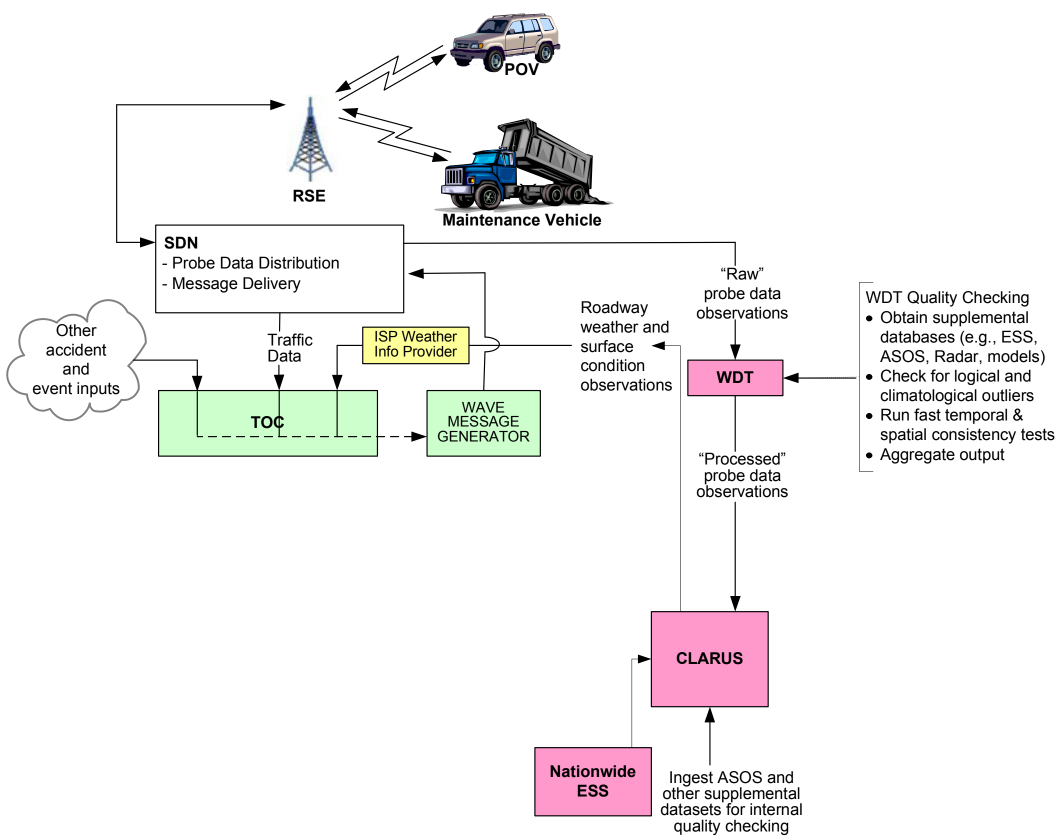
At this point in time, the *Clarus* initiative is both technically and programmatically on track. The *Clarus* initiative has received the near full support of the private sector weather information community, and it is highly likely that the *Clarus* program will be fully implemented—probably as a program under the NOAA. Nevertheless, as will be discussed in more detail in the next section, whether *Clarus* is or is not available, it is likely that an ISP that specializes in weather forecasting (broadly defined as the “Weather Enterprise”) will play a key role in the application—and will provide the local TOC with value-added roadway weather information.

Thus, if *Clarus* is not available, the Weather Enterprise community would operate as they do today, gathering weather-related data from numerous sources (including, in the future, VII probe data), integrating it, and offering various weather reporting and forecasting products and services to their customers.

9.1.1. Overview of the Weather Information-Traveler Notification Application

The purpose of this application is to gather vehicular probe data generated by VII vehicles, analyze and integrate those observations with weather data from traditional weather information sources, develop highly localized weather reports and forecasts for specific roadway links, and broadcast this information via WAVE-formatted messages over the VII network to the appropriate locations where the information is relevant. A very preliminary process flow and architecture diagram for the application is shown in Exhibit 7.

Exhibit 7 – Weather Information Architecture Diagram



An overall description of the application is as follows:

- VII-equipped privately owned vehicles (POVs), as well as selected roadway maintenance vehicles that have been properly equipped, will include in their probe messages a variety of data elements relevant to documenting current weather and roadway surface conditions. Such data elements might include outside temperature, wheel slip events (activation of traction or stability control functions if the vehicle is so-equipped), ABS braking events, windshield wiper status and wiper speed setting, status of exterior lights, and sun or rain sensors if the vehicle is equipped with such sensor. Maintenance vehicles might be configured with additional or more accurate sensors such as infrared detection of pavement temperature, humidity readings, and possibly even wind conditions (taken when the vehicle is at a standstill).

- This probe data will be forwarded to a "Weather Data Translator" (WDT). The role and processing capabilities of WDT have yet to be fully defined. However, the FHWA vision for the WDT is for a robust data quality checking system which makes use of numerous supplemental data sets (both in-situ and remotely sensed) and contains complex routines for evaluating bias and outliers. In addition, the WDT is expected to reduce the processing load of downstream systems by providing normalized, aggregated or formatted output. The WDT must be formally considered for design and implementation since it will play a significant role in all weather applications. Moreover, the WDT will likely touch many other VII applications since weather is a cross-cutting area for transportation. The idea for a WDT, which originated in the FHWA Road Weather Management Team, is currently under consideration by the National Center for Atmospheric Research (NCAR). A report on its feasibility and potential capabilities is expected in the fall of 2006.
- The "processed" probe data from WDT is then forwarded to USDOT's *Clarus* system (http://www.Clarusinitiative.org). *Clarus* ingests data from environmental sensor stations (ESS) across the nation, as well as ASOS and other supplemental datasets for internal quality checking. The roadway weather and surface condition observations from *Clarus* could then be forwarded to the TOC directly. Alternatively, a private sector Information Service Provider (ISP) that specializes in weather information could subscribe to *Clarus* to analyze the data to develop localized weather and surface condition reports for specific roadway links, and then forward this "enhanced" information to the TOC.
- The roadway link weather information would then be converted to WAVE-formatted messages, delivered to the SDN, and routed to the appropriate RSEs. It is possible that an ISP may be contracted by the TOC (or state DOT) to develop the WAVE messages and link directly with the SDN. The current and forecasted environmental and surface conditions by route segment will also be provided back to vehicles through intermediary actors such as the media (radio, TV), 511 traveler information systems, variable message signs (VMS), and/or highway advisory radio (HAR).

The Weather Information-Traveler Notification application may very well evolve into a private sector provided service and application. It is conceivable, and in fact likely, that relevant weather-related probe data could be provided to the Weather Enterprise by the VII "operating entity" for free, and the Weather Enterprise would then deliver the Weather Information application to TOCs (or state DOTs) in exchange for the probe data.

9.1.2. Relationship to Other VII Applications

It should be recognized that the Weather Information-Traveler Information application represents a subset of the general public sector Traveler Information application. There are several basic development tasks associated with the public sector Traveler Information application that also apply to the Weather Information application. These tasks include refining probe data collection and distribution functions; developing and refining roadway link definitions and resolution; and refining WAVE message broadcast strategies for different types of operating environments including rural, suburban, and central business district environments.

9.1.3. Overview of Deployment Plan

Based on these assumptions and background information, the Deployment Plan for the Winter Maintenance application is organized as follows:

- Application Refinement and Research
- POC Testing
- Prototype Development and Testing
- Full-Scale Deployment

The proposed application development plan is characterized by work phases that represent a progressive development of the application from concept refinement through full-scale development. During concept refinement, the roles of various entities involved in the application will be clarified and more details related to the overall architecture will be developed. The overall Application Deployment plan proposed in this document will also be reviewed.

During POC, basic functionality will be demonstrated. Probe data related to weather information and surface conditions would be gathered and combined with other weather-related information. Comparatively simple (and coarse) localized weather information for various road segments would be developed and messages delivered to the appropriate RSEs. The POC would be divided into two stages: systems integration and application demonstration. Because of the special nature of weather information, it is recommended that a firm or organization specializing in weather data information and consolidation be added to the POC team.

Toward the end of the POC, a Weather Information-Traveler Information Application Development Team would be selected to build and test a full prototype application. The prototype weather application would focus on implementing complete end-to-end functionality including a fully operational WDT, and full integration with *Clarus*. It is assumed for purposes of this Application Development Plan that the prototype development effort would take place at the Michigan DTE.

9.2. Application Refinement and Research

9.2.1. Fundamental Research

Considerable fundamental research is required related to how probe data could be used to report on, and forecast, the weather and road condition surface information along roadway links or at specific roadway locations. Much of this research surrounds how the raw probe data from VII vehicles would be "translated" into more meaningful observations. As noted in the Overview section, this function could be performed by software and systems that are notionally termed a "Weather Data Translator". Some basic research related to the use of vehicle probe data to improve the reporting and forecasting of roadway weather conditions is already being done by NCAR (***VII Probe Weather Data Feasibility Study)***. Additionally, Mitretek has been tasked with conducting empirical field studies related to assessing the accuracy and usefulness weather related probe data acquired (or transmitted) from vehicles under varying speed and other operating conditions, (***VII Probe Weather Data Accuracy Study).*** This research is discussed more fully in the Introduction (Section 2.3).

9.2.2. Develop Day-1 Concept of Operations

While the initial use case for the Weather Information-Traveler Notification application has been developed, it should be understood that the logical links and exact roles of various entities, as well as the overall architecture including the components outside the VII network still require refinement. For example:

- What are the specific functions that will be performed by the WDT? Should it be limited to quality control functions, or should some level of analysis of probe data be done at this level? It appears that the WDT should perform quality checking, which will involve ancillary data sets, and will perform some statistical analysis of the probe data to create representative output (on a grid perhaps). This will allow probe data subscribers to obtain either raw, quality checked, and/or a subset of the data on a regular grid or at selected points (in data poor regions). The statistical analysis will also help the bandwidth issue as most subscribers will likely go for the quality checked, filtered data (statistical sample).
- Where/who should perform the WDT function? Should it be incorporated into VII? Or into *Clarus*? Or, should it be assumed that this will be done by the ISP and the Weather Enterprise? Perhaps the WDT should hang off of the VII network cloud and interface with *Clarus*. This would likely point to a government entity having authority over that function. The WDT could be a NOAA function (perhaps performed by a contractor or within). This concept will need to be explored in the ConOps.
- Should the functionality of the WDT be executed centrally and at a national level, or should standardized software modules be developed for "translating" weather-related probe data into more useable weather information, and then such software distributed to local TOCs and/or state DOTs?
- How long will it take to develop a full-scale WDT? Many of the concepts for the Weather Information application will be described in the VII weather report that NCAR will be releasing during the fall of 2006. Subject matter expertise will need to be used to develop a Day-1 Weather Information application. Some serious research is needed to assess the quality of the VII-based road weather data, to process the data, and develop methods and techniques for creating or enhancing road weather products based on the VII probe data. This will take some time, perhaps two years, and it would be good to get started on some of this work during the POC testing phase.
- Should the Weather Information application reside completely outside of the domain of the TOC or state DOT—and be provided in total by the private sector (with the public sector, or operating entity, only responsible for the delivery of probe data)? Or, should the public sector TOC/state DOT be "in the loop" for roadway weather information including control over the delivery of messages to the VII network?

A first step in the development process will be to clarify and embellish the overall Concept of Operations for Day-1, and to gain more widespread consensus on the boundaries for this application. It will also be important to gain consensus among key stakeholders (i.e., state and local agencies, as well as the U.S. DOT, *Clarus*, and VII team members involved in the respective projects) on the overall development plan for the Weather Information application. This report presents an initial, high-level straw man for a development plan; however, the plan will need buy-in from stakeholders before moving forward.

