

# AASHTO Connected Vehicle Infrastructure Deployment Analysis

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# Preface/ Acknowledgements

This report was developed by the American Association of State Highway and Transportation Officials (AASHTO) Connected Vehicle Working Group with support from U.S. DOT. The purpose of the report is to explore infrastructure deployment approaches and potential issues for state and local transportation agencies, primarily from a state DOT perspective. The analysis does not significantly consider the needs and interests of transit and trucking stakeholders, as these communities' visions and issues are being considered elsewhere in the ITS program in conjunction with their respective stakeholder organizations.

The AASHTO Working Group is made up of representatives of eleven state agencies, along with three local transportation agencies, and one metropolitan planning organization. Automotive representatives from the Vehicle Infrastructure Integration Consortium (VIIC), private sector equipment manufacturers, and telecommunications service providers were also invited to the Deployment Plan meetings, and they actively and constructively participated in the discussions leading to this report.

The report covers connected vehicle applications of most interest to the states, current state and local programs underway, deployment readiness in the vehicle market, aftermarket devices and communications, the magnitude of effort to upgrade the nation's signal controllers with Dedicated Short Range Communications (DSRC) capabilities, and a set of deployment scenarios with corresponding strategies and actions for the state and local transportation community.

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# List of Acronyms

<b>3G</b>	3 <sup>rd</sup> Generation Telecommunications Services
<b>AASHTO</b>	American Association of State Highway and Transportation Officials
<b>ADA</b>	Americans with Disabilities Act
<b>APS</b>	Accessible Pedestrian Signals
<b>AVL</b>	Automated Vehicle Location
<b>CICAS</b>	Cooperative Intersection Collision Avoidance System
<b>CVII</b>	Commercial Vehicle-Infrastructure Integration
<b>CVISN</b>	Commercial Vehicle Information Systems and Networks
<b>DMA</b>	Dynamic Mobility Applications
<b>DSRC</b>	Dedicated Short Range Communications
<b>DUAP</b>	Data Use, Analysis, and Processing
<b>EVP</b>	Emergency Vehicle Pre-emption
<b>FCC</b>	Federal Communications Commission
<b>FHWA</b>	Federal Highway Administration
<b>FMCSA</b>	Federal Motor Carrier Safety Administration
<b>FTA</b>	Federal Transit Administration
<b>GHz</b>	Gigahertz
<b>GPS</b>	Global Positioning System
<b>HIA</b>	DSRC-based Here-I-Am devices
<b>HOT</b>	High Occupancy Toll
<b>I2V</b>	Infrastructure-to-Vehicle Communications
<b>IRI</b>	International Roughness Index
<b>ITS</b>	Intelligent Transportation Systems
<b>MBUF</b>	Mileage-Based User Fees
<b>NCAR</b>	National Center for Atmospheric Research
<b>NCHRP</b>	National Cooperative Highway Research Program
<b>NHTSA</b>	National Highway Traffic Safety Administration
<b>NYSERDA</b>	New York State Energy Research and Development Authority
<b>OBD-II</b>	Onboard Diagnostic port
<b>OBE</b>	DSRC Onboard Equipment
<b>PDA</b>	Personal Digital Assistant
<b>PFS</b>	Cooperative Transportation System Pooled Fund Study



<b>PND</b>	Personal Navigation Device
<b>POC</b>	VII Proof-of-Concept
<b>POS</b>	Point-of-Sale
<b>QPL</b>	Qualified Product List
<b>RFID</b>	Radio Frequency Identification
<b>RSE</b>	DSRC Roadside Equipment
<b>SPaT</b>	Signal Phase and Timing
<b>TSP</b>	Transit Signal Priority
<b>U.S. DOT</b>	U.S. Department of Transportation
<b>V2I</b>	Vehicle-to-Infrastructure Communications
<b>V2V</b>	Vehicle-to-Vehicle Communications
<b>VIDAS</b>	Vehicle-based Information and Data Acquisition System
<b>VII</b>	Vehicle-Infrastructure Integration
<b>VIIC</b>	Vehicle Infrastructure Integration Consortium
<b>VMT</b>	Vehicle Miles Traveled
<b>WDT</b>	Weather Data Translator

# Executive Summary

In 2009, AASHTO prepared its IntelliDrive<sup>SM</sup> Strategic Plan. Among the specific actions identified in the plan was the need to perform an analysis of the potential approaches for deploying the infrastructure components of Connected Vehicle systems by state and local transportation agencies. The plan also called for the identification of AASHTO's role in all aspects of Connected Vehicle infrastructure deployment. This report provides the results of that analysis. The principal findings of the analysis are summarized here.

## Background

A significant body of work has been completed under the Connected Vehicle program and its predecessors. This earlier and ongoing work addresses several topics of relevance to AASHTO's Connected Vehicle Deployment Analysis that includes the following:

- Alternative deployment approaches, strategies, and scenarios have been considered over the course of the programs. Early estimates of deployment needs called for around 300,000 DSRC locations to provide initial nationwide coverage.
- Many potential applications of Connected Vehicle systems were defined during the predecessor initiatives to the current Connected Vehicle program.
- Core research, development, testing, and evaluation activities are central to the current federal Connected Vehicle program. Strategic planning and technical analyses are being undertaken jointly with two consortia of automobile manufacturers: the Vehicle Infrastructure Integration Consortium (VIIC), and the Crash Avoidance Metrics Partnership (CAMP). Together this work will inform and influence the deployment activities planned by AASHTO members.
- Several states around the country have been actively developing and deploying Connected Vehicle technologies, and their experiences were also considered in developing this report.

## Deployment Readiness: Markets and Technologies

There are many external dynamics that will affect the nature and timing of the benefits that will accrue to state and local transportation agencies and their constituents from Connected Vehicle system applications. In turn, these issues will influence the infrastructure deployment decisions of the state and local agencies. There are a number of key topics that have the potential to affect the agencies' approaches to Connected Vehicle infrastructure deployment in the coming years that includes the following:

- The scale and characteristics of light, heavy, and specialist vehicle markets, and the effects of market dynamics on the potential availability of Connected Vehicle technologies and systems
- External factors affecting the role of aftermarket devices and applications in public sector Connected Vehicle system deployments
- The options for providing data communications capabilities in Connected Vehicle systems, including a brief introduction to security and certificate management needs
- The scale, technical considerations, and potential costs of interfacing Connected Vehicle RSEs to traffic signal controllers

## Connected Vehicle Applications of Interest to Public Agencies

For this deployment analysis, it is important to understand the applications that have the greatest applicability to state and local transportation agencies. To identify which applications may best serve the interests of the state and local transportation agencies and their constituents, it is useful to examine the objectives behind any Connected Vehicle deployments by the public sector. Five objectives can be considered in the selection of applications by state and local agencies.

**Improve Safety** - Improving transportation safety has become the keystone opportunity for Connected Vehicle deployment. A recent National Highway Traffic Safety Administration (NHTSA) analysis concluded that up to 79 percent of all crashes by unimpaired drivers could potentially be addressed by V2V and V2I technology combined.<sup>1</sup>

In terms of more specific objectives, applications contributing to improved safety would, for example, create results that include the following:

- Reduce the likelihood of collisions at intersections
- Reduce the likelihood of forward and lateral (lane change and merge) collisions
- Reduce the likelihood of secondary crashes
- Reduce the likelihood of road departure crashes
- Provide more accurate and timely road condition alerts

**Enhance Mobility** - The societal economic incentives to improve mobility are well known. Traffic congestion costs the U.S. economy millions of hours and billions of dollars every year. Improved utilization of the existing infrastructure would take pressure off construction of new facilities and increase attention to rehabilitation and improved maintenance of existing facilities. Objectives contributing to enhanced mobility would include the following:

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<sup>1</sup> National Highway Traffic Safety Administration (October 2010), Frequency of Target Crashes for IntelliDrive<sup>SM</sup> Safety Systems, Washington, D.C., DOT HS 811 381, (Document prepared by the John A. Volpe National Transportation Systems Center, U.S. DOT).

- Make more efficient use of capacity (e.g., implement adaptive flow control)
- Provide more accurate and timely traveler information
- Reduce impacts of incidents on traffic flow
- Increase reliability of freight movements and transit schedules

**Reduce the Environmental Impact of Road Travel** - Current economic and global environmental conditions are turning attention to the impacts of travel on the environment. Operational objectives for reducing the environmental impacts coincide with and reinforce some of the objectives noted above. Operational objectives include the following:

- Reduce excess emissions from inefficient traffic operations that otherwise reduce mobility
- Reduce excess treatment materials (e.g., salt), further reducing costs and improving operational performance

**Facilitate Electronic Payment** - Improving the speed and accuracy of electronic payments within the transportation infrastructure could contribute to enhanced mobility and reduced cost of operations. The focus here is on those payments made to transportation agencies, but the technologies could facilitate other payments as well.

**Improve Agency Operational Performance** - Although much of the focus in Connected Vehicle discussions has been on safety and traveler benefits, the transportation agencies could benefit more directly from these deployments. Agencies could, for example, seek improvements that include the following:

- Reduce dependence on DOT traffic monitoring infrastructure
- Improve transportation asset condition monitoring
- Reduce resources needed for system maintenance
- Increase the availability of information for performance measurement

Beyond these key objectives, there are additional practical considerations that help identify the applicability of particular applications to state and local agencies. These topics help differentiate the role of the public sector versus that of the private sector in the delivery of an application. These topics include the following:

- The need for a roadside infrastructure for the successful operation of an application
- The need for access to publicly-gathered or generated data to create an effective application
- The need for devices to be installed in publicly maintained vehicle fleets for the successful operation of an application
- Access to public sector right-of-way

## Deployment Scenarios and Strategies

This plan approaches Connected Vehicle infrastructure deployment as a set of likely sequential scenarios. It recognizes that technologies and events will continue to impact agency operations even without intentional decisions on the part of those agencies. The focus is on articulating the needs of the agencies and anticipating the context in which agencies will make specific deployment decisions.

The scenarios describe the progressive deployment of Connected Vehicle systems out to a twenty-year horizon. They start with an assessment of the current state, touching on key drivers and activities. Each step in time corresponds to a new deployment goal—a particular emphasis for that phase of development. Anticipated external events and policy decisions are also identified, and the most likely arc of technology developments is projected from the current state.

As a general guiding principle, the scenarios assume that public agencies will be motivated to deploy the field infrastructure for Connected Vehicle systems to achieve near-term benefits from applications that enhance mobility, provide localized safety improvements, or enhance the operational performance of the agency in some manner. Public agencies will deploy DSRC field infrastructure in recognition of its long-term value in Connected Vehicle active safety applications, but will leverage that investment to support a variety of applications in the near-term.

NHTSA plans to make two decisions relating to DSRC deployment. The first will be for light vehicles in 2013, and the second will be for heavy vehicles in 2014. NHTSA is not calling this a regulatory decision, but rather an “Agency” decision, and has committed to analyzing research results between now and then to determine whether or not subsequent action is merited. Subsequent action could include a rulemaking to require V2V safety equipment in vehicles. However, action could take many forms, with rulemaking being only one option.

For the purposes of this report, the scenarios assume that NHTSA will, in some fashion, decide to move forward with a requirement to mandate factory-installed DSRC equipment on-board both light and heavy vehicles. Assuming this happens, prior experience would suggest that on-board equipment (OBE) will first appear in newly-manufactured light vehicles for the 2020 model year, rolling out in 2019.

This timing assumption has a major influence on the deployment approach presented in the scenarios. While it can be said that the benefits to drivers of OBE-equipped passenger cars and heavy vehicles will increase as the deployment of RSEs increases, it is also true that there are no benefits to the deployers of RSEs if there are no OBE-equipped vehicles with which to communicate. Therefore, in order to encourage near-term deployment of DSRC roadside infrastructure, the state and local agencies must pursue approaches that do not rely on the presence of a growing population of factory-equipped passenger vehicles before the end of the current decade.

The scenarios address this problem by placing early deployment emphasis in the following areas:

- Focus on the deployment approaches and appropriate applications that meet the needs of potential early deployers, such as commercial vehicles, transit vehicles, and emergency and public safety vehicles.
- Focus on the deployment approaches and appropriate applications that can satisfy operational objectives of an agency and can be met by using equipped vehicles that are

controlled by the agency, such as agency fleet vehicles, maintenance vehicles, and other specialized vehicles.

- Focus on applications that are of interest or importance to agencies and where the end users have a strong incentive to obtain the necessary devices to participate. These may include location-specific safety applications or fee collection applications.
- Focus on approaches that lead to the early deployment of retrofit, aftermarket, and other consumer devices that operate within Connected Vehicle systems and emphasize applications that are of interest to state and local agencies and that will function effectively with these devices.

The scenarios begin with a focus on activities that will provide benefits directly to the state and local agencies and their customers and therefore give an initial incentive to start infrastructure deployment. However, the scenarios also support AASHTO's dual roles of leadership and partnership in the national Connected Vehicle program, as defined in the 2010 AASHTO Strategic Plan. As such, the scenarios identify a number of activities that are most effectively accomplished through collaboration between AASHTO, the carmakers, and U.S. DOT.

It is recognized that work currently underway or planned by U.S. DOT will affect the infrastructure deployment decisions and approaches taken by the state and local agencies. Therefore, the scenarios seek to provide ways in which AASHTO and its members can effectively support, participate, and influence these activities as appropriate. In particular, the scenarios assume that state and local agencies will favor deployment approaches that provide compliance with a national Connected Vehicle system architecture and national standards.

The deployment scenarios are used to formulate specific strategies and actions to be undertaken by AASHTO and its members to achieve broad Connected Vehicle infrastructure deployment. Key activities include the following:

- Develop a General Concept for Deployment that begins with identification of the specific systems and associated applications that should be deployed; the remaining research and development needs for these systems; and a general geographic phasing of deployment. Initial focus will be placed on Connected Vehicle freight, Emergency Vehicle Priority (EVP), Transit System Priority (TSP), enhanced agency operational activities, and isolated safety applications using DSRC.
- Establish an Information Exchange Forum that will monitor relevant U.S. DOT activities (e.g., pilot tests, application development, reference implementation activities), conduct briefing and discussion sessions with members, and provide advice memoranda to U.S. DOT.
- Establish a task force to address the relationship between Connected Vehicle systems and traffic signal control systems, including the development of relevant applications, RSE siting and interface issues, recommendations for deployment of RSEs during regular signal upgrades, development of appropriate standards and specifications, deployment guidance needs, and outreach and education needs.
- Encourage U.S. DOT and the VIIC to join with AASHTO and establish the appropriate forum through which the three parties can explore the resolution of governance, liability, security, and privacy issues.

- To broaden awareness across the entire AASHTO membership and possibly local agencies, develop a plan for a Connected Vehicle Education and Outreach Program, including the initiation of scanning tours to states with programs that are well-advanced.
- To prepare for initial infrastructure deployments by the state and local agencies, establish a task force to begin work on the development of a national footprint plan for DSRC RSE infrastructure, building on and continuing support of ongoing state efforts.
- To support the implementation of the General Concept of Deployment and the national 5.9 GHz DSRC footprint, begin development of policies that would encourage AASHTO members to adopt recommended Connected Vehicle freight corridors, begin migration from existing commercial vehicle screening technologies to DSRC, and support the minimum desired deployment levels of DSRC.
- Assess the need and provide recommendations on the development of formal Connected Vehicle Infrastructure Design Guidelines.
- Develop a national funding strategy, collaborating with other partners as appropriate.

## Policy and Business Considerations

The report concludes with a set of issues that could be considered by the AASHTO leadership for policy action. These issues include the following:

- Providing leadership in certain national program areas, particularly those that accelerate resolution of outstanding governance, liability, security, and privacy issues.
- Assuring the availability of 5.9 GHz DSRC licenses to state and local transportation agencies for Connected Vehicle systems and applications.
- Encouraging state DOTs to support the migration of existing commercial vehicle electronic preclearance and screening technologies to 5.9 GHz DSRC and the designation of priority freight corridors for early deployment.
- Encouraging AASHTO members to commit to the minimum levels of DSRC infrastructure deployment identified in the national footprint plan.

# Purpose

In March 2009, the American Association of State Highway and Transportation Officials (AASHTO) completed a Connected Vehicle Strategic Plan that articulated the commitment and the role of AASHTO and its members in the national Connected Vehicle program. The Strategic Plan described areas of leadership for AASHTO in the national program, as well as activities that would be best accomplished through collaboration and partnership with the federal government and the carmakers. In addition to strategic themes, the plan described a set of actions required to prepare the state and local transportation agencies for the development, deployment, and operations of Connected Vehicle infrastructure and systems. One of the identified actions was to conduct a deployment analysis to provide insights and direction on what approaches would be practical for infrastructure deployment; what the vehicle, communications infrastructure and application environment would look like in the future; and the advantages and challenges of a phased infrastructure deployment approach by the agencies.

The purpose of this Deployment Analysis is to advance the thinking and provide ideas that the state and local agencies can advance within their institutions to support infrastructure deployment. The analysis will also provide state and local agency perspectives to the U.S. Department of Transportation (U.S. DOT) as input to current and planned Connected Vehicle program initiatives, including any potential decisions planned by NHTSA surrounding V2V technology on light vehicles in 2013 and heavy vehicles in 2014.