To this end, the U.S. DOT could consider engaging in a short-term application scoping effort (perhaps a 4 to 6 month effort). The focus of the effort would be to develop a more detailed Concept of Operation for the Weather Information-Traveler Notification application, and to refine the overall deployment plan. A Weather Information-Traveler Notification development task force could be assigned to lead this effort. The task force would likely consist of members of NCAR and Mitretek as well as members of the VII development team (Booz Allen and Iteris), key staff at the U.S. DOT, FHWA Road Weather Management Team, and the JPO. It will also be important to engage those entities involved with the development of *Clarus* and MDSS.

9.3. POC Testing

As noted in section 2.4, "VII Systems Integration and Proof of Concept (POC)", the POC will focus on demonstrating end-to-end functionality for several applications, including the weather information application, and is divided into three phases. *Laboratory Testing and Simulation: Systems Integration and Testing:* and *Application Integration and Testing:*

The focus of the POC is not to deliver production-ready software, processes, and component designs for either the analyses of probe data or the generation weather related messages. This level of development is targeted for the Prototype development effort.

The POC in Detroit is scheduled to begin in the first quarter of 2007. However, technical requirements as well as programmatic issues related to executing the weather information application remain to be addressed—and an overall ***POC Applications Concept of Operation*** must be developed. The POC Applications ConOps should detail activities to be completed in each phase and provide a basis for a detailed Test Plan. It should also include Organizational Responsibilities Matrix, Schedule, and a Resource Requirements Plan. The following sections provide an overview of these topics, as a starting point for work to be completed during the POC.

9.3.1. Laboratory Development and Testing

Laboratory development and testing of the VII network and services will begin in the last quarter of 2006. Relevant to the weather information application will be the development of the probe data dissemination service, the message delivery/advisory service (or broadcast service), as well as other basic security and provisioning services that will allow the network to be monitored, and for updates in software to be executed.

9.3.2. Systems Integration and Testing

Before the Weather Information application demonstration can begin in earnest, it will be necessary to have completed basic systems integration testing of the VII network—including the development and demonstration of various application "stubs." For the Weather Information application, there are three key network services that must be developed and demonstrated. These include probe data dissemination, advisory message delivery, and session management. During the systems integration phase of the POC, all of these services would have been developed and demonstrated in the Detroit DTE.

9.3.3. Application Integration and Testing

The POC testing in Detroit will be the first opportunity to demonstrate the ability to collect probe data useful in documenting and forecasting localized weather and road surface conditions. Prior to the initiation of the POC, it will be important to refine requirements and goals for developing and demonstrating the Weather Information application at the Detroit test bed. Key issues to be addressed include:

- What specific sensor data that is useful in determining surface conditions could/should be available from the "core" VII test fleet (traction control events, actuation of stability control systems, temperature sensors, wiper system status, steering wheel rate of change, ABS events, vertical acceleration threshold events, sun sensor, rain sensor, etc.)? Which specific sensor data will be available from various subfleets within the test fleet?
- What specific sensor data related to weather and road conditions will be available from the 2800 Chrysler provided "drone" probe vehicles?
- What specific sensor data could/should be available from fleet maintenance vehicles, in addition to the above (infrared surface temperature detection, status/position of snow plows, status of sand or salt application apparatus)?
- How will "ground truth" regarding the conditions of the roadways be determined so that sensor data can be analyzed to determine how to correlate readings with "ground truth"? What SCE or ESS already exist in the DTE area? Is this sufficient? How can it be augmented?
- Given that a limited number of vehicles will be involved in the effort, would it be overly aggressive to try to integrate with *Clarus*, or to engage in a robust WDT development effort.

It will also be important to establish the overall scope of the POC relative to the following:

- The extent of development for the WDT
- The degree to which weather information from local sources will be integrated into the effort, as well as local SCEs and ESS, and other data sources
- The degree to which weather information from the NWS and/or for-fee services will be incorporated into the POC
- Whether a firm/agency with expertise in weather research, reporting and forecasting should be added to the POC development team
- The overall architecture for the POC application

For the POC, a weather information specialist firm or organization would need to collect the raw probe data, integrate it with other conventional or traditional sources of roadway weather information, and develop messages for localized roadway links. Some type of simplified WDT would need to be developed to support this effort. These messages would then be forwarded to the TOC in RCOC, converted to the WAVE message format, and delivered to the VII network. We suspect that because of the limited number of test vehicles involved, the roadway weather messages would primarily be developed based on conventional data sources.

- ***Test Plan***: In preparation for the POC, a test plan should be developed that details any "special" or contrived test situations that should be implemented to demonstrate functionality and/or test the overall end-to-end application. For example:
  1. Staging of a specific number of traction-loss events along a specific roadway link to see if all of the events were captured by the network and forwarded to the TOC
  2. Additional tests related to the ability to accurately determine the road conditions on specific lane(s)
  3. Tests to validate that localized weather messages are being delivered to the correct RSEs (i.e., locations that would allow for communication of the weather information to vehicles heading into the observed weather and roadway conditions)
  4. Testing of the overall application "processing time" (or delay) between reporting of weather-related data elements by vehicles, and the reporting back of roadway weather conditions.
- ***Resource Requirements:*** As part of the preparation for the POC, the following high-level resources categories will need to be addressed.
  1. *Infrastructure* – As noted earlier, based on the requirements defined for the POC, it may be necessary to install additional "conventional" roadway sensors to establish the "ground truth" regarding roadway conditions and establish baseline data sets. This work could begin almost immediately.
  2. *Vehicles* – It may be prudent to equip a limited number of test vehicles (either the "core" test fleet, or the maintenance vehicles) with a particularly capable and advanced array of environmental sensors. Such sensors, for example, could include infrared temperature detection of the road, optical sensors (or even digital cameras) to determine whether the road is covered with snow, and/or special rain and sun sensors to more precisely measure those conditions. Such data could be "over-sampled," and/or innovative strategies for capturing the data based on various triggers might be developed. Such vehicles would effectively serve to enhance knowledge of actual roadway conditions, and could be used in conjunction with the other infrastructure environmental sensors.

POC Application Development Tasks. During the POC, the following tasks are planned to be completed:

- Subscribe to and receive weather-related probe data elements
- Analyze weather-related probe data and convert it to link-based road weather observations (simplified weather data translator)

- Integrate probe-based observations with "conventional" road weather observations
- Generate WAVE-formatted weather information advisory messages and send to the SDNs for delivery to appropriate RSEs
- The OBE application will display the localize weather messages with the correct priority and in the correct locations

9.3.4. Summarize Results from POC Testing

The POC is expected to be concluded in early 2008. At that point, an Application Development Report will be developed that summarizes the performance and functionality features that were demonstrated, documents how technical issues were resolved, and reports on development issues that require additional test and refinement (including technical, organizational, and programmatic challenges).

9.4. Prototype Development and Testing

The focus of a weather information prototype would be to comprehensively demonstrate end-to-end functionality, including development of the WDT, and the integration of the application with *Clarus*. Once the prototype application was developed and implemented, it would operate for at least one full year (all four seasons) and would include provisions for comparing the observed and forecasted roadway data derived from the various sources (including probe data) with the “ground truth” observations developed through various means. (Ground truth observations might be made only periodically for practical reasons.) The prototype effort would also include full integration with the Winter Maintenance application.

9.4.1. Refine Prototype Requirements and Objectives

A first step in the prototype development effort would be to refine the objectives and overall scope. The prototype would essentially be a combined effort to develop and implement a state-of-the-art roadway weather advisory system in Michigan, while at the same time integrating the VII network and *Clarus* programs. The refinement and scoping effort would be a cooperative effort between the U.S. DOT and MDOT, and would also likely include NOAA and other *Clarus* stakeholders. Funding for the prototype would presumably be shared among all parties. It should also be recognized that one or more ISPs that specialize in providing value-added weather reporting and forecasting products would likely join the Prototype team at this point in the development effort (if in fact, they had not already joined as part of the POC effort). Such entities would likely be a key component of the overall Prototype since they would help define not only how the VII weather application would be developed and deployed, but also establish a precedent for how *Clarus* would interact with such entities—both operationally and contractually. In addition to requirements previously mentioned, it will be important during this scoping effort to also determine to what extent the overall prototype will not just support the VII weather information application, but also help to disseminate roadway weather information through more conventional outlets (DMS, web sites, etc.).

9.4.2. Expand/Create the Prototype Development Test Environment

As reviewed in section 2.5.1, for most of the public sector applications, (with the exception being toll payment and possible ramp meter applications), it will clearly be efficient and effective to continue application refinement in Michigan. The Detroit, MI, location will offer quite diverse weather environments such that the application can be comprehensively tested. The DTE put in place for the POC might be expanded for the Prototype in the following ways:

- *Additional RSEs to increase the coverage area:*. It may be advantageous to include areas to the west and north of Detroit that are less urbanized, and to also include the downtown CBD area (in addition to the initial DTE in the suburban Oakland county area). The weather information prototype would therefore include a variety of operational and environmental conditions.
- *Additional roadway maintenance vehicles*: It may be useful to include the roadway maintenance activities from two or more counties. The roadway maintenance in Michigan is controlled at the county level (similar to several other states), and therefore, the prototype would comprehend and address provisions for integrating such operations.
- *Additional vehicles*: The POC is targeting only about 50 fully functional VII vehicles. While it will likely be impractical for the Prototype to include a sufficient number of vehicles to support robust and exhaustive probe data analyses, a significantly larger fleet population will likely be needed to support effective evaluations of the weather information application.
- *Additional SCE and ESS equipment*. Such assets would serve to improve the accuracy and coverage of the local weather observations.

9.4.3. Prototype Development Team

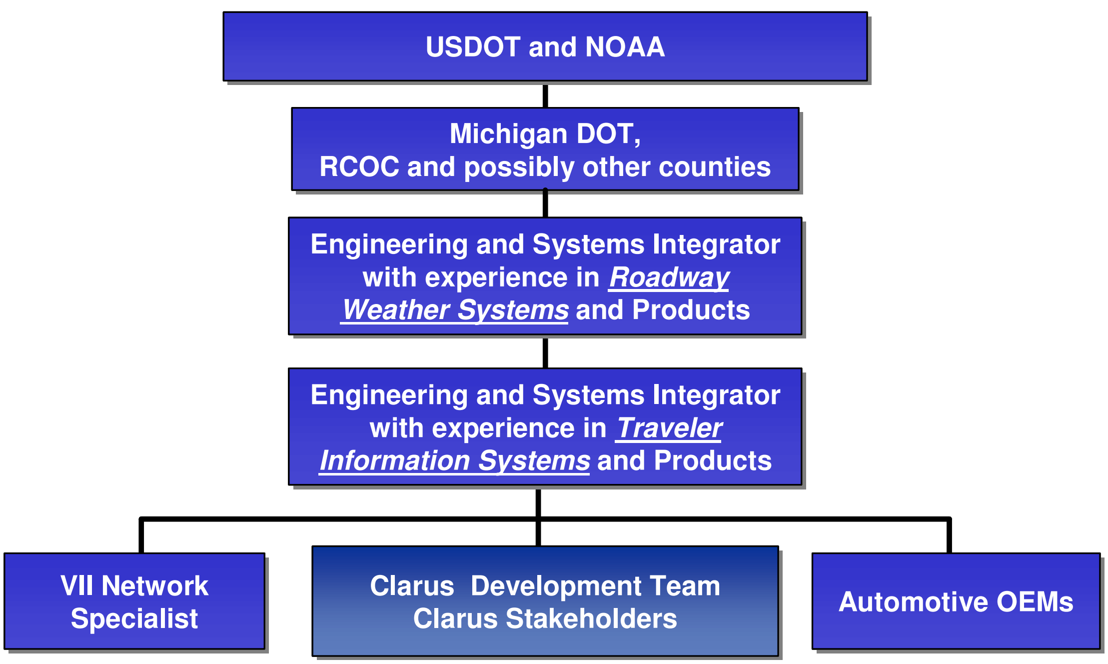
The resources and capabilities needed to support weather information Prototype are considerable. Core team members would include:

- U.S. DOT (JPO) and the FHWA Road Weather Management Team to oversee and help fund the effort
- Michigan DOT to co-sponsor the prototype
- Road Commission of Oakland County (RCOC) (as well as perhaps an additional county) that would have jurisdiction over the region in which the development test environment would be implemented (e.g., host-site operators)
- Key *Clarus* stakeholders—most notably NOAA, including members of the MADIS development effort.
- A systems integration firm with experience in developing and implementing roadway weather and surface condition reporting and forecasting (to lead the technical development effort). It should be noted that such firms also tend to be involved with the development and deployment of roadway MDSS. Therefore, the same systems integration firm that would be tasked to lead the Winter Maintenance/MDSS application might also be tasked to lead the Weather Information-Traveler Notification application.