The results of the analysis describe the current state of relevant development and deployment efforts; the readiness of technologies and markets to support Connected Vehicle system deployments; the applications of Connected Vehicle systems that are of greatest significance to the state and local agencies; a viable, phased deployment scenario for the agencies based on a set of key observations and assumptions; and a set of potential strategies and actions to be undertaken by AASHTO and its members to advance Connected Vehicle system deployments.



# Background

A significant body of work has been completed under the Connected Vehicle program and its predecessors. This earlier and ongoing work addresses several topics of relevance to AASHTO's Connected Vehicle Deployment Analysis. This section provides summaries of key documented topics that may influence the approach and findings of this study. It is intended to be a foundation for the subsequent sections of this report, not an exhaustive review of previously-published documents. In particular, this background seeks to describe existing work in the following areas:

- Alternative deployment approaches, strategies, and scenarios that have been considered over the course of the earlier programs
- Applications that have been defined for the Connected Vehicle predecessor programs, specifically identifying those that have been defined as “public sector” applications
- The current emphasis and direction of the national Connected Vehicle program and recent work of the Vehicle Infrastructure Integration Consortium (VIIC) that may influence deployment activities undertaken by AASHTO members
- Connected Vehicle efforts currently underway among AASHTO members

## Deployment Strategies to Date

Over the course of the Connected Vehicle program and its predecessors, several pieces of work have been performed to address the scale and approaches for Connected Vehicle deployment. A recent white paper from U.S. DOT<sup>2</sup> describes the premise of the original approach to the Vehicle-Infrastructure Integration (VII) initiative that provides the basis for the earliest discussions of a deployment strategy. The white paper explains that vehicle-to-vehicle (V2V) communications could provide the greatest safety gains but it would take time to equip all cars, trucks, and buses to achieve these benefits and could potentially result in approximately \$44 billion in safety benefits. The addition of communications between in-vehicle equipment and a roadside infrastructure (vehicle-to-infrastructure or V2I communications) would allow some safety benefits of VII to be generated more quickly and would incentivize in-vehicle equipment deployments.

In addition, the original VII approach assumed that dedicated short range communications (DSRC) operating at 5.9 GHz would be required for all V2V and V2I communications. While the Federal Communications Commission (FCC) had allocated the spectrum for safety applications, it allowed unused bandwidth to be applied to other uses, including those for mobility and convenience applications. Early assessments suggested that safety applications would not consume the entire available bandwidth, and, therefore, the program proceeded with an assumption that both safety and

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<sup>2</sup> U. S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office, “Achieving the Vision: From VII to IntelliDrive<sup>SM</sup>. Policy White Paper,” April 30, 2010.

non-safety applications would be supported through this nationwide network of DSRC equipment. The VII Concept of Operations<sup>3</sup> identifies an additional requirement for the implementation of this network: A coordinated deployment of the in-vehicle DSRC equipment by the automotive industry and the roadside infrastructure on all major U.S. roadways by the public sector.

This retrospection helps provide context to the deployment assumptions that were developed during the VII program. The original VII Concept of Operations laid out a phased VII deployment approach. This approach assumed a period of pre-deployment planning and testing, leading to a go/no go decision on VII deployment taking place in 2008. Beyond that date, deployment would have proceeded in two phases.

Phase 1 would have provided a core level of VII infrastructure deployment necessary to enable so-called “Day One” applications (described later in this report). The goal of Phase 1 was to provide infrastructure covering half of signalized intersections in the 50 largest U.S. metropolitan areas. In addition, metropolitan freeways and Interstate highways would have been covered, as well as rural Interstate highways, but at a lower density of infrastructure than in urban areas.

Phase 2 would have begun in 2012 to coincide with the assumed date at which vehicle manufacturers would have begun rolling out VII-equipped vehicles. At this time the public would have been able to use the defined Day One applications. During Phase 2, the VII infrastructure would have been expanded to cover all 452 urbanized areas with a population of 50,000 or greater. Phase 2 would have seen approximately 70 percent of the nation’s signalized intersections added to VII infrastructure, as well as additional rural highways.

Subsequent analyses<sup>4,5</sup> defined the scale of the required nationwide VII infrastructure deployment, as shown in Table 1.

RSE Location		Estimated # of Sites		
Urban	Arterial Traffic Signal	210,000	235,000	252,000
	Arterial (no signal)	0		
	Highway/Freeway/Interstate	25,000		
Rural	Interstate/Other NHS Routes	17,000	17,000	

**Table 1: Estimated Size of a Nationwide VII Infrastructure Deployment**

The 2008 benefit-cost analysis also noted an adjusted infrastructure deployment period from 2011 to 2015, consistent with an assumed decision point in 2010. The “Achieving the Vision” white paper published in 2010 appears to utilize a slightly modified analysis of the scale of infrastructure deployment by referring to “approximately 300,000 roadside equipment units ... needed to support initial applications at a nationwide scale.”

<sup>3</sup> U.S. Department of Transportation, Federal Highway Administration, “Vehicle Infrastructure Integration (VII) Concept of Operations. Version 1.2.” September 2006 (Prepared by Booz Allen Hamilton).

<sup>4</sup> U.S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office, “VII Life Cycle Cost Estimate.” April 2007.

<sup>5</sup> U.S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office, “VII Initiative Benefit-Cost Analysis. Version 2.3 (Draft).” May 8, 2008 (Prepared by the John A. Volpe National Transportation System Center, U.S. DOT).

An unpublished document circa 2007 indicates the start of some work on developing alternative deployment options. The set of alternatives considered comprised the following:

- Big Bang
- Urban then Rural
- Interstates, NHS, Arterial;
- By Function – Easiest First
- By Function – Safety First

Since the document was not published, this material will not be discussed further here. However, a more comprehensive development of Connected Vehicle deployment scenarios incorporating some of these themes from the federal perspective<sup>6</sup> was presented to the broader Connected Vehicle community for comment in late June 2010.

These newer deployment scenarios reflected the shift in thinking that has occurred between the initial VII initiative and its successor programs relating to the core wireless communications technologies that support V2V and V2I connectivity. During the VII initiative both V2V and V2I required the use of DSRC equipment operating at 5.9 GHz in the vehicle and the infrastructure. During the course of the VII program, wireless technology and mobile communications devices proliferated, and telecommunications providers expanded bandwidth through 3<sup>rd</sup> generation (3G) services to support high-speed transmission of text, voice, and video data. The subsequent Connected Vehicle programs, beginning in 2009, continue to emphasize DSRC, with its high-speed, low-latency, secure data communications capability, for V2V and V2I safety applications, but acknowledge the potential of other communications approaches for non-safety applications, including mobility applications.

With this background, the newer deployment scenarios were intended to present a range of possible futures. The scenarios focused on the role of the federal government in program development and deployment (the roles of state and local governments, and other partners were not explicitly addressed in the first round of scenario development) and were policy oriented in nature.

Four deployment scenarios were initially identified:

- Full Throttle – This scenario is most similar to the predominant deployment view developed during the VII initiative. This scenario assumed that U.S. DOT commits to the deployment of a DSRC-based infrastructure within the next 1-2 years and actively works with state agencies to develop deployment plans. The scenario also assumed a positive outcome to current federal research activities leading to NHTSA's actions to pursue DSRC-equipped vehicles in 2013 and 2014. The scenario further assumed that vehicle manufacturers would begin developing DSRC capabilities in advance of the any NHTSA decisions, allowing the first DSRC-equipped new vehicles to become available in late 2016.

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<sup>6</sup> U.S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office, "IntelliDrive<sup>SM</sup> Deployment Scenarios," June 17, 2010 (Prepared by Pinyon Labs, LLC.).

- Safety Net – This scenario assumed that U.S. DOT focuses on safety applications using DSRC for V2V communications. The scenario assumed that essentially no funding would be available for infrastructure deployment. With this premise, U.S. DOT was assumed to spend the next two to three years assessing the benefits of V2V DSRC in support of possible NHTSA actions; and developing stakeholder support (including state agencies and vehicle manufacturers).
- Proving Ground – This scenario assumed that U.S. DOT remains focused on the use of DSRC to provide V2V and V2I Connected Vehicle capabilities but that funding for a large-scale deployment would not become available for at least 10-15 years. In the meantime, the private sector will have implemented Connected Vehicle applications using existing wireless communications networks. (No mention is made in the scenario description of the likelihood of the state and local agencies similarly deploying applications using other wireless networks which would seem to be a possibility.)
- Facilitator – This scenario assumed that U.S. DOT is unable to prove the safety benefits of V2V DSRC and cannot justify any NHTSA actions to advance DSRC-equipped light or heavy vehicles. The scenario also assumed that funding is not available for a large-scale infrastructure deployment. Instead, U.S. DOT would take a broad view of vehicle connectivity without focus on DSRC, and would emphasize near-term deployment efforts that can achieve desirable outcomes within the constraints of the available funding, technologies, and infrastructure.

In addition to the scenario descriptions, the report contains two tables describing items of relative certainty and items of relative uncertainty<sup>7</sup>. These two tables are thought provoking and highlight some key issues that will be relevant to the development of deployment scenarios for AASHTO and the state and local agencies.

The scenarios were presented to a broad stakeholder community at a public workshop, including representatives of state and local transportation agencies, on June 22-23, 2010. Pinyon Labs subsequently reported that the stakeholders generally rejected the Full Throttle, Proving Ground, and Facilitator scenarios, and instead favored something close to Safety Net but with the incorporation of infrastructure elements for both active safety and mobility applications.

The result of the stakeholder review has been the development of a Quick Wins scenario<sup>8</sup>. Quick Wins envisions a series of locally-driven deployments beginning in the next 3 to 5 years in response to operational needs, the availability of technologies, and the readiness of state and local agencies to begin their adoption. The Quick Wins scenario suggests that deployments will expand quickly as peer deployers learn from one another. The scenario envisions early deployments in four application areas: data capture and management; fleet management; intersection management; and commercial vehicle clearance, control, and enforcement. The Quick Wins scenario further envisions four candidate groups taking responsibility for the early deployment activities: state and local DOTs; transit agencies; public safety agencies; and agencies responsible for commercial vehicle operations.

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<sup>7</sup> *ibid.* Table 7: Relative certainties for IntelliDrive<sup>SM</sup> deployment scenarios and Table 8: Relative uncertainties for IntelliDrive<sup>SM</sup> deployment scenarios.

<sup>8</sup> U.S. Department of Transportation, Research and Innovative Technologies Administration, ITS Joint Program Office, "Quick Wins, Connected Vehicles Deployment Scenario. A grassroots approach to safer roads, greater mobility, and cleaner air," Draft Report – January 28, 2011 (Prepared by Pinyon Labs, LLC and Noblis, Inc.).

## Historical Context for Connected Vehicle Applications

This section provides historical context to the early identification and development of Connected Vehicle applications. It provides background information on potential applications of Connected Vehicle systems that are considered in more detail in later sections of this report. Specifically:

- The section on *The Case for Infrastructure Deployment* provides a more thorough assessment of applications that may have the greatest interest and benefit to state and local transportation agencies at the present time.
- The *Deployment Scenarios* describe the role of particular applications in incentivizing and demonstrating the benefits of deployment.

The definition of key applications of VII data was a significant activity from the very beginning of the initiative. The VII Concept of Operations<sup>9</sup> identified a very comprehensive list of potential applications that would be developed by either the public sector or the automakers (see Table 2 below). The Concept of Operations noted that application development would be spread among a variety of public and private entities. The development model would be one that best suits the needs of the specific application developer. The report also suggests that applications which are uniquely in the public interest would likely be developed through partnerships between the federal and state governments and research institutions. In that model, sponsored research into processes and algorithms would be undertaken until operating agencies could be confident of successful deployment.

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<sup>9</sup> U.S. Department of Transportation, Federal Highway Administration, "Vehicle Infrastructure Integration (VII) Concept of Operations. Version 1.2." September 2006 (Prepared by Booz Allen Hamilton).

LOCAL USE CASES	NETWORK USE CASES
<ul style="list-style-type: none"> <li>• Infrastructure-based Signalized Intersection Violation Warning</li> <li>• Infrastructure-based Signalized Intersection Turn Conflict Warning</li> <li>• Vehicle-based Signalized Intersection Violation Warning</li> <li>• Infrastructure-based Curve Warning</li> <li>• Highway Rail Intersection-</li> <li>• Emergency Vehicle Preemption at Traffic Signal</li> <li>• Emergency Vehicle at Scene Warning</li> <li>• Transit Vehicle Priority at Traffic Signal</li> <li>• Stop Sign Violation Warning</li> <li>• Stop Sign Movement Assistance</li> <li>• Pedestrian Crossing Information at Designated Intersections</li> <li>• Approaching Emergency Vehicle Warning</li> <li>• Post Crash Warning</li> <li>• Low Parking Structure Warning</li> <li>• Wrong Way Driver Warning</li> <li>• Low Bridge Warning</li> <li>• Emergency Electronic Brake Lights</li> <li>• Visibility Enhancer</li> <li>• Cooperative Vehicle-Highway Automation System</li> <li>• Pre-Crash Sensing</li> <li>• Free-Flow Tolling</li> <li>• Cooperative Glare Reduction</li> <li>• Adaptive Headlight Aiming</li> <li>• Adaptive Drivetrain Management</li> <li>• GPS Correction</li> <li>• In-vehicle Signage <ul style="list-style-type: none"> <li>- Work Zone Warning</li> <li>- Highway/Rail Intersection Warning</li> </ul> </li> <li>• Vehicle-to-Vehicle <ul style="list-style-type: none"> <li>- Cooperative Forward Collision Warning</li> <li>- Cooperative Adaptive Cruise Control</li> <li>- Blind Spot Warning</li> <li>- Blind Merge Warning</li> <li>- Highway Merge Assistant</li> <li>- Cooperative Collision Warning</li> <li>- Lane Change Warning</li> <li>- Road Condition Warning</li> <li>- Road Feature Notification</li> </ul> </li> <li>• Rollover Warning (see curve warning above)</li> <li>• Instant Messaging</li> <li>• Driver's Daily Log</li> <li>• Safety Event Recorder</li> <li>• Icy Bridge Warning</li> <li>• Lane Departure-inadvertent</li> <li>• Emergency Vehicle Initiated Traffic Pattern Change</li> <li>• Parking Spot Locator</li> <li>• Speed Limit Assistant</li> </ul>	<ul style="list-style-type: none"> <li>• Vehicles as Probes <ul style="list-style-type: none"> <li>- Traffic information</li> <li>- Weather data</li> <li>- Road surface conditions data</li> </ul> </li> <li>• Crash Data to Public Service Answering Point</li> <li>• Crash Data to Transportation Operations Center</li> <li>• Advance Warning Information to Vehicles</li> <li>• Electronic Payment <ul style="list-style-type: none"> <li>- Toll collection</li> <li>- Gas payment</li> <li>- Drive-thru payment</li> <li>- Parking lot payment</li> </ul> </li> <li>• Public Sector Vehicle Fleet/Mobile Device Asset Management</li> <li>• Commercial Vehicle Electronic Clearance</li> <li>• Commercial Vehicle Safety Data</li> <li>• Commercial Vehicle Advisory</li> <li>• Unique Commercial Vehicle Fleet Management</li> <li>• Commercial Vehicle Truck Stop Data Transfer</li> <li>• Low Bridge Alternate Routing</li> <li>• Weigh Station Clearance</li> <li>• Cargo Tracking</li> <li>• Approaching Emergency Vehicle Warning</li> <li>• Emergency Vehicle Signal Preemption</li> <li>• SOS Services</li> <li>• Post Crash Warning</li> <li>• In-vehicle AMBER Alert</li> <li>• Safety Recall</li> <li>• Just-in-Time Repair Notification</li> <li>• Visibility Enhancer</li> <li>• Cooperative Vehicle-Highway Automation System</li> <li>• Cooperative Adaptive Cruise Control</li> <li>• Road Condition Warning</li> <li>• Intelligent On-Ramp Metering</li> <li>• Intelligent Traffic Flow</li> <li>• Adaptive Headlight Aiming</li> <li>• Adaptive Drivetrain Management</li> <li>• Enhanced Route Guidance and Navigation <ul style="list-style-type: none"> <li>- Point of Interest Notification</li> <li>- Food Discovery and payment</li> <li>- Map Downloads and Updates</li> <li>- Location-based shopping/advertising</li> <li>- In-route Hotel Reservation</li> </ul> </li> <li>• Traffic Information <ul style="list-style-type: none"> <li>- Work Zone Warning</li> <li>- Incident</li> <li>- Travel Time</li> </ul> </li> <li>• Off-Board Navigation</li> <li>• Mainline Screening</li> <li>• On-Board Safety Data Transfer</li> <li>• Vehicle Safety Inspection</li> <li>• Transit Vehicle Data Transfer (gate)</li> <li>• Transit Vehicle Signal Priority</li> <li>• Emergency Vehicle Video Relay</li> <li>• Transit Vehicle Data Transfer (yard)</li> <li>• Transit Vehicle Refueling</li> <li>• Download Data to Support Public Transportation</li> <li>• Access Control</li> <li>• Data Transfer <ul style="list-style-type: none"> <li>- Diagnostic Data</li> <li>- Repair-Service Record</li> <li>- Vehicle Computer Program Updates</li> <li>- Map Data Updates</li> <li>- Rental Car Processing</li> <li>- Video/Movie downloads</li> <li>- Media Downloads</li> <li>- Internet Audio/video</li> </ul> </li> <li>• Locomotive Fuel Monitoring</li> <li>• Locomotive Data Transfer</li> <li>• Border Crossing Management</li> <li>• Stolen Vehicle Tracking</li> </ul>

**Table 2: Initial List of Potential VII Applications**

Following the initial definition of use cases, efforts continued to refine and prioritize the list, with a set of Day-1 applications being selected by the VII Working Group in June 2005. Day-1 applications were those that were of high priority to stakeholders and that would be available after the first phase of

infrastructure deployment, when vehicles would begin to be available with VII equipment. The Day-1 use cases published in 2005 are shown in Table 3.