- The systems integration firm that is tasked with developing the Traveler Information prototype application. This firm would need to work closely with the Weather/MDSS systems integration firm described above. Essentially, roadway links as well as other basic parameters for broadcasting and interpreting public messages would be defined within the Traveler Information application. The basic architecture that would support the Weather Information application would be defined within the Traveler Information application. Hence, the lead system integrator for the Traveler Information application would need to be engaged to lend support during the development of the Weather Information application.
- Vehicle OEMs to supply the test fleets and build the on-board application components—including a commercial vehicle OEM who would be interested in adapting and supporting a small fleet of vehicles with OBEs.
- VII network and architecture specialists to lead communications trade-off analyses, support message delivery strategy development, and support development of any new network services required.

Exhibit 8 presents a hypothetical organization chart for the prototype development team. As shown in Exhibit 8, the Weather Information Application Development Team would need to work cooperatively with the *Clarus* Deployment Team since that effort would be responsible for the collection and analyses of weather-related probe data, integration of that data with other weather information sources, and the generation of consolidated observations about the weather and surface conditions on roadway links.

Exhibit 8 – Team Organization for Weather Information Prototype Application



9.4.4. Conduct the Prototype Development and Testing

The Weather Information Prototype in Detroit would begin at the conclusion of the POC (or in early 2008). The Prototype test period should include at least one full winter season, which means that the Prototype would continue through to spring of 2009. Key tasks and activities to be completed might include the following (depending on outcome of the Day-1 Concepts of Operation documentation effort):

- Develop WDT.
- WDT provides translated weather observations to *Clarus*.
- *Clarus* generates consolidated roadway link observations.
- ISP develops weather status and forecasts for specific roadway segments (links) (integration with Weather Enterprise).
- TOC validates and/or modifies roadway link weather observations and generates WAVE-formatted messages.
- Integration with existing weather information systems (DMS, HAR, 511).
- Separate OBE applications/interfaces for each OEM.

9.4.5. Evaluation and Monitoring

A rigorous evaluation and monitoring plan would need to be implemented throughout the Prototype and would include an assessment of the following:

- Contribution of weather related probe data to development of accurate road segment weather reporting and forecasts. Projections of how roadway weather advisory information will be enhanced with higher VII vehicle market penetration rates.
- Effectiveness of weather information broadcast strategies for targeting the right RSEs (i.e., strategies for getting the appropriate information to the right RSEs at the right time).
- OBE effectiveness in prioritizing and conveying weather-related information.
- Impacts on general safety and mobility measures during adverse weather conditions.
- Overall level of customer satisfaction. Comments for improvements.
- Impacts on overall capital and operating cost estimates for implementing and operating the application.

The monitoring and evaluation tools developed and implemented would provide the feedback necessary to raise awareness of the Weather Information application's impact, and report on whether additional development work would be needed to realize predicted benefits. The Prototype Results Report would also include sections on the evaluations of cost, benefits, and overall performance of the application and network. This would include summaries of public acceptance evaluations, failure mode testing, and safety and mobility benefits, as well as performance, reliability, and maintainability measures.

9.5. Full-Scale Deployment

To help accelerate widespread deployment of the Weather Information application, it will be important that "core" software modules, database designs, and analysis techniques be developed and documented during the Prototype. These "deliverables" would likely focus on:

- Software to support the analyses of probe data elements to yield reliable observations of roadway weather and surface conditions
- Software and techniques for integrating this probe data analyses with other "traditional" weather and road surface condition data
- A comprehensive report that summarizes all technical, programmatic, and institutional issues associated with the deployment of the Weather Information application
- A summary of all capital and operating costs items, and a listing of resources and equipment needed to support the application.

9.5.1. Policy, Liability, and Institutional Issues

There would appear to be no direct privacy, data security, or data ownership issues associated with this application. However, there are institutional issues associated with the role of government versus the private sector (see next section). In addition, it is likely that any public agency that is broadcasting weather and surface condition data will be held to high standards for ensuring the accuracy of the information. For example, if the weather and surface condition broadcast information is erroneous or excessively "old," and a motorist is involved in a collision after having acted on weather information received from the public entity (e.g., the motorist proceeded along a road based on information about the reported roadway conditions, but then encountered conditions that were much different or worse), then it is conceivable that the motorist would hold the public agency liable for the collision. The general issue of "information accuracy" is a pervasive issue for several VII applications, and this issue will need to be addressed during deployment.

9.5.2. Key Risk Areas

The risks areas associated with the Weather Information application are both technical and institutional, and include the following:

- ***Role of the Private Sector***. Consumers (and motorists) have a high demand for weather-related information, and the reporting of weather and roadway surface conditions is a highly competitive market. This is in some ways a "double edged sword." The benefit is that the broader Weather Enterprise community should be eager to assist with application development. However, this same community may become the "800 pound Gorilla" in the process—and want to drive the specifics of application development to meet the needs of for-fee customers (rather than focusing on developing a publicly provided weather information service). This community may resist the effort to overly "homogenize" roadway weather reporting.
- ***Organizational Complexity***. Like VII, the *Clarus* program is a complex initiative with numerous stakeholders. There will inevitably be challenges for managing the technical and

programmatic complexities of the two projects. This might be exacerbated as the *Clarus* project evolves toward NOAA leadership and control. Decisions about who is responsible for various phases of development, and where and how the work will be completed will need to be sorted out. For example, the functionality to be provided by the WDT could reside within VII or *Clarus*, and could be centralized or distributed. We suspect that there will be several other design and implementation details that will surface during development. A strong and clear management structure for the application deployment (particularly for the Prototype effort) will be needed.

- ***Sufficient Number of Probe Vehicles.*** Without a sufficient number of probe vehicles, the Weather Information application will have to rely on conventional or traditional sources of weather and road surface condition reporting. However, our preliminary research indicates that the Detroit area has limited SCE or ESS equipment. Therefore, a pre-condition of the application development program may be to install additional equipment and systems to establish "ground truth" for roadway weather and surface conditions.

10. ELECTRONIC PAYMENTS: TOLL ROADS

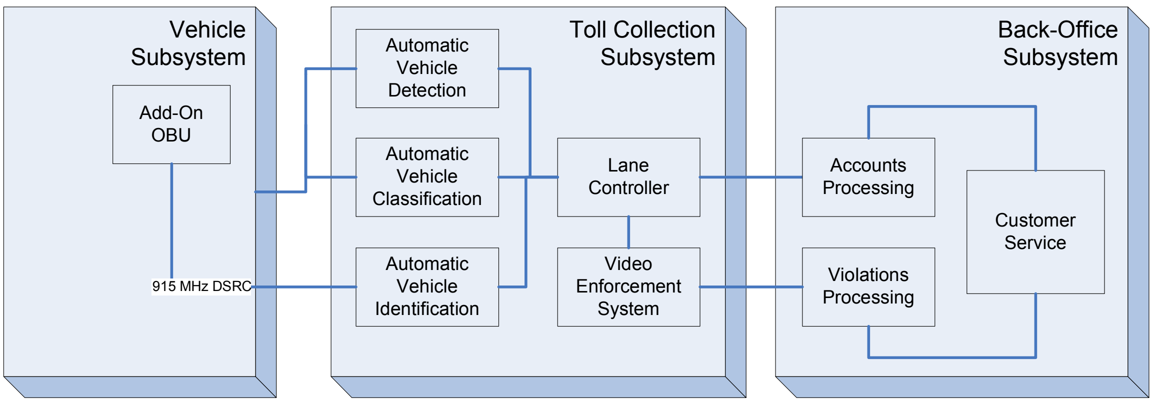
Three of the 20 “Day-1” applications deal with electronic payments for tolling, parking, and gas purchase, with tolling designated as a public sector application. This chapter focuses on tolling and presents a high-level road map for development of the Electronic Toll Payment application by Day-1.

10.1. Application Description

10.1.1. Background

Electronic toll collection (ETC) systems typically comprise three major subsystems, namely vehicle subsystem, toll collection subsystem, and back-office subsystem. Exhibit 9 provides an overview of the components within each of these three subsystems that support the ETC process from end to end.

Exhibit 9 – Typical Schematic of Current ETC Systems



- The vehicle subsystem essentially consists of an add-on OBU or transponder (issued by the Back-Office Accounts Processing) that is encoded with a unique identification number.
- The toll collection subsystem typically includes the following RSE: automatic vehicle detectors (AVD), automatic vehicle classifiers (AVC), automatic vehicle identifiers (AVI), lane controllers, and video enforcement system (VES).
  - The AVD equipment detects the presence of vehicles in the toll lanes and measures traffic flow characteristics such as volumes and speeds.
  - The AVC equipment distinguishes vehicle types passing through the toll facility by detecting vehicle characteristics such as height, number of axles, and presence of dual tires.
  - The AVI equipment communicates with vehicle-mounted transponders via dedicated short range communications (DSRC), and currently operates at 915 MHz frequency in the U.S.

  - The lane controller includes software necessary to processes toll transaction in the lane and triggers the VES equipment to capture video images of non-toll paying vehicles' license plates. The lane controller forwards the toll transaction data to the toll authority's back office subsystem.

- The back office subsystem in general has three broad functions:
  1. ***Accounts Processing***: Issuing transponders, establishing and maintaining ETC customers' accounts, posting toll transactions and payments to customers' accounts, interfacing with a credit card clearing house, issuing customer statements, and disbursing toll revenue to the toll authority's bank account
  2. ***Customer Service***: Handling ETC customers' inquiries through walk-in facilities, call centers, and web portal
  3. ***Enforcement Support:*** Processing toll violating vehicles' license plate images, interfacing with Department of Motor Vehicles, issuing citations, and collecting payments.

While largely viewed as successful applications, most current 915 MHz ETC systems in the U.S. rely on proprietary vehicle-to-roadside communications (i.e., one vendor's AVI equipment cannot communicate with another vendor's transponder) and offer limited interoperability amongst each other (i.e., only a limited number of toll authorities can accept electronic toll payments from other toll authorities' ETC customers). At most, the current toll industry offers regional interoperability at the lane hardware side (e.g., Caltrans' Title 21 standard), but much less at the back-office subsystem level.

In October 2004, the FCC allocated the 5.850 - 5.925 GHz band (commonly referred to as 5.9 GHz band) for next-generation DSRC. The new band is intended for use in vehicle-to-vehicle and vehicle-to-roadside communications applications such as intersection collision avoidance and electronic payments respectively. The U.S. ETC industry, through organizations such as the OmniAir Consortium and the DSRC Industry Consortium, is currently working on leveraging the next-generation DSRC to overcome the existing 915 MHz ETC systems' limitations mentioned above by developing approaches for non-proprietary and nationally interoperable electronic payment services (EPS).

The expectation that, starting in 2011, vehicles will be shipped nationwide with built-in 5.9 GHz devices naturally lends itself to the need for non-proprietary vehicle-to-roadside communications (i.e., an RSE should be able to communicate with all OBE-equipped vehicles, regardless of the vehicle manufacturer) and nationwide interoperability (i.e., a toll authority should be able to accept electronic toll payments from all VII EPS-enabled vehicles, regardless of who owns the EPS account).