Day -1 Use Case
Emergency Brake Warning
Traffic Signal Violation Warning
Stop Sign Violation Warning
Curve Speed Warning
In-Vehicle Signage: Local Notifications
Traffic Information: Traveler Information
Electronic Payments: Gasoline Purchases
Electronic Payments: Parking Fees
Electronic Payments: Toll Roads
In-Vehicle Signage: Regional Road Advisories
Traffic Information: Vehicle Route Redirection
Roadway Condition: Weather
Roadway Condition: Potholes
Traffic Management: Corridor Management
Traffic Management: Ramp Metering
Traffic Management: Signal Timing Optimization
Traffic Management: Winter Maintenance

**Table 3: VII Day-1 Use Cases**

An important component of the VII initiative was an effort to develop and test a VII Proof-of-Concept (POC), the results of which would support a deployment decision. For the POC, a refined list of applications was identified, as shown in Table 4<sup>10</sup>. These applications were intended to be developed in prototype form to test basic, technical functionality of the VII system. These POC applications would not demonstrate the effectiveness or end user value of the identified applications. Ultimately, given the limitations regarding the scope of the tests—POC testing included fewer than 30 vehicles and represented only light passenger vehicles—testing focused on evaluation of message exchange between partially developed “stub” applications, using draft DSRC standards<sup>11</sup>.

<sup>10</sup> U.S. Department of Transportation, Federal Highway Administration, “VII POC Applications Concept of Operations. Version 1.4,” January 2007 (Prepared by Booz Allen Hamilton and the VII Consortium).

<sup>11</sup> U. S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office, “Achieving the Vision: From VII to IntelliDrive<sup>SM</sup>. Policy White Paper,” April 30, 2010.

POC Application Name	Public or Private Lead
Traveler Information	Public
In-Vehicle Signage	Private
Off-Board Navigation	Private
Electronic Payments: Parking	Private
Electronic Payments: Gasoline	Private
Electronic Payments: Toll Roads	Private
Signal Timing Optimization	Public
Ramp Metering	Public
Pothole Detection	Public
Weather Information	Public
Corridor Management: Planning Assistance	Public
Corridor Management: Load Balancing	Public
Emergency Electronic Brake Light	Private
Traffic Signal Violation Warning	Private
Stop Sign Violation Warning	Private
Curve Speed Warning	Private

**Table 4: POC Applications**

## U.S. DOT Connected Vehicle Program

According to U.S. DOT's ITS Strategic Research Plan<sup>12</sup>, the Connected Vehicle program is the centerpiece of the ITS program's research. The Connected Vehicle program comprises a number of individual tracks addressing applications, technology issues, and policy and institutional issues. Associated with these tracks are "road maps" that lay out U.S. DOT's planned research activities.

A number of key activities emerge from the road maps and associated research activities that may affect deployment activities by the state and local DOTs. The following summarizes these key activities.

### Safety Program

The safety program includes both the V2V and V2I safety activities. Central to U.S. DOT's program in this area are activities that will support NHTSA in making a decision in 2013 to potentially take actions to encourage deployment of DSRC devices in light vehicles, and heavy vehicles in 2014. Early efforts in this respect include a 2009 NHTSA study to quantify the frequency of crashes that can be addressed with Connected Vehicle safety systems using V2V or V2I communications<sup>13</sup>. A second study in 2010 documented that in situations where V2V systems are the primary countermeasure, these systems can potentially prevent 79 percent of all crashes involving unimpaired drivers (i.e., those that do not involve a drunk or drowsy driver). This would account for more than 4.4 million

<sup>12</sup> U.S. DOT, Research and Innovative Technology Administration (January 2010). *ITS Strategic Research Plan, 2010-2014. Executive Summary*. Washington, D.C.

<sup>13</sup> Najm, W.G. "Target Crashes for IntelliDrive<sup>SM</sup> Safety Technology." U.S. DOT Volpe Center, prepared for NHTSA, June 19, 2009.



police-reported crashes involving at least one light-vehicle, based on average annual figures for a four-year period covering 2005-2008.<sup>14</sup>

A subsequent analysis performed for the Federal Highway Administration (FHWA) Office of Safety R&D<sup>15</sup> of V2I communications for Connected Vehicle safety applications is of particular significance to this project. The findings of this study are described in greater detail in the section of this report on *The Case for Infrastructure Deployment*. These findings, together with discussions between FHWA personnel and AASHTO Connected Vehicle Working Group members, form the basis for identifying V2I safety applications that are of greatest interest and potential benefit to state and local transportation agencies.

A significant component of the U.S. DOT Connected Vehicle safety track is the Safety Pilot. This activity will comprise several components including the following:

- Device development – involving the creation of Qualified Product Lists for Here-I-Am (HIA) devices; aftermarket safety devices; and roadside equipment (RSE)
- Driver clinics – that will introduce members of the general public to vehicle-embedded safety systems and determine their reaction to those systems
- A Model Deployment that will:
  - demonstrate V2V and V2I safety applications in a real-world environment using multiple vehicle types (light and heavy vehicles and buses);
  - collect data in support of the NHTSA 2013 and 2014 agency decisions;
  - assess the ability to accelerate safety benefits through HIA, aftermarket, and retrofit devices;
  - evaluate the scalability, security, and interoperability of devices using DSRC; and
  - test the use of Signal Phase and Timing (SPaT) messages in V2I safety applications.
- A Model Deployment evaluation

The Safety Pilot Model Deployment will be conducted using sixty integrated light vehicles, two to three integrated heavy vehicles, and three transit vehicles with retrofit devices, plus a pool of 2,500 to 3,000 light vehicle volunteer drivers using either HIA or aftermarket safety devices. The test will involve twelve signalized intersections capable of transmitting SPaT data to an RSE. The Safety Pilot program was initiated in 2010 and will extend into 2014.

## Mobility Program

Key components of the mobility program are the Real-Time Data Capture and Management Program and the Dynamic Mobility Applications Program. The Data Capture and Management Program is

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<sup>14</sup> National Highway Traffic Safety Administration (October 2010), *Frequency of Target Crashes for IntelliDrive<sup>SM</sup> Safety Systems*, Washington, D.C., DOT HS 811 381, (Document prepared by the John A. Volpe National Transportation Systems Center, U.S. DOT).

<sup>15</sup> U.S. Department of Transportation, Federal Highway Administration (June 2010). *Crash Data Analyses for IntelliDrive<sup>SM</sup> Vehicle-Infrastructure Communications for Safety Applications*. Washington, D.C. (Document prepared by Vanasse Hangen Brustlin, Inc.)

focused on the creation and expansion of access to high-quality, real-time, multi-modal data from Connected Vehicles, which in turn can be used to enhance current transportation operations and management practices.

Dynamic Mobility Applications (DMA) focus on providing transportation agencies and others with real-time monitoring and management tools based on V2I connectivity. The development of DMAs within the federal program should be of strong interest to state and local DOTs and is considered in the development of the deployment scenarios in this project.

In 2010, U.S. DOT issued a call for mobility application concepts and, between May and October, 93 ideas were received. These were consolidated into 33 application concepts that were presented to the Connected Vehicle community in December 2010. High priority mobility applications were identified by U.S. DOT in January 2011<sup>16</sup> in the following areas:

- Arterial applications
  - Safety messages between mobile devices and the infrastructure for enhanced pedestrian signal operations
  - Safety messages via DSRC combined with transit vehicle data for enhanced transit signal priority
  - An over-arching control applications that coordinates these and other signal control applications for optimized arterial operations
- Freeway applications
  - V2V safety messages via DSRC to enhance speed harmonization through integration with in-vehicle adaptive cruise control technologies
  - Warnings to drivers of unexpected queues
  - A cluster of applications relating to response, emergency staging and communications, uniform management, and evacuation
- Regional (information) applications
  - Advanced traveler information applications enabled through the provision of integrated, multi-source, multi-modal data
  - Freight-related information applications, including freight-specific route guidance and coordinated load management to reduce empty-load trips
- Corridor (control) applications
  - Optimization of integrated transit operations, including passenger connection protection, transit dispatching, and dynamic ridesharing
  - System-wide integration of enhanced operational practices and information services to optimize corridor mobility

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<sup>16</sup> U.S. DOT, Research and Innovative Technologies Administration, "Mobility Applications Program. High Priority Applications and Development Approach." Document reference FHWA-JPO-11-053, January 2011.

The development of selected mobility applications is anticipated to take place through the Cooperative Transportation Systems Pooled Fund Study (PFS), as well as other procurement mechanisms.

## Policy Program

U.S. DOT has prepared a Policy Road Map for V2V and V2I safety<sup>17</sup>. The Policy Road Map covers a number of topics. Policy issues that are of most significance to this deployment analysis are highlighted below:

- Device and Equipment Certification - provides a process that ensures that all devices and equipment in the Connected Vehicle system meet specific criteria relating to security, performance, and privacy. State and local agencies will need to understand these criteria and how to specify, within their procurements, the appropriately certified devices and equipment.
- Certificate Authority, Privacy, and Security - A certificate authority is an entity that issues digital certificates that validate that the person, vehicle, organization, or other entity looking to access the system is a legitimate user. Certificates will need to be incorporated onto vehicles and into nomadic devices, and may also be needed as part of roadside equipment.
- Risk Allocation and Liability/Data Ownership.
- Cost-Benefit Analyses in Support of NHTSA Agency decisions.
- Rules of Operation and Application of Standards - provide consistency (especially across jurisdictions) and interoperability (especially across different vehicle makes and models) in a nationwide system.
- Spectrum Analysis and FCC Role - it will be crucial to understand how the 5.9 GHz spectrum will be allocated and managed, as well as the process by which different entities will be able to license the spectrum.
- Infrastructure – Connected Vehicle safety systems will include both V2V and V2I interactions. For V2V, there needs to be a determination regarding whether and what type of infrastructure will be required for security and certificate authority processes. For V2I, there are a number of safety applications that will require infrastructure. From a policy perspective, there are numerous issues regarding funding, deployment, and maintenance of infrastructure that are similar to other ITS infrastructure issues but may need to be tailored to meet the needs of a multi-jurisdictional system.
- Governance Structure and Authority - A governance structure defines the type and level of authorities needed for V2V and V2I deployment, system operations, and enforcement, and defines the roles and responsibilities of the players engaged in the system.

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<sup>17</sup> U.S. DOT, Research and Innovative Technology Administration. "Policy Road Map for IntelliDrive<sup>SM</sup> Safety: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I), Draft: 05/19/2010.

## VIIC Activities

Select activities planned or performed by the VIIC are also important to AASHTO and the state and local agencies. The VIIC Strategic Plan 2010-2013<sup>18</sup> cites the need for collaboration with AASHTO and U.S. DOT to deploy DSRC capabilities on a nationwide basis, and identifies a number of key strategic issues that must be addressed. Some of these topics may influence infrastructure deployment issues by state and local transportation agencies are described below:

- Security - Identification of the requirements and means to establish secure and trusted communications among vehicles and roadside equipment
- Interoperability - Seamless operation of DSRC systems across North America
- Standards - Finalized standards for 5.9 GHz DSRC
- Enforcement - Mechanisms in place to ensure the integrity of 5.9 GHz DSRC
- Privacy - Resolution of 5.9 GHz DSRC privacy concerns in accordance with the National VII Privacy Policies Framework
- Funding Models - Establishment of funding models for 5.9 GHz DSRC deployment
- Governance - Agreement on governance authority and arrangements that ensure consistent, stable, long-term sustainability for 5.9 GHz DSRC
- Risk - Identification of potential system operational risks
- Intellectual Property - Identification and resolution of potential intellectual property issues

In particular, the VIIC Strategic Plan specifically calls out the need for collaboration with AASHTO on the development of a plan and approach for deployment funding, and the identification of deployment “champions.”

One technical issue that has emerged through consultations with VIIC relates to the infrastructure needed to support security requirements between a Certificate Authority and vehicles. The VIIC has suggested that an initial deployment of at least 5,000 DSRC sites would be required nationwide to satisfy this requirement. There appear to be differences of opinion between VIIC and the AASHTO community on this topic, but this subject has the potential to affect infrastructure deployment decisions by the state and local agencies. This issue is explored in more detail as part of the *Deployment Scenarios* discussion later in this report.

## Survey of State and Local Programs

A survey of state and local agencies was undertaken to gain an understanding of some of the Connected Vehicle applications that agencies are pursuing, and to highlight any issues they may be facing that would help inform the deployment analysis. This survey is not intended as an exhaustive

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<sup>18</sup> VII Consortium. “VIIC Strategic Plan 2010-2013.” May 2010.

resource on state and local deployment status or the challenges of Connected Vehicle applications. Its purpose is to review some state transportation agency activities and provide insight on what is important to the states, including the main common issues facing the agencies.

## Survey Process

The survey was conducted by email and was based on a detailed questionnaire sent out to agency representatives. Each questionnaire consisted of fifteen questions divided into four categories: Status; Applications; Infrastructure; and Challenges and Opportunities.

The recipients of the interview requests were given the option to either fill out the questionnaire in writing or through a phone interview. Generally, survey subjects preferred to fill the questionnaire in writing at their own convenience, and follow-up calls were undertaken as needed. Ten completed surveys were received. Table 5 contains a list of the interviewees.

Interviewee	Affiliation	Role	Contact Info
Ray A. Starr	Minnesota Department of Transportation (Mn/DOT)	Assistant State Traffic Engineer – ITS	<a href="mailto:ray.starr@state.mn.us">ray.starr@state.mn.us</a>
Greg Larson	Caltrans (California DOT)	Active member of the AASHTO Connected Vehicle Working Group	<a href="mailto:greg_larson@dot.ca.gov">greg_larson@dot.ca.gov</a>
Robert Koeberlein	Idaho Transportation Department (ITD)	Mobility Services Engineer	<a href="mailto:robert.koeberlein@itd.idaho.gov">robert.koeberlein@itd.idaho.gov</a>
Rick McDonough	New York State Department of Transportation	Acting Director, Planning and Development Bureau, Office of Safety and Security; CVII and CVISN Program Manager	<a href="mailto:rmcdonough@dot.state.ny.us">rmcdonough@dot.state.ny.us</a>
Faisal Saleem	Maricopa County DOT	ITS Branch Manager	<a href="mailto:faisalsaleem@mail.maricopa.gov">faisalsaleem@mail.maricopa.gov</a>
Carol Kuester, Melanie Crotty, Janet Banner	Metropolitan Transportation Commission (MTC)	MTC - 511 Program	<a href="mailto:JBanner@mtc.ca.gov">JBanner@mtc.ca.gov</a> , <a href="mailto:CKuester@mtc.ca.gov">CKuester@mtc.ca.gov</a> , <a href="mailto:MCrotty@mtc.ca.gov">MCrotty@mtc.ca.gov</a>
John E. Fisher	City of Los Angeles DOT	Transportation design, operations and implementation	<a href="mailto:John.fisher@lacity.org">John.fisher@lacity.org</a>
Bill Legg	Washington State Department of Transportation	State ITS Operations Engineer	<a href="mailto:leggb@wsdot.wa.gov">leggb@wsdot.wa.gov</a>
Steven Cook	Michigan Department of Transportation	Connected Vehicle Research, development and deployment	<a href="mailto:cooks@michigan.gov">cooks@michigan.gov</a>
Ken Earnest	Virginia Department of Transportation	Assistant Division Administrator	<a href="mailto:Ken.Earnest@VDOT.Virginia.gov">Ken.Earnest@VDOT.Virginia.gov</a>

**Table 5: Responding Individuals**

This summary captures the major focus areas and issues that were extracted from the completed surveys and is based solely on those responses. The terms “interviews,” “surveys,” and “questionnaires” are used interchangeably throughout the summary.

## Status of State and Local Activities

Survey respondents reported numerous Connected Vehicle activities within their organizations across all areas of traveler information, commercial vehicle systems, fleet vehicle programs, incident

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management, payment systems, and intersection safety. Safety and mobility applications appeared central to most programs. Activities described by the survey respondents were in the testing, pilot, demonstration, research or planning phases. Demonstrations that were either under consideration or being deployed were generally small in size. The deployments within each state are summarized below:

- **Minnesota** is focusing on demonstrations for in-vehicle signing and traveler information systems; stop sign assist using DSRC; and mileage-based user fees using GPS. Mn/DOT is also investigating a roadway departure system using high-accuracy GPS.
- **Caltrans** has already installed fifteen RSE units along freeways and at signalized intersections for Connected Vehicle applications. Caltrans is also investigating the possibility of variable speed programs, and eco-friendly driving applications.
- **Idaho DOT** recently developed a Connected Vehicle Concept of Operations for Eastern Idaho, incorporating current and planned roadside equipment, fleet vehicles and its communications infrastructure. The concept includes Connected Vehicle applications in the areas of road-weather information and weather alerts, pavement condition monitoring, incident management, safety alerts, real-time traveler information, dynamic route guidance, and animal avoidance alerts.
- **New York State DOT** has conducted multiple deployments for commercial and heavy vehicle applications, including those showcased at the 2008 World Congress in New York City. The New York Commercial Vehicle-Infrastructure Integration (CVII) program includes the use of DSRC for driver identification, wireless roadside safety inspections, and commercial vehicle advisories. Eco-driving and dynamic mobility for real-time routing are under consideration for future expansion areas.
- **Maricopa County, Arizona** and Arizona DOT developed and prototyped a signal priority application for multiple emergency response vehicles at an intersection in the field. They also tested applications to support V2V communications and traveler information in a laboratory environment. The County plans to perform corridor level testing of emergency and transit vehicle priority in the summer of 2011. The County is also interested in using Connected Vehicle data to develop speed maps and improve signal coordination. ADOT also recently completed a study to develop a Concept of Operations for dynamic routing of emergency vehicles using the Connected Vehicle platform.
- **Washington State DOT** has over half of its snow plow fleet equipped to provide probe data on weather and surface status for winter operations, and then turns this data into traveler information on mountain passes and road closures. WSDOT is also designing open-road tolling and CVO pre-screening programs.
- **Michigan DOT** is developing a Data Use Analysis and Processing (DUAP) system to acquire and use Connected Vehicle data in the management and operations of the transportation system. The system includes data collection from highway infrastructure state and federal test beds, and fleet vehicles, including a soon to be deployed Vehicle-based Information and Data Acquisition System (VIDAS).