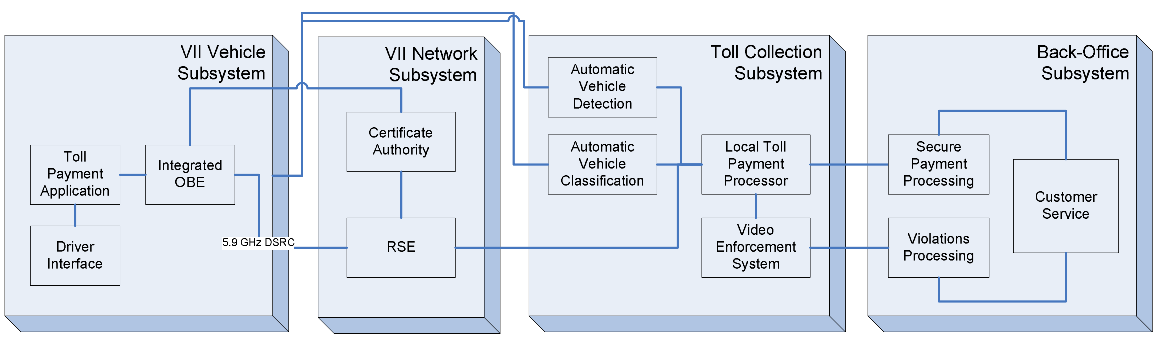
From the standpoint of adopting the new technology, because of the frequency difference, both the existing 915 MHz systems and the new 5.9 GHz systems can coexist on the same roadway. The new 5.9 GHz roadside equipment is expected to utilize the existing in-lane tolling infrastructure to the extent feasible, support existing violation enforcement functions, and facilitate a smooth migration from existing 915 MHz DSRC to next-generation 5.9 GHz DSRC-based ETC systems. Toll lanes that currently accept 915 MHz transponders can be equipped to accept the new 5.9 GHz transponders as well. Toll authorities can gradually phase out the existing 915 MHz transponders at their desired pace.

With the onset of new technology, the expectation that there will be millions of VII-enabled vehicles that will potentially generate billions of EPS transactions, will likely generate opportunities for new players (such as financial institutions) into the business of back-end toll accounts processing and management, and customer service. Consequently, toll authorities looking to migrate to the new technology will be able to choose between upgrading their own existing back-office subsystems, outsourcing the back-office functions to these new players, or taking some sort of a hybrid approach.

10.1.2. Overview of VII-Based Electronic Toll Payments Application

In 2011, conceptually, when a vehicle with built-in 5.9 GHz device (i.e., OBE-equipped) comes within the radio range of an RSE, the potential exists for secure transactions to facilitate payment for various goods and services such as gas, parking, and tolls. In the context of road tolling, this concept can be leveraged to potentially simplify the infrastructure necessary to handle toll payments, as well as provide flexibility with regard to tolling schemes, toll payment options, and operating models. Exhibit 10 provides an overview of the components within the VII-based tolling application.

Exhibit 10 – Schematic of VII-Based Tolling Application



A general description of the application components is as follows:

- The vehicle subsystem will consist of an integrated OBE, a toll payment application, and driver interface (commonly referred to as HMI). The OBE will include a 5.9 GHz DSRC radio. The toll payment application will notify the driver via the driver interface that he is approaching or exiting a toll facility, present payment instructions to the driver, receive driver input, send payment authorization via the OBE, and display toll payment status to the driver via the driver interface.
- The VII network subsystem will consist of an RSE and a Certificate Authority. An RSE communicates with an OBE via 5.9 GHz DSRC. It will notify an OBE that it is approaching or exiting a toll facility, send toll-related information (e.g., amount) to the OBE, and receive payment authorization from the OBE. The Certificate Authority issues security certificates to the OBE and RSE to enable secure toll payment-related message exchanges between the RSE and OBE. RSEs and OBEs will not be able to conduct toll transactions without these certificates.

- The toll collection subsystem will include an AVD, AVC, local toll payment processor, and VES. The AVD, AVC, and VES components will function similar to the way they do in current ETC systems. The local toll payment processor will, in theory, also function similar to a lane controller in current ETC systems. It will notify the vehicle about toll due via the RSE, receive payment authorization from the vehicle via the RSE, and trigger the VES equipment to capture video images of non-toll paying vehicles' license plates.
- The back office subsystem will include three broad functions: secure payment processing, violations processing, and customer service. These functions are essentially the same as those in current ETC systems as described in Section 8.1.1, except that the secure payment provider will not be issuing transponders for VII-based tolling.

Toll Road Types:

For Day-1, VII is expected to support the following three types of toll roads:

- Roads that charge a fixed toll at a given location (i.e., open system)
- Roads that charge a variable toll based on the distance traveled (i.e., closed system)
- Roads that charge a toll for improved level of service (i.e., high-occupancy-toll (HOT) lanes), and may change the toll amount based on level of congestion, time of day, or entry/exit location.

For fixed-toll limited-access roads, VII-based toll payment will function very much like today's transponder-based toll payment. As an OBE-equipped vehicle approaches a toll payment location, it will interact with an RSE. If the vehicle operator has enabled electronic payment on the OBE, it will electronically pay the toll and notify the driver of valid payment.

For distance-based tolling applications, the OBE-equipped vehicle will interact with an RSE located at an entry to the tollway, and again with an RSE located at an exit. Upon exiting the tollway, if the vehicle operator has enabled electronic payment on the OBE, it will electronically pay the toll and notify the driver of valid payment.

For HOT lane applications, an RSE situated prior to the HOT facility will interact with vehicles and share the locations of HOT lanes and current toll rates. Tolls are charged electronically on the HOT lanes via interaction between a qualifying OBE-equipped vehicle and an RSE at the toll payment location.

In all three toll road types described above, in the case of a failed or non-payment, the vehicle will be treated as a violator and will be processed as such through the toll facility's VES.

Toll Payment Methods:

For Day-1, each of the three toll road types described above is expected to support at least two different methods for payment: account-based payments (similar to transponder-based systems in use today) and credit card/debit card payments from within the vehicle at the toll payment location (i.e., point-of sale transactions). Although electronic purses could in theory be used for electronic toll payment, their adoption for Day-1 seems questionable until they are widely accepted by both consumers and retailers for general purpose use.

Toll Payment Scenarios:

Combining the two payment methods with the three toll road types yields six toll payment scenarios as illustrated in Table 6.

Table 6 – Toll Payment Scenarios

Toll Road Type	Toll Payment Method
Open System (e.g., Dulles Toll Road)	Account-based
	Credit Card/Debit Card
Closed System (e.g., New Jersey Turnpike)	Account-based
	Credit Card/Debit Card
HOT Lanes (e.g., SR 91 Express Lanes)	Account-based
	Credit Card/Debit Card

10.1.3. Relationship to Other VII Applications

The Electronic Toll Payment application is one of the three sub-applications within the Day-1 electronic payment application; the other two being Parking Payment and Gas Payment. There are several basic development tasks associated with the Electronic Toll Payment application that also apply to the other two sub-applications. These tasks include developing strategies for presenting payment instructions to the driver, defining approaches and limitations for driver input, identifying methods for transaction flow from end-to-end, exploring the concept of private RSEs for payment applications, delving into options for securing the transaction, and assessing the viability of different payment options including credit/debit cards and electronic purse.

10.1.4. Overview of Deployment Plan

The plan for developing and deploying the Electronic Toll Payment application is organized into the following four phases:

- Application Refinement and Research
- POC Testing
- Prototype Development and Testing
- Full-Scale Deployment

The following sections describe the proposed work efforts within these four phases.

10.2. Application Refinement and Research

The VII National Working Group has developed the use case numbered IP-44.a, titled "Electronic Payments: Toll Roads (Day-1)." The use case was primarily developed to expose the VII network-centric needs and was not intended to present the final Day-1 application complete from end-to-end. The use case was only partially vetted by some toll industry experts and the International Bridge, Tunnel, and Turnpike Association (IBTTA) members. It has not been fully vetted to the point where one could reasonably say that there is industry consensus on which to base a successful VII-based tolling program. Therefore, it is recommended that the U.S. DOT support the development of a Day-1 ConOps for VII-based electronic toll payments. Specific topics that the ConOps should address include:

- How will the application function from different stakeholders' viewpoints (e.g., drivers, toll authorities, account issuers, VII Entity)? What new capabilities will the application provide?
- How will a driver "sign up" for VII-based toll payments? How will payment instructions be provided to a driver? What does the driver have to do to make a toll payment? What level of consistency should be expected for this interface?
- How will a toll authority implement and operate the VII-based tolling application in a new or existing toll environment? How will vehicle identification, classification and violation enforcement be dealt with in the VII tolling environment? How will vehicle-transaction correlation be different with VII vehicle positioning, compared to current technologies and methods? Should license plate number be transmitted to RSEs?
- What penetration levels (for OBE-equipped vehicles) will make it worthwhile for toll authorities to consider implementing VII-based tolling? What are the high-level costs and benefits for implementation? Should a toll authority own the RSEs? How will the vehicle positioning and DSRC range capabilities affect the roadside tolling infrastructure? Can the number of antennas (RSEs) be reduced?
- How will the transactions flow from end to end? What are possible options and implications? How will exception (i.e. non-vanilla) transactions be dealt with? At what point does electronic signature or end of transaction take place in a VII tolling scheme?
- How will the transaction be secure? Is there a need for a separate security certificate at the application level? Who could issue application security certificates? Should public-key certificate directories be published to non-tolling RSEs that are within the geographic boundaries of a toll facility?
- What payment options will be supported? How will account-based and credit/debit card-based transactions work? What are the implications of real-time versus batch processing of credit/debit card payments? What is the potential for electronic purse as a payment option? Should a two-piece OBE be considered for payment?
- How will the tolling back-office operations work in a VII environment? What are the business models?
- What current and evolving standards are applicable? Is there a need for new standards to be developed? In what areas? Should standard for contact less credit cards be adopted as standard (banking standard) for transactions?

- Who are the key players? What are their roles and responsibilities? What are the functions of the VII entity? Who will have access to various elements of the application? Who will own the "account"?
- What resources are required to develop and deploy the application? What is the timing of various activities? What do results from the OmniAir's Electronic Payment Services National Interoperability Specification (EPSNIS) Reference Implementation Test (RIT) at New York State Bridge Authority (NYSBA) and VII POC testing in Detroit mean for the application's full-scale deployment?
- What is the scope for an after-market 5.9 GHz tag? How will it co-exist/work in an "built-in tag" environment? What are the technical and non-technical challenges?

Based on the ConOps, requirements for the application will be developed. Specific requirements that will be addressed include how a vehicle shall be authenticated and classified, how normal and exception transactions shall be handled, how transaction shall flow from end to end (i.e., whether through the VII network or external to the network), and how payment shall be verified. These requirements will drive the development of VII-based tolling applications for Day-1 and beyond.

10.3. POC Testing

The concept of VII-based electronic toll payment will be demonstrated during the POC testing planned in Detroit, MI. For purposes of this test, plans are currently underway to test the "Open System – Account Based" toll payment scenario (see Table 5 above). The POC testing efforts include refining application requirements, developing the application components, preparing the test environment, demonstrating the application, and summarizing test results.