- **Metropolitan Transportation Commission** in the San Francisco Bay Area has completed an analysis of the potential uses of Connected Vehicle technologies for supporting High Occupancy Toll (HOT) lane operations.
- **Virginia DOT** is leading the **Cooperative Transportation Systems Pooled Fund Study**. The Cooperative Transportation Systems Pooled Fund Study (PFS) is a partnership of transportation agencies to facilitate development and evaluation of Connected Vehicle-enabled large-scale system operations applications. The PFS was established in 2009 with VDOT as the lead agency and administrative support provided by the University of Virginia. There are ten core members: Virginia, California, Florida, Michigan, Minnesota, New York, Texas, Washington State, Maricopa County, and FHWA. Associate members include Palm Beach County, FL, Oakland County, MI, the Metropolitan Transportation Commission, Montgomery County, MD, and Transport Canada. The PFS conducted three Year-One projects as follows:
  - Investigating the Potential Benefits of Signal Phase and Timing was led by California PATH. This project identified SPaT use cases, developed a Concept of Operations for each use case, and conducted a high-level benefits assessment. The project was slated for completion in March 2011.
  - Investigation of Pavement Maintenance Support Applications of Connected Vehicles was led by Auburn University. The project developed estimates of the International Roughness Index (IRI), detected and mapped potholes, and documented specific risks, constraints, and opportunities in large-scale deployments. Project completion was also slated for March 2011.
  - Connected Vehicle Traffic Signal Control Algorithms was led by the University of Virginia. This project sought to develop and evaluate new traffic control algorithms using Connected Vehicle data, develop tools for generating arterial measures of effectiveness, and document specific risks, constraints, and opportunities in large scale deployments. This project was completed in February 2011.

Two new projects were recently awarded for Year-Two that began in April 2011:

- Certification Program for Connected Vehicles will seek to develop foundational knowledge necessary to inform PFS members on certification issues related to DSRC hardware and software. This project is planned to run from March to June 2011.
- Aftermarket Connected Vehicle On-Board Equipment (OBE) will investigate methods to accelerate the introduction of aftermarket OBE units to vehicle fleets. This project is planned to run from March 2011 through February 2012.

In all surveys the respondents discussed working with numerous partners in collaborative efforts. Most respondents mentioned working with their state universities and research centers, as well as regional and local agencies. The MTC personnel reported that they viewed their role as a support function to Caltrans and as a partner in its deployment activities in the Bay Area. All the states reported involvement of other stakeholders, such as U.S. DOT, state Departments of Revenue, State Patrols, consultants, vendors, equipment providers, software developers, the automobile industry, and communications service providers.

Respondents often mentioned that project activities tracked closely to demonstrations or pilots of earlier deployment efforts. Data collection, research, field testing, concept of operations, and

simulation modeling were all being undertaken to provide the foundation for individual state Connected Vehicle programs.

## Specific Areas of Interest

A broader analysis of Connected Vehicle system applications of interest to state and local transportation agencies is provided in the *Applications of Interest* section of this report. This section addresses the levels of interest in a subset of applications by the survey participants. For this survey, participants scored a shortlist of applications based on their current activities and interest. The survey asked participants to score their interest in these applications from one (meaning little interest in the application) to ten (meaning high interest in the application). Obviously this was a subjective way to judge agency interest in each application—each respondent used his or her own weighting system, and may be representing an individual assessment rather than an agency position. With this in mind, the exercise is intended to show the overall relative interest in various applications. Table 6 represents each of the respondent's interest in the various applications.

Application / Agency	MN	CA	ID	NY	Mari-copa	MTC *	L.A.	WA	MI	VA	AVG.
Probe Data Traffic Information	10	10	9	10	9	10	7	8	10	10	9.3
In-Vehicle Signing	10	8	9	10	10	10	10	5	5	8	8.5
Lane and Roadway Departure	8	8	8	10	10		5	8	10	7	8.2
Intersection Safety	10	10	3	10	10		3	8	10	7	7.9
Probe Data Weather Information	3	8	9	10	10		3	8	10	8	7.7
CICAS-Stop Sign Assist (CICAS-SSA)	10	7	3	10	10		3	6	10	6	7.2
CICAS-Signalized Left Turn Assist (CICAS-SLTA)	1	10	3	10	10		3	6	10	6	7.2
Commercial Vehicle Safety	5	7	8	10	8		5	9	7	6	7.2
CICAS-Violation (CICAS-V)	5	10	3	10	10		3	6	10	7	7.1
Probe Data Pavement Conditions	2	3	6	10	9		N/A	7	10	8	6.9
Commercial Vehicles and Freight	5	7	6	10	5		3	9	7	7	6.6
Payment Systems	8	3	1	10	1	10	1	9	1	6	5.0

\* Note: MTC did not score all applications and only scored those applications where they would have involvement.

**Table 6: Application Interest by Survey Respondent**

Clearly the agencies have a high level of interest in probe data traffic information, in-vehicle signage, and lane and roadway departures. These applications track directly to the DOTs' collective interests in managing the system with better information, communicating with drivers safely, and addressing the most pressing highway safety problems. Intersection safety and weather data follow closely. It is interesting to note that Payment Systems received mostly either very high or very low scores, indicating that agencies were either extremely interested or not at all. Commercial vehicle applications, CICAS-V, and CICAS-SSA all garnered mid-range scoring, indicating medium interest by most agencies.



## Key Issues Identified by Survey Respondents

Through the survey responses and discussions with the agencies, the respondents identified several issues that they felt should be considered as agencies advance their Connected Vehicle deployment plans. These are summarized below.

### ***Communications***

Communications infrastructure presents a variety of challenges, especially since technology is changing so rapidly. Depending on the application, different communications media will be either desirable or necessary. Fiber optic cable, in which many states have invested heavily, and radio systems including 800 MHz were frequently mentioned as either needing expansion or requiring new infrastructure to support backhaul. It was noted that where signalized intersections will be equipped with DSRC RSEs for safety applications, technical issues remain, such as line-of-sight, and interference. Any of these could potentially impact a safety system's ability to function properly. Respondents also mentioned that many of the Connected Vehicle system applications of interest to the agencies have less restrictive communications requirements than the safety systems, and could use existing cellular technologies.

### ***Power Supply***

Providing power to equipment in the field is always a consideration and often a difficult issue, particularly in rural areas. The question of AC or DC power supplies, solar power, and the ability of batteries to meet specifications are real. Supplying power to a DSRC unit for a curve warning system in a remote area will be a practical concern to the people who have to design and install Connected Vehicle technology applications.

### ***Back Office Systems***

Most applications will require back office systems for data processing, storage, retrieval, and end-user presentation. Defining these systems often presents opportunities for agencies to better understand their needs and streamline processes by going through the systems engineering process. However, many states have experienced the challenges of integrating systems across multiple agencies. For example, automating the commercial trucking credentialing, permitting, and taxing back office systems within a state involves the DOT, State Police, Department of Revenue, Departments of Motor Vehicles and Licensing, FMCSA and usually others. Additional issues may arise in integrating new data elements from mobile sources into existing systems—for example, 511, CARS, HPMS, MDSS, and emergency services CAD systems. A thorough assessment of the data needs and interfaces between all system stakeholders will be needed to assure successful implementation and agency acceptance.