10.3.1. Refine Requirements for POC

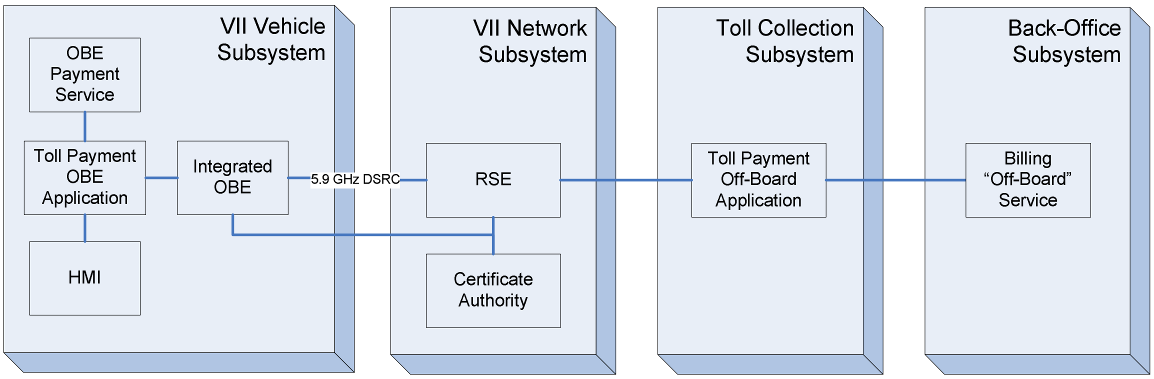
As a first task within the POC effort, it is important to refine the use case and develop testing requirements. Key topics to be addressed include:

- What specific tolling scenario(s) should be tested at the POC to adequately prove the concept of VII-based electronic tolling? What is the concept of operation for the selected scenario(s)? What observations will constitute a successful demonstration of a secure toll payment transaction?
- What application components are required to support the operational concept? What software requirements and interface specifications need to be in place for the various application components? Who is developing what pieces of the application components?
- What are the physical requirements for testing the operational concept? How can we simulate a toll environment given that the Detroit POC DTE does not include a toll facility? How closely should the test environment resemble a real toll facility in terms of RSE (e.g., vehicle detectors, classifiers, enforcement equipment)?

10.3.2. Develop Application Components for POC

The VIIC will develop and implement the application components for POC testing. Exhibit 11 provides an overview of these components.

Exhibit 11 – Schematic of Tolling Application For POC Testing



A general description of the application components is as follows:

- ***Toll Payment OBE Application Component:*** This application component will receive toll-related information from an RSE, notify the driver that he is approaching a toll collection point, present payment instructions to the driver, receive driver input, send vehicle information and driver input to the RSE, and coordinate payment of toll.
- ***OBE Payment Service:*** This application component will associate the vehicle (or driver) with a toll account that was pre-established with a toll authority and generate appropriate WAVE certificates in IEEE 1609.2 format for use in conducting secure toll payment transactions.
- ***Toll Payment "Off-Board" Application Component:*** This application component will notify an OBE-equipped vehicle that it is approaching a toll facility and send toll-related information to its OBE, receive payment authorization from the OBE, and process toll payment.
- ***Billing "Off-Board" Service:*** This service will provide a secure means for customer accounts registration, generation and distribution of account certificates to OBEs and RSEs, receipt and verification of toll payment transactions, collection of toll charges, and posting of the transactions to customers' accounts. In other words, this service will emulate the typical functions of a toll authority's CSC in a very simple manner.

10.3.3. Prepare Test Environment

In preparation for the POC, a test plan will be developed for the tolling application. The test plan will define the objectives and scope of the testing effort and identify specific functions that will be tested (e.g., advance toll facility and fare notification, driver input, payment authorization, and transaction completion) and methodology that will be used to conduct the test (e.g., pre-defined test scenarios, test procedures, and expected results or success criteria). The test plan will also include a testing schedule.

Based on the test plan, the testing team will identify the requirements for the hardware and software including vehicle detectors, RSEs, OBE-equipped vehicles, and tolling application software components. The POC testing for this application will be conducted in a simulated toll environment as part of the DTE. Depending on the test scenarios that will be defined in the test plan, the test fleet could include some vehicles that are fitted with the Ambassador Bridge's ETC transponders.

10.3.4. Application Integration and Testing

During this phase of the POC, the test team will demonstrate the tolling application in the simulated toll environment as per the test plan. During this testing period, the test team will manage and maintain the toll environment hardware, software components, and interfaces; manage all of the logistics of the test and demonstrations including managing test vehicles and drivers; and run reports on collected toll transactions data.

10.3.5. Summarize Results from POC Testing

Upon completion of the tolling application demonstration, the test team will prepare a report describing how the tolling application was implemented, operated, and tested, and detailing the results of conducting secure VII-based toll transactions in a high-speed vehicular environment. The report will include a listing of all changes and recommendations made to the overall design of the tolling application components during the testing period.

10.4. Prototype Development and Testing

10.4.1. Overview

The POC will test the concept of VII-based toll payment application in terms of whether or not the OBE, RSE, and VII network components can successfully communicate and conduct a secure electronic toll payment transaction. Beyond the POC testing, there exists a need for a prototype application development effort that will demonstrate the electronic toll payment application from end to end, as well as provide qualitative and quantitative data to facilitate a cost-benefit analysis of the application.

10.4.2. Location for Prototype Application Development

Given that the prototype will be the first real-world demonstration of the VII-based tolling application from end to end, it is recommended that the application demonstration be conducted at an actual toll facility, where an ETC system is currently in operation. Depending on the intent and desired outcome, the VII-based tolling application could be demonstrated either as a stand-alone or as part of a larger prototype application development effort that includes various other Day-1 applications (similar to the Detroit POC). In either case, it is recommended that the application be demonstrated in multiple tolling environments (e.g., open system, closed system, and HOT lanes) to ensure that the implementation and operational variations between the three different tolling environments are adequately captured and demonstrated.

In this context, it is important to recognize that OmniAir will conduct a RIT at the NYSBA to validate its 5.9 GHz EPSNIS and its system architecture. Given that this test will already set up a toll environment that comes closest to that of a future VII-based tolling environment, it is worthwhile to consider conducting the prototype application demonstration at the NYSBA. But before this decision is made, issues such as timing of the prototype application development with respect to the planned RIT, capability of RSEs used during the RIT to communicate with the VII network, and ability to mobilize OBE-equipped vehicles to New York area will need to be addressed.

An alternative location for the prototype application development might be the Ambassador Bridge, where an ETC system is already in place, availability of OBE-equipped vehicles is not an issue, and the toll environment set up for the POC DTE could be transferred to the Bridge site with relatively less effort, compared to setting up a totally new environment. However, given that this Bridge is privately owned and operated, and that it connects to a Canadian Province, there will be institutional issues that need to be investigated and weighed in prior to making a decision.

It is recommended that similar analysis of potential locations be carried out for conducting the prototype application development at closed system and HOT lane facilities.

10.4.3. Define Prototype Application Development Requirements and Objectives

As part of scoping out requirements for the prototype application, it is recommended that several tolling situations be demonstrated, with the objective of promoting adoption of the application by the tolling community. Examples of these situations could include the following:

- Mix of vehicles with 915 MHz add-on tags, 5.9 GHz add-on tags (if applicable), and integrated OBEs
- Mix of payment types such as account-based, credit/debit cards, and electronic purse (if applicable)
- Different classes of vehicles (automobiles, towing trailers, etc.)
- Different vehicle speeds
- Barrier plaza versus open road tolling
- Exception (or non-vanilla) transactions
- VII vehicle non-payment/violator enforcement
- Adjacent toll lanes equipped with VII-RSEs

It is recommended that further work be carried out to detail the scope of this phase.

10.4.4. Prototype Development Team

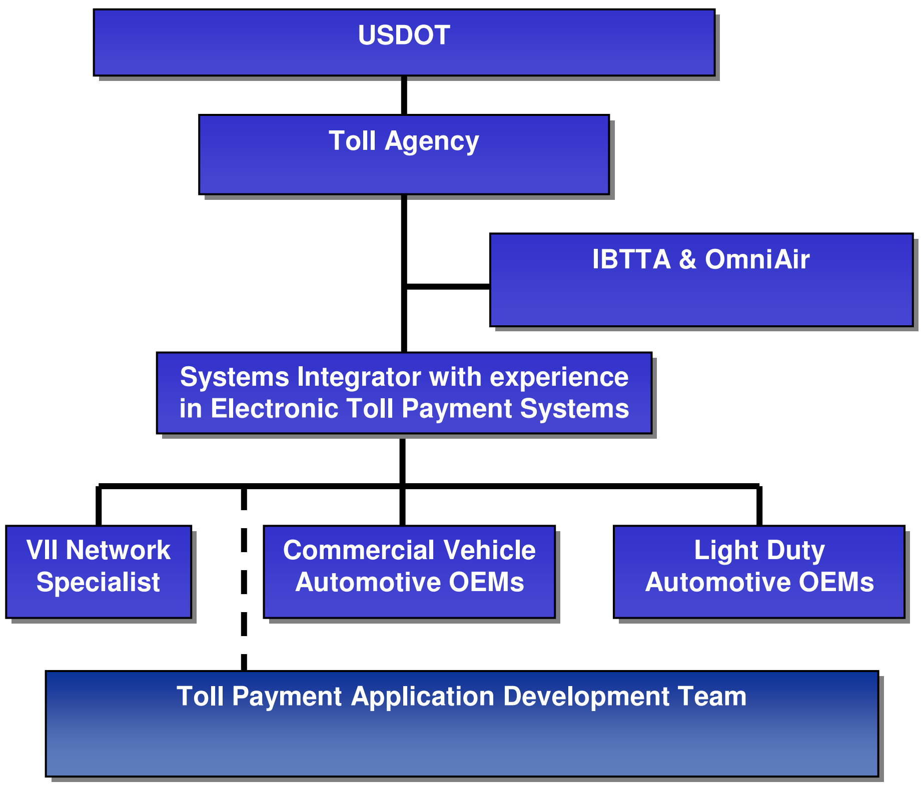
The resources and capabilities needed to support Toll Payments Prototype are considerable. Core team members would include:

- U.S. DOT to oversee and help fund the effort

- Toll Agency to co-sponsor the prototype
- IBTTA and OmniAir to help drive the focus and scope of the prototype
- A systems integration firm with experience in developing and implementing toll payment systems and applications
- Vehicle OEMs to supply the test fleets and build the on-board electronic payment application components
- VII network and architecture specialists to lead communications trade-off analyses, support message delivery strategy development, and support development of any new network services required.

Exhibit 12 presents a hypothetical organization chart for the prototype development team.

Exhibit 12 – Team Organization for Toll Payment Prototype Application



10.4.5. Conduct the Prototype Development and Testing

The Toll Payment Prototype would begin at the conclusion of the POC (or in early 2008). Key tasks and activities to be completed might include the following (depending on outcome of the Day-1 Concepts of Operation documentation effort):

- Development of payment accounts management system
- Development of OBE application and interface to tie accounts to vehicles/drivers

- Development of enhanced local toll payment processor
- Integration with existing in-field toll collection system
- Integration with back office accounts management system

10.4.6. Evaluation and Monitoring

A rigorous evaluation and monitoring plan would need to be implemented throughout the Prototype. The monitoring and evaluation tools developed and implemented would provide the feedback necessary to raise awareness of the Toll Payment application's impact, and report on whether additional development work would be needed to realize predicted benefits. The Prototype Results Report would also include sections on the evaluations of cost, benefits, and overall performance of the application and network. This would include summaries of public acceptance evaluations, failure mode testing, and safety and mobility benefits, as well as performance, reliability, and maintainability measures.

10.5. Full-Scale Deployment

Full-scale deployment of the VII tolling application largely depends on the success of the prototype application development phase. Other critical dependencies include the maturity levels of various applicable standards including OmniAir's EPSNIS, outcome of OmniAir's RIT at NYSBA, VII application and network services development, and resolution of privacy and application access control related issues.

Assuming the above dependencies are met, the VII tolling community will need to continue its efforts for the application to reach full-scale deployment. For instance, the U.S. DOT, in collaboration with IBTTA, could begin to reach out to the tolling community regarding the costs and benefits of VII-based tolling, and help ensure that the toll authorities successfully transition to accept toll payments from VII vehicles. State DOTs and toll authorities could begin to invest in carrying out additional prototype application development efforts, developing custom applications for the VII tolling environment, and evaluating different business models for back-office operations. OmniAir, given its current role in advancing the next-generation DSRC, could get engaged in refining the business models in the context of VII, developing guidelines for toll authorities looking to migrate to VII-based tolling, and expanding the Day-1 VII tolling Concept of Operations to cover the breadth of Electronic Payment Services in general.

10.5.1. Policy, Liability, and Institutional Issues

The following issues need to be researched further before full-scale deployment will take place.

- ***Vehicle Classification:*** Toll authorities typically classify vehicles and charge appropriate tolls. These classification schemes include, for example, number of axles, number of tires, dimension, and weight. The VII tolling community should explore the potential for a nationwide uniform classification scheme (e.g., similar to IAG classification scheme). VII vehicles are expected to come with the appropriate vehicle classification coded on the OBE. However, the issue then arises regarding how to deal with an automobile towing a trailer, for example. Perhaps, the OBE will be designed to reclassify the vehicle if it detects a trailer (based on vehicle performance indicators). Alternatively, the tolling authorities may revise their vehicle classification schemes to, for example, not deal with the trailer in the above example. So the solution could lie in the technology or on the tolling business process side. These solutions would have to be explored further.

- ***Non-Revenue Vehicles:*** Almost every toll authority has a non-revenue program in which specific types of vehicles such as police cars and government vehicles are exempted from paying toll. The VII tolling application is expected to support these programs. But the challenge lies in how to recognize these non-revenue vehicles in a VII tolling environment. Currently, this is dealt with using specially coded non-revenue transponders. For VII tolling, the questions are: will there be specially coded non-revenue OBEs (most likely not), will there be some other means of recognizing a non-revenue vehicle, or should the toll authorities change their policies on non-revenue vehicles. This topic needs to be explored further.
- ***Enforcement :*** VII-based tolling would need to address the issue of dealing with non-payments (i.e., toll violators). Violations (or "exceptions") could result from various situations including non-VII vehicles passing through VII toll lanes, VII vehicles with malfunctioning OBEs, and failed payment transactions. In all of these cases, the toll authorities will need an alternative way to collect tolls. It appears that VES, similar to those that are in use today, could be the solution for VII toll violation enforcement. This would mean that toll authorities that currently do not have VES supporting legislation, operating policies, or technical infrastructure should begin to pursue these issues prior to Day-1. However, the toll industry currently does not fully understand how VES will operate in the 5.9 GHz environment where the toll collection "zones" could be in hundreds of feet, unlike today's 915 MHz environment where the zones are very short in the order of tens of feet. While it does not seem technically impossible, this area still needs to be explored further.

10.5.2. Key Risk Areas

The risks areas associated with the tolling application include the following:

- ***Transaction Time:*** Current transaction time of greater than five seconds for real-time credit/debit card payments is unsuitable for open system toll facilities because the vehicles are in the toll collection zone for a short period of time (a few seconds). So a potential way to deal with this issue is to process the credit/debit card payments in batches offline at the back-office. For a closed system, this issue could potentially be dealt with by locating RSEs at the entry/exit locations along the toll facility, where an RSE at the vehicle entry point initiates the credit/debit card payment, and another RSE at the vehicle exit point completes the payment. Here, further research is needed to ensure that the two RSEs can complete the payment transaction seamlessly, without losing transaction integrity. Without the ability for real-time payment transactions, VII tolling application may not realize its full potential.
- ***Penetration Rate:*** In today's ETC environment, ETC penetration levels are driven by customers making an active effort to obtain a transponder. In the VII tolling environment, the vehicles will come with built-in OBEs so the customers would not have to make an active effort to get a transponder. They simply need to opt to pay tolls via the VII tolling application resident on the OBEs. It is expected that nearly 20 percent of approximately 250 million automobiles in the U.S. will be VII capable by 2015. This vehicle penetration rate is key to

the full-scale deployment of the tolling application. It is also important to note that given the time period between today and Day-1, an after-market 5.9 GHz tag could potentially enter into the tolling market, perhaps positively contributing to the penetration rates, prior to Day-1. However, these after-market tags will need to be tested and evaluated in current tolling environments, and the toll authorities will have to understand the implications of adopting these after-market tags, given that the near future tolling environment will be based on built-in tags. This area needs to be explored further.

- ***Transaction Type:*** One of the factors to consider for full-scale deployment is the toll transaction type. In the case of "account-based" transactions, the toll authority knows who the toll payer is and is therefore able to collect toll from him/her at some point in time. However, the situation is slightly different in the case of "anonymous" transactions where the toll payer pays the toll using a credit/debit card at the toll collection point. Given that tolling is not like a typical retail payment environment (where 'no pay' = 'no service'), toll authorities dealing with large numbers of such anonymous transactions could potentially incur high costs associated with enforcement of unpaid tolls. These high costs, coupled with the drawbacks associated with less-than-perfect DMV driver-lookup databases, could pose an operating risk to the tolling authorities looking to adopt VII-based anonymous tolling. This risk area needs to be explored further.

11. CORRIDOR MANAGEMENT

11.1. Application Description

Background

The VII Day-1 use cases include both a use case for corridor management planning assistance (CMPA) and for corridor management load balancing (CMLB). These use cases were developed by the U.S. DOT/Booz Allen team and reviewed by a group of stakeholders selected by the U.S. DOT and the American Association of State and Highway Transportation Officials (AASHTO), including state transportation engineers and researchers.

The resulting CMPA use case described mechanisms that provide transportation planning agencies with:

- Historical travel time data on all roadways in a region
- Origin-destination (O-D) and travel-time information for a limited subset of vehicles in a region.

This information would enhance the planning process with more ubiquitous data, and vastly simplify the collection of information that today requires specialized counters and surveys.

The CMLB use case described scenarios that would enable transportation management agencies to develop load balancing plans in order to:

- Leverage their existing traffic management systems including traffic signal systems, ramp metering systems, and lane control systems to directly affect freeway and arterial performance
- Utilize their traveler information resources, including the VII network, HAR, dynamic message signs, 511, as well as private sector information providers to provide routing suggestions designed to empower travelers to make decisions that will benefit both their trips and the performance of the overall transportation network

Additionally, the use case proposed the development of a real-time map of the transportation network, which could be used as the primary decision-making tool for agencies to implement their load balancing plans.

The CMLB application will provide the functionality necessary to enable traffic management agencies to receive and process probe data in order to develop corridor management strategies and make real-time decisions related to executing those strategies. However, this functionality requires significant research and development, above and beyond the utilization of the VII system. It will be necessary to investigate and understand how coordinated changes in signal control, ramp meters, and alternative route suggestions (via traveler information messages) affect the flow of traffic through a corridor. Significant fundamental research into this will be important if the CMLB is to be realized. The ability to develop a complete CMLB application (in conjunction with the signal timing, ramp metering, and traveler information applications) within the Day-1 timeframe is likely unrealistic. However, the development of support tools for CMPA and understanding of where opportunities are to improve freeway and arterial performance in a corridor is an obtainable goal, and valuable use of VII at Day-1.

11.1.1. Relationship to Other VII Applications

CMLB is inherently dependent on three other Day-1 use cases: signal timing optimization, ramp metering and traveler information. It is not practical to field a full CMLB application unless those other applications are somewhat mature.

11.1.2. Overview of Application Development Roadmap

Based on these assumptions and background information, the Deployment Plan for the Corridor Management applications are organized as follows:

- Application Refinement and Research
- POC Testing
- Prototype Development and Testing
- Full-Scale Deployment

The proposed application development plan is characterized by work phases that represent a progressive development of the application from concept refinement through full-scale development. During concept refinement, the roles of various entities involved in the application will be clarified and more details related to the overall architecture will be developed. The overall Application Deployment plan proposed in this document will also be reviewed.

During POC testing, basic functionality of the VII System will be tested and demonstrated to show the ability to receive probe data and transmit advisory messages to vehicles. Additionally, probe data would be combined with existing information systems to develop a consolidated "view" of the roadway network. This network view would then be analyzed to determine where/if opportunities might exist for load balancing of the network. However, actual implementation of those opportunities would not be executed.

After the POC is complete, (and a deployment decision has been made), a prototype application would be need to be developed that would fully demonstrate how VII data could be used to assist with corridor management and load balancing—including actually implementing some of the strategies and tactics in a real-world environment.

11.2. Application Refinement and Research

11.2.1. Fundamental Research

The CMLB application requires fundamental research to develop algorithms sufficient to profile the state of the roadway network, and to suggest tactics for messaging and other means of influencing driver behavior in a manner that would help balance flow through the network and improve overall traffic conditions. Some of this research is already being initiated under the auspices of the Integrated Corridor Management Initiative (CMI). Research done to facilitate

CMLB should coordinate with the CMI, and focus on how to use VII-specific technologies to support a CMLB application. CMLB research should also determine how best to utilize the VII system for disseminating data directly to vehicles, addressing questions regarding the types, frequency, and distribution area of messages.

11.2.2. Concept of Operations

The first step of the actual application development process for the Corridor Management applications is to develop a detailed Concept of Operations for Day-1. The ConOps would define the technical and functional characteristics of the applications, as well as provide an overview of the institutional and organizational issues relevant to implementing the applications in a real world setting. Some of the key technical and institutional challenges that would need to be addressed in the ConOps include:

- Geo-located speed data provided by the VII system would be used to derive travel conditions within a corridor, including link speeds and travel times over all freeways and arterials within the targeted corridor. Such information could be provided in a form that, if necessary or desired, could be fused with other data sources, including existing roadway sensors and incident data reports.
- Travel condition information, maps, and other "externality" type information necessary to characterize the travel conditions during a particular period will be archived in order to provide historical reference and allow both prediction of future conditions, as well as to gauge the results of implementing different corridor management plans.
- Traffic management agencies would develop corridor management plans from the travel condition information. These plans would include:
  - A routing strategy, which includes signal timing plans, ramp metering plans, lane control plans, and routing suggestions for motorists that would be disseminated on dynamic message signs, 511, HAR, and through the VII network as well as other ISPs.
  - Threshold conditions and operating policies to indicate what travel conditions would precipitate the activation of this plan.
  - Predicted changes in travel conditions upon implementation of this plan, and at predefined time intervals.
- Travel condition information would be used to periodically generate a "state of the roadway network" report, including maps and probably textual markers that help to identify problem areas. This report would be compared against existing archived corridor management plans, and a determination made as to which plan to implement.
- The ConOps would include a section describing implementation of CMLB processes between and across multiple traffic management agencies.

While some progress on the ConOps for the corridor management applications can begin immediately, we suspect it will be more productive to first complete the ConOps for other enabling applications (i.e., traveler information, signal timing, and ramp metering), and to have completed limited testing during the POC. At such a point in time, (perhaps midway through the POC), there will be significantly better understanding of how probe data can support the characterization of traffic flow, and how public sector messages can be disseminated to motorists. Further, there will be fundamental progress on how the roadway network will be defined, and how mapping applications will be executed. The ConOps for the Corridor Management applications could begin in earnest at that time. The development of the ConOps should be led by USDOT but with strong support from State and local transportation agency partners—and the Working Group should be heavily involved. The key stakeholders involved in the POC (including the VIIC and the Systems Integration contractor) should also be involved in developing and detailing the ConOps since the application will leverage network services, and must be supported with an appropriately designed on-board application.

11.3. POC Testing

The POC testing in Detroit will be the first opportunity to demonstrate the ability to collect VII probe data useful to improve freeway and arterial performance. Prior to the initiation of the POC, it will be important to refine requirements and goals for demonstrating or otherwise supporting the development of the corridor management application at the Detroit test bed. The specific capabilities and features that will be tested during the POC that showcase how VII can support corridor planning and management will be detailed in a "POC Concepts of Operation" document.

It is envisioned that additional development work focused on corridor management during the POC would be comparatively modest. It would primarily focus on confirming that the system is capable of distributing probe data and confirming that the system could support the traveler information, signal timing, and ramp metering applications that are the building blocks of the VII application framework.

The application testing and demonstration phase of the POC is expected to be concluded at the end of 2007 or early 2008. At that point, an Application Development Report will be developed that summarizes the performance and functionality features that were demonstrated, documents how technical issues were resolved, and reports on development issues that require additional test and refinement (including technical, organizational, and programmatic challenges).

11.4. Prototype Development and Testing

11.4.1. Refine Prototype Requirements and Objectives

As stated earlier, the development of a complete CMLB application for the Day-1 timeframe is unrealistic due to the limited penetration rate of VII-equipped vehicles and local agencies' likely hesitation on actively managing their corridors based on such data. Therefore, the Prototype for corridor management would be focused on the development of support tools and processes for providing transportation planning agencies with the information needed to help improve their corridor networks. The Prototype application for corridor management would be designed to meet numerous objectives, including:

- Develop, test, and validate tools and processes for manipulating and presenting information needed to improve corridor planning and determining freeway and arterial performance in a corridor

- Integrate non-VII traveler information collection and dissemination capabilities (e.g., 511, DMS, non-VII probe data such as tracking cell phones and/or tracking of ETC vehicles) in order to enhance corridor management strategies and tactics during early deployment stages when VII vehicle will have low penetration rates.
- Develop load balancing strategies and plans, as well as mechanisms for implementing these plans based upon VII probe data collection and message dissemination capabilities.
- Demonstrate the potential improvements that could be realized in documenting current travel patterns and conditions through "opt-in" programs that would allow for continuous tracking of vehicles. Assess how required market penetration levels needed to support effective planning and load balancing might be impacted (improved) through such opt-in programs.

11.4.2. Expand/Create the Prototype Develop Test Environment

While the corridor planning Prototype could be developed in the Detroit test environment, localities that already have well executed and highly capable traveler information systems might be better suited for developing the "VII-enhanced" versions of such systems. While the necessary VII infrastructure would have to be in place, traditional information systems and field equipment would be very beneficial in supplementing VII probe data as well as providing alternative methods for relaying information to drivers and controlling signal systems. Conducting the Prototype for this application might therefore be best accomplished by a locality that has defined corridors (and alternative routes) with existing traffic detection capabilities, advanced signal control systems with the ability to centrally manage the signal coordination, and perhaps a ramp metering system already in place.

- ***Vehicles****:* For the CMPA prototype, the origin-destination use case (within the overall corridor planning application) requires only a small number of vehicles to demonstrate the capability. Ten vehicles would likely suffice for this. For the travel-time related part of the application however, the Prototype would benefit from the use of more vehicles. A comprehensive picture of roadway performance is required within a targeted network, and most likely several thousand vehicles would be required. A better understanding of the required fleet size needed to effectively demonstrate the Prototype would likely be developed during the completion of the ConOps.
- ***TOC****:* This is a general operations center that impacts transportation (e.g., traffic, transit, emergency management, traveler information). The TOC must be configured to control:
  - DMS
  - Ramp Meters
  - Roadway Sensors
  - Traffic Signals.

  The following additional subsystems would provide a superior test environment, and allow more complete testing of the CMLB application:
  - HAR
  - Closed Circuit Television (CCTV)
  - Lane Control Signals.

11.4.3. Prototype Development Team

The proposed Prototype Development Team members would consist of the following:

- An ITS/traffic engineering firm with experience in traffic operations and systems integration to lead the effort.
- A state partner and/or local transportation agency partner (host site operator) with a TOC, deployed traveler information systems including DMS, and deployed roadway sensors capable of determining roadway conditions (either sensors capable of determining occupancy and speed or CCTV systems covering the majority of the test environment). The ability to interface with each element is also necessary. Essentially a local agency or state partner that has a well executed 511 system in place would make an ideal host site for the corridor planning Prototype development.
- Vehicle OEMs to build the on-board applications component (VIIC). The vehicle will need some sort of basic HMI display capability for traveler information. This capability should be part of other application development tasks as well
- VII network specialists to lead trade-offs analysis, support message delivery strategy development, and support development of any new network services required.
- Traffic engineering research specialists familiar with operational processes used in the transportation planning process, prototyping efforts to generate CMLB plans, familiar with traffic engineering theory and operations, and knowledgeable of the CMI, to revise algorithms and suggest improvements in operations.

11.4.4. Conduct the Prototype Development and Testing

The Prototype development effort would begin at the conclusion of the POC (or in early 2008) and after some initial research work was completed. The Prototype development period should be long enough to collect data on vehicles to help develop tools for understanding the corridor performance and comparing alternative corridor management plans. This likely means that the prototype would continue through 2009 and into early 2010.

11.5. Full-Scale Deployment

Full-scale deployment of the corridor management and load balancing applications will in general be linked with the penetration of VII vehicles into the marketplace. It will likely be possible to develop reasonable measurements of overall traffic conditions in a particular corridor with fairly modest VII vehicle penetration rates—thus permitting improved planning activities (this will be particularly true if "opt-in" tracking programs become prevalent or accepted). However, to the extent that the VII network and associated in-vehicle applications will be the key means of issuing suggestions/messages to motorists for modifying their routing and driving behavior, it will likely require a majority of vehicles to be equipped with VII before highly responsive and broad-based load balancing activities could take place. Further, it is likely that load balancing applications is will require significant fundamental research. Therefore limited, if any, capability to actively coordinate and balance a corridor would be available at Day-1. Both operations and planning agencies would need to get comfortable with VII and VII-based data streams well before accepting any actively managed application.

Full-Scale deployment tasks and strategies for all of the VII public sector applications are discussed in section 2.6 “Full Scale Deployment”, and, general cross-cutting issues affecting full-scale deployment are also discussed in section 3.0, “Cross-cutting issues. However, the following are selected deployment and institutional risk issues that are particularly associated with the corridor management application.

11.5.1. Policy, Liability, and Institutional Issues

“Opt-in” Programs. Deployment and acceptance of the various “opt-in” programs requires cooperation between individual drivers, vehicle OEMs, and public agencies that may be difficult to manage and implement. The opt-in programs will allow agencies to track true origin and destination patterns throughout a network and thus can be enormously useful for planning and management of the network. However, because of privacy concerns by the motoring public, the implementation of such programs will be challenging from an institutional and management perspective.

New-found capabilities for managing network flow. The current operational paradigm of most State and regional transportation management entities is centered around planning activities (including long term capacity issues, contingency management, and providing for special events). The corridor management load balancing application empowers the management entity to directly affect the performance of the roadway network through modification of traffic management devices, and to indirectly affect performance through the dissemination of traffic condition information to drivers. The ability to perhaps significantly alter the traffic flow on the roadway network in real time fashion is not the paradigm of transportation agencies today. We suspect that all-new operational models, business rules, and public policies will need to be developed that will guide (and perhaps limit) how transportation agencies utilize this newfound ability to control the roadway network.

Inter-Agency Coordination. Closely related to the above issue is the impact that VII will have on relationships between traffic management entities in adjacent roadway infrastructure facilities. The corridor management planning and load balancing applications will essentially force, or otherwise exacerbate, the need for regional transportation agencies to work together with regard to: establishing operating policies; metrics for measuring network performance; thresholds for intervening with “normal” traffic flow; and, specific tactics for balancing the network in reaction to such thresholds etc. Such cooperation is necessary so that the traffic flow intervention tactics of one agency are not in conflict with those from the adjacent agencies. It is likely that an entire new set of processes, procedures and rules will need to be developed to guide how adjacent transportation agencies will need to work together to leverage VII capabilities.

APPENDIX A. LIST OF ACRONYMS

AAM	Alliance of Automobile Manufacturers
AASHTO	American Association of State and Highway Transportation Officials
ABS	Antilock Braking System
AMI-C	Automotive Multimedia Interface Collaboration
ASTM	American Society for Testing and Materials
CA	Certification Authority
CAMP	Crash Collision Avoidance Metrics Partnership
CICAS	Cooperative Intersection Collision Avoidance Systems
CSP	Content Service Provider
DIC	DSRC Industry Consortium
DiD	Defense In Depth
DOT	Departments of Transportation
DSRC	Dedicated Short Range Communications
EDMap	Enhanced Digital Map
ENOC	Enterprise Network Operations Center
ENS	Event Notification System
ESS	Environmental Sensor Stations
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FTA	Federal Transit Administration
GHz	Gigahertz
GPS	Global Positioning System
GSA	General Services Administration
HMI	Human Machine Interface
IdAM	Identity and Access Management
IEEE	Institute of Electrical and Electronic Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act
IT	Information Technology
ITIL	Information Technology Infrastructure Library
ITS	Intelligent Transportation System
ITSM	Information Technology Service Management
IVHS	Intelligent Vehicle Highway Systems
IVI	Intelligent Vehicle Initiative
LBS	Location Based Services
MDSS	Maintenance Decision Support System
MPO	Metropolitan Planning Organization
NAP	Network Access Point
NHS	National Highway System

NHTSA	National Highway Traffic Safety Administration
NMS	Network Management System
NOC	Network Operations Center
NWS	National Weather Service
O&M	Operations and Maintenance
OBE	On Board Equipment
OBU	On Board Unit
OEM	Original Equipment Manufacturer
OSI	Open Systems Interconnection
PATH	Partners for Advanced Transit and Highways
PSAP	Public Service Answering Point
QoS	Quality of Service
RSE	Road Side Equipment
RSU	Road Side Unit
RWIS	Road Weather Information System
SAE	Society of Automotive Engineers
SDLC	System Development Life Cycle
SDN	Service Delivery Node
SNMP	Simple Network Management Protocol
SOC	Security Operations Center
SSL	Secure Sockets Layer
TEA-21	Transportation Equity Act for the 21st Century
TMC	Traffic Management Center
TOC	Traffic Operations Center
VII	Vehicle Infrastructure Integration
VPN	Virtual Private Network
VSC	Vehicle Safety Communications
U.S. DOT	U.S. Department of Transportation

APPENDIX B. TRAFFIC SIGNAL CONTROL SYSTEM OPERATION

Background on Traffic Signal Control Systems

Traffic signal control systems primarily provide a management tool for signal operators. Signal timing parameters are stored in signal control equipment located at the intersection ("local controllers"), with a copy also stored in the signal system for the convenience of the operator. Signal systems provide remote access to the local controllers and are located where convenient for the operating agency ranging from a traffic management center to the maintenance office to the office of the responsible professional. Agencies use this access to manage the local equipment, both by maintaining the timing parameters and by observing the operation of the equipment in response to complaints. This observation can be used by maintenance forces to troubleshoot potential faults. Most systems in the U.S. use control parameters ("timing plans") that are defined by engineers and stored in the local equipment and signal system for engagement as needed. The engagement of timing plans in operating signal controllers may either be based on a daily schedule or on measured traffic performance.

The timing plans themselves are traditionally developed based on historical traffic count data for each movement at an intersection, which is usually collected *ad hoc,* both manually and using temporarily installed traffic counting equipment. Operating agencies must update signal timing plans as traffic flow conditions change, but currently the practice offers little guidance on when this should be done or how to determine when conditions have deteriorated sufficiently to warrant the considerable amount of effort involved. Most agencies are constrained by resources such that systems are not updated frequently enough, and often this is because of the time and expense of collecting data and performing new optimizations based on those data.

Some advanced systems attempt to optimize the operation of traffic signals on the basis of system-gathered traffic data, using one of several optimization strategies and objectives. These optimization objectives may vary from minimizing delay to maximizing capacity or smooth flow, with both the objectives and supporting data measured in a variety of ways, as discussed further down.

Signals operate independently unless tied together into a coordinated system. Both approaches, however, use the same or similar local signal control equipment. Local signal controllers are known as "traffic-actuated signal controllers", and their operation was first standardized by the National Electrical Manufacturers Association in the 1970's. Not all current signal controllers conform to all NEMA physical standards, and some use different physical connections in the control cabinet, for example. But all of them generally follow the NEMA-defined scheme of traffic-actuated control.

The conventional traffic-actuated control approach defines the control logic for each of the separate movements of vehicles at an intersection. A signal controller manipulates *load switches,* a hardware device in the local controller cabinet that uses the signal from the controller to switch 120-volt electrical current to the signal display or displays for a particular movement of vehicles or pedestrians. . The logic in the controller that controls a load switch is called a *phase.* Because some movements through an intersection can operate concurrently without physical conflict, actuated signal controllers must also operate phases concurrently without logical conflict. For example, a through movement is compatible with the adjacent left turn but not with the opposing left turn. The rules for governing how signal controllers operate are known as *ring rules*, and are based on a physical ring concept for actuated controllers that predated the NEMA standard. NEMA controllers, however, are microprocessor-controlled devices that execute their operation in accordance with ring rules within their embedded software.

Each phase is controlled by traffic detection unless some external discipline is imposed on it. Traffic detectors are devices either embedded in the pavement or looking down on the pavement that detect the presence of vehicles in the detection zone. Typical actuated controllers have at least one detector for each movement served by a phase. A phase will not be served at all unless it is *called.* It may either be called by command from the software (using minimum recall, by declaring it a non-actuated phase, or by some other feature) or by detecting traffic on the approach lane or lanes served by that phase. Thus, detectors used for intersection signal control have a *calling* function.

Once called, the phase will be served when its turn comes up. It will remain green for some user-defined minimum time that typically ranges from five to ten seconds. Then, it will remain green for as long as vehicles are present on the detectors assigned to that phase. In this role, the detectors *extend* the phase. When a gap in traffic beyond a user-defined threshold appears, the phase will terminate as long as there is an outstanding call on a competing phase. The placement and timing of extension detectors varies widely, with different objectives for finding gaps in different situations.

The phase may also terminate as a result of reaching a user-defined maximum time period. This is not used for coordination, but rather to impose some discipline to keep an actuated controller from running too long a cycle length.

Actuated traffic signals are coordinated with each other in a network by establishing a background cycle timer. That timer starts when the main-street phases terminate, at which time all the minor phases may be served if they have been called. Each phase runs normally, unless it extends too long to stay within the design of the coordination, and which point it is forced off. The *force-off* is a point in the background cycle at which a particular phase is terminated.

Clearance intervals, which are visible as a yellow indication and a period between the end of yellow and the start of a conflicting green known as red clearance, are timed after a phase is terminated. Clearance interval methods vary, but the most common approach is calculated to provide sufficient time for the last driver who cannot safely stop to be able to go and still enter the intersection legally (i.e., while the signal is yellow, which is based on the Uniform Vehicle Code and the legal standard in most states). This approach is based on the safe stopping distance, which is assumed to be wet pavement providing a 10 ft/s/s maximum deceleration.

The relationship between signals is controlled by delaying the local background cycle timer such that it follows a master cycle timer by a user-defined amount. The master cycle timer is derived from time of day and is the same at all intersections in the coordinated system. When the master cycle timer reaches the cycle length, it restarts at zero. After a user-defined delay, the local background cycle also reaches zero. That delay is known as the *offset*.

Thus, a coordination timing pattern comprises a cycle length, a set of force-offs for all the phases at each of the coordinated intersections, and the offset at each intersection.

The pattern usually includes a range of special features and functions of which there are dozens if not hundreds available across the range of current signal controllers and systems.

Coordinated networks may be operated according to a daily schedule, according to manual control, or on the basis of measured traffic performance.

Time-Of-Day Operation

Most coordinated networks are adequately operated by a daily schedule, known as *time-of-day operation*. The schedule is based on traffic volumes collected by signal timing engineers, who then predict future peak periods that require a separate timing pattern on the basis of that historical data.

Obtaining the best operation from a system that relies on time-of-day operation requires an understanding of demand variability on a daily time scale and on a seasonal time scale or long-term trend. If the daily patterns are too variable, this approach may not provide optimal operation during all periods of the day. Equally importantly, as traffic demand varies over months and years, the patterns based on historical data will grow stale and require a new design based on a new round of data collection. Such data is usually collected manually or with automated equipment installed *ad hoc*, because detectors located for calling and extending are not ideally located for collecting the approach and turning-movement traffic volumes needed by signal timing optimization tools.
Variations in traffic demand affect not only the daily schedule, but the values in the timing patterns themselves.

In some situations, traffic is stable over the long term and good daily-schedule patterns might remain effective for many years. This is often the case in downtown areas, for example. In some situations, the growth in demand is so steep that the patterns should be updated every few months. Most agencies, however, at least check their coordinated systems annually or biannually, and most would like to update their timing plans once every 3-5 years, if resources allow it.

Most agencies provide at least three or (more typically) four signal timing patterns for use in a typical daily schedule. There is one each for the directional morning and afternoon peak periods, plus one for heavier non-directional daytime traffic and one for lighter non-directional night-time traffic. Many cities use more patterns for specialized situations, and some provide custom patterns for many scenarios to include such events as holidays, incident diversion and so on.

Traffic Responsive Operation

In some networks, daily variation is high enough so that a prediction based on historical data is not sufficiently precise. These systems use specially located and designated "system detectors" to measure the volume and detector occupancy at key locations in the network. Detector occupancy is the period of time the detection zone is occupied by a car, and is an easily measured surrogate for traffic density. Volumes and occupancies are weighted according to user-define factors, which are determined empirically for each implementation. The weighted representation of current conditions is then compared either against thresholds or against a signature in order to select the pre-engineered pattern most appropriate for those conditions. The pattern is then engaged, and the signals add or reduce time to phases in order to transition the controller into the new pattern. Transition strategies vary widely, as do approaches for setting up the thresholds or signatures and weighting values. This method of coordination has been available in some form for decades and is known as *traffic-responsive operation.*

By selecting plans on the basis of traffic conditions, traffic-responsive operation addresses demand variability on a daily scale, but it does not address long-term demand variability that affects the accuracy of the signal timing patterns themselves. It also has an operational defect in that it lags behind the condition it purports to serve. First, it must measure the conditions for a period of time, select an appropriate pattern, and then transition to it. By the time the new pattern is engaged, the traffic conditions may well have changed. A more subtle weakness is that it bases its pattern selection decision on volume and occupancy at a few locations rather than on the conditions that create driver dissatisfaction with the operation.

Agencies often develop at least as many patterns as with daily schedule operation, though traffic responsive operation can work more effectively with a collection of patterns covering the entire cycle length range in use. This allows the system to step into peak periods rather than jump into them.

The difficulty of fine-tuning the pattern-selection thresholds and the uncompelling effectiveness in many situations limits the popularity of traffic-responsive operation. Detailed statistics are not available but industry experts generally estimate that well under 10% of coordinated systems in the U.S. use traffic-response pattern selection.

Traffic Adaptive Operation

Some systems used outside the U.S. (and in the U.S. on an experimental or limited basis) do not use pre-engineered signal timing patterns. Instead, they vary coordination timings incrementally on the basis of measured conditions, and in accordance with some network objective. The changes are implemented near real time, with control decisions made every few seconds. These systems are collectively known as *traffic-adaptive.* Examples include:

- SCOOT: A British system that brings detector information to a central processor which then determines the network cycle length every few minutes and the phase lengths every few seconds. Cycle length is determined on the basis of achieving a high saturation at the busiest intersections.

- SCATS: An Australian system that is based on smaller networks that can be grouped into larger networks as their selected cycle lengths become similar. Cycle length is determined on the basis of achieving a high saturation at the busiest intersections.
- RT-TRACS: A U.S.-based commercial system that uses the Operational Program for Adaptive Control developed at the University of Massachusetts-Lowell. Cycle length is selected on the basis of achieving a high saturation at the busiest intersections.
- ACS-Lite: A current FHWA research program now reaching maturity. It uses a small collection of cycle lengths designed to resonate with the network geometry, with incremental variations in phase lengths. ACS-Lite is the only system specifically designed for implementation in U.S.-style distributed signal systems, and specifically designed to work with progression-enhancing cycle-length resonance. (Progression is when a coordinated signal system carries a platoon of vehicles through a succession of green traffic signals)

The principle advantage of adaptive control is that once the system has been calibrated, it should better track both short and long-term changes in traffic demand patterns. Studies have shown at best marginal benefits over conventional time-of-day operation, *when the patterns in the daily schedule are current.*

Most agencies have greater access to capital funds than to maintenance funds, and thus favor systems that may be more expensive up front but that require less effort to maintain in subsequent years. This is a primary goal of adaptive control—to provide a system that will follow changes in traffic demand and require much less frequent retiming or recalibration.

Some traffic adaptive systems also include a prediction algorithm, even if the prediction is made on a very short horizon as a result of measuring traffic a little farther upstream. Thus, many of the adaptive systems are best served when the detectors are located in accordance with their optimization strategy. For example, SCOOT generally requires detectors as far upstream from the intersection as possible, and the detectors are often place on the outbound legs of upstream intersections.

In practice, adaptive control has been applied in the U.S. only on a limited basis because the case for the benefits of such control have not been clearly demonstrated, in comparison with time-of-day or traffic-responsive control.

Few agencies have any means of evaluating signal system performance except by direct observation on the ground.

Some agencies use the ability of their signal systems to note when phases do not terminate as a result of gaps in traffic. If the phase must be forced off repeatedly, that is an indication that the traffic demand exceeds the allotted time (or that a detector has malfunctioned). Most systems have some mechanism for reporting that information, but it is not widely used except on an *ad hoc* basis.

Agencies with limited resources often do not evaluate their signal operation except when new timings are first installed, and instead wait for complaints from citizens to identify operational problems. In any case, evaluating signal system operation depends directly on the optimization goal of the agency.

Traffic Signal System Architecture

A key characteristic of traffic signal systems in North America is architectural diversity, and any systems designed to support signal systems must be flexibly designed to accommodate different architectural approaches. This is especially true if VII is used to support traffic-responsive pattern selection, which may be implemented in a central system or in a remote processor in different architectural configurations.

Even the most basic traffic signal systems include local traffic signal controllers. They can achieve coordinated operation on the basis of a daily schedule, and stay coordinated by the use of accurate embedded clocks in each controller. This architectural approach is known as *time-base coordination.* It provides coordination but it does not provide access by the operator to the timing parameters in the local signal controller. Nor does it allow for monitoring of the local controller equipment, which is the main motivation for building signal systems.

At the other end of the scale, systems may include a central computer or network of computers. Relatively few systems in current use in the U.S. use a central computer for controlling the phase operation at the controller, and those few systems are being replaced through attrition. Most systems with a central computer use those computers primarily to manage signal timing parameters that are stored in the local signal controllers. Considering all the phase timing parameters, phase assignment parameters, detector configuration parameters, coordination parameters, daily schedules, special features, and so on, a typical signal controller contains thousands of data elements. Most signal systems are built to facilitate maintenance of those data from a convenient location.

In some cases, an agency may not have a need for a central computer, and instead have an array of smaller systems spread over a wider area. For example, a city might have a large system with central access, but the state DOT may be responsible for some traffic signals in growth areas at the fringes of the city that are not yet incorporated. These systems are often operated by a remotely located computer, which is known as a *field master controller.* Operators usually access the field master by the use of inexpensive intermittent communications. Thus, the field master provides the connection point between the reliable fixed communications infrastructure that ties the signal controllers together and the inexpensive, low-reliability infrastructure used between the field master and the operator. In some cases, the field master may provide a means of increasing the reliability of the system by distributing processes to less vulnerable parts of the network even when a central computer system is employed.

Most field master and central computer systems are capable of coordination using pattern selection based on time-of-day, manual control, or traffic responsive operation.