### ***Standards***

Standards have been and continue to be a major issue facing the industry. Communications standards, interoperability standards, data dictionaries and message sets, and the need for open systems where appropriate are vital to success. Existing and evolving consumer electronic devices such as personal navigation devices, smart phones, and tablets highlight the need for interoperability and coordination within the market place. Agencies typically want to use standards when procuring systems because it makes their jobs easier and they can generally procure equipment at lower cost. Some agency personnel actively participate in standards-setting organizations and are familiar with emerging standards, but most agencies wait until standards have matured before they are willing to

use them. Agencies will also want guidance and training on standards as they are adopted. However, the need for them to be developed thoughtfully and in a timely manner is a precursor to their use, and the U.S. DOT will have to continue to take the lead.

### ***Funding, Staging, and U.S. DOT Leadership***

Since the population of vehicles equipped with the necessary DSRC and other vehicle technology will start very small, the state DOTs must weigh the benefits and costs of deploying RSEs.

Until there is a national DSRC/RSE deployment strategy, the 2013/14 NHTSA decisions are made, and the vehicle penetration rates increase dramatically, most agencies feel they have limited ability to define long-range programs.

Many of the survey respondents noted that making the political and financial commitment to Connected Vehicles is more immediately important than fulfilling the infrastructure needs. That commitment also needs to recognize the maintenance and operations costs and expertise needed to sustain a successful Connected Vehicle program in the long-term.

Many of the respondents were optimistic that any NHTSA decisions in 2013 and 2014 will be the primary catalyst for moving ahead with infrastructure deployment. However, they were also quick to note that there are some serious technical and policy challenges that must be overcome. This would be the first time that the auto manufacturers and public agencies would be operating a truly cooperative vehicle/infrastructure system. While the respondents were optimistic, they were also realistic and understand the amount of work that will be needed, along with leadership from U.S. DOT.

If NHTSA actions do not result in requirements for on-board DSRC equipment for light and heavy vehicles, the agencies will likely still carry on with many of their plans for applications that will benefit their management and operations.

### ***Integration across Existing Infrastructure***

As mentioned earlier, the states and other agencies have invested heavily in Intelligent Transportation Systems (ITS) and Connected Vehicle technologies over the years. They have invested in the hardware, software, training, and have importantly even enhanced their planning and programming processes to accommodate technology deployments. But with that investment, it will be important to continue to leverage and make the most of current systems so that Connected Vehicle applications contribute to them, rather than render them obsolete.

### ***DSRC Certificate Authority***

DSRC certificate authority was also noted in the surveys as an issue that will have to be resolved. This essentially refers to the process by which a vehicle's on-board system is authenticated and deemed trustworthy on a regular basis. This is a fundamental prerequisite to all of the DSRC-enabled active safety applications. Who issues the certificates, on what communications networks are they transmitted, on whose servers are they hosted, and who is responsible if there is a system failure? These are all questions that will need to be resolved. Some are technical, some are policy and others are legal issues. The U.S. DOT will have to take the lead in addressing them, but the agencies and the auto manufacturers will have to be active participants.

## Survey Conclusions

The agencies surveyed have a lot at stake in the Connected Vehicle infrastructure program. They are already heavily invested and fundamentally committed to ITS and the promises of the Connected Vehicle program. The responding agencies see great opportunities to enhance how they operate and manage their systems, as well as the potential for dramatic safety improvements. There is a lot of interest in Connected Vehicle applications, particularly those around availability of data for operations, communicating with the public, and certain high-payoff safety applications.

However, there are some important issues that the agency responders saw the need to address; some up front and others along the way. Basic operational considerations, such as power and communications availability, will continue to present challenges both in the near and long terms. Technical issues surrounding standards, equipment interoperability and functionality will continue to be of concern to the agencies. Integration with existing systems and the need for new and expanded data warehousing and processing systems will require a great deal of effort in each locale. And significant policy considerations ranging from funding to responsibility for system failure will need to be resolved.

U.S. DOT leadership will be important to resolving issues in some areas. The state and local agencies are also optimistic about the partnership with the federal government and the automakers as a mechanism to make progress on identified issues in other areas. However, in general, the agencies expressed a commitment to move forward with certain Connected Vehicle deployment activities irrespective of the actions of these other parties.

# Deployment Readiness: Markets and Technologies

There are many external dynamics that will affect the nature and timing of the benefits that will accrue to state and local transportation agencies and their constituents from Connected Vehicle system applications. In turn, these issues will influence the infrastructure deployment decisions of the state and local agencies. This section of the report introduces and describes a set of key topics that have the potential to affect the agencies' approaches to Connected Vehicle infrastructure deployment in the coming years.

The topics described in this section include the following:

- The scale and characteristics of light, heavy, and specialist vehicle markets, and the effects of market dynamics on the potential availability of Connected Vehicle technologies and systems
- External factors affecting the role of aftermarket devices and applications in public sector Connected Vehicle system deployments
- The options for providing data communications capabilities in Connected Vehicle systems, including a brief introduction to security and certificate management needs
- The scale, technical considerations, and potential costs of interfacing Connected Vehicle RSEs to traffic signal controllers
- Vehicle Markets

## Light Passenger Vehicles and Trucks

The U.S. auto industry produces approximately 15 million light passenger vehicles and heavy vehicles each year. The overall population of such vehicles is relatively stable at about 200 million units, which means that about 15 million vehicles are also retired each year. Vehicles last in the fleet an average of 12 years, although this average includes vehicles that are destroyed the day they are purchased, and other vehicles that are more than 50 years old.

The relatively long average lifespan results in some interesting market dynamics for passenger vehicles, and consequently complex dynamics for the deployment of Connected Vehicle equipment. Specifically, any fixed equipment (including, for example, Connected Vehicle OBEs) sold on a passenger vehicle will be in use for an average of 12 years. The passenger vehicle market is also marked by rather long development cycles. A new vehicle platform takes about four years to develop. Typically the components used in the vehicle are “frozen” about one year into the development cycle. Given the comparatively fast lifecycle for consumer electronics equipment (about 18 months) this means that consumer electronics related equipment embedded in a vehicle (phone, radio, media interface, navigation, etc.) will be about 15 years (10 generations) old by the time the average vehicle

is retired. In other words, the radios and other equipment are already a few years old before they have even reached the showroom floor.

A good example of this issue was the OnStar system, which initially used an analog cellular telephone. The first vehicles with this system were sold around 1997. In early 2003 the FCC announced a five-year “sunset,” after which the cellular providers would no longer be required to support the analog mobile phone system. Despite a request for delay, the so called “analog sunset” became effective in February 2008. Shortly thereafter most carriers ceased providing analog mobile phone service. At that point at least five years of GM production vehicles and about three years of Lexus vehicles were on the road using this system. The OnStar systems in those vehicles became obsolete on Feb 18, 2008.

Similar issues have occurred with iPod plugs, USB plugs, memory cards, navigation databases, hands-free systems, and other technological conveniences manufactured into passenger vehicles.

In general the passenger vehicle industry is also exceedingly cost conscious. Each vehicle platform is based on a production cost budget, and any extra cost either increases the price or reduces the profitability of the vehicle. As a result, vehicle manufacturers weigh the cost of every part against the need for that part, or the estimated value to be perceived by a prospective buyer. Vehicle executives are highly wary of adding cost without proof that the added value provided by that cost will pay off. The result of this situation is that it is challenging to add new equipment to a vehicle. Typically the demand for the equipment must be obvious in the marketplace before such equipment will be embedded in the design. Many examples of this exist in the history of the motor vehicle. The first car radios appeared in about 1928, eight years after they were available for home use. In 1962 Philips invented the compact audio cassette medium for audio storage, introducing it in Europe in August 1963, and then in the United States in November 1964. However, it was not until about 1974 that cassette players were available for cars, and sometime after that before the cassette player was standard equipment.

As a result, deploying Connected Vehicle equipment in vehicles requires that the system provides clear value to the vehicle user (such that a vehicle manufacturer can be sure that the added feature will provide value to the customer commensurate with the cost of the equipment). This value must be realizable by customers in a time frame that is relevant to their ownership of the vehicles (that is, they must realize its value while they own the car, and preferably when they are considering their vehicle purchase). These considerations are generally in conflict with the dynamics of the market. The time required to achieve sufficient penetration in the fleet, such that some benefits (value) are obvious to the owner, is longer than that which would motivate the installation (and cost) of the equipment.

## Medium and Heavy Vehicles

There are approximately nine million medium and heavy vehicles on the road today (FHWA 2006), and each year about 260,000 new heavy vehicles are manufactured (the production rates for 2009 were substantially below normal levels due to economic factors). In general, the population of medium and heavy vehicles is expected to rise at a rate of about 2% per year. More than 700,000 of the heavy vehicles are private buses and motor coaches<sup>19</sup>.

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<sup>19</sup> The total number of buses in the United States is about 800,000 (FHWA 2005), of which 70,000 are used as public transit vehicles.

Truck life spans are typically quoted in miles as opposed to years (about 1.2 million miles), although using estimates of annual vehicle miles traveled for heavy trucks (an average of 130 thousand miles per year) indicates an average life span of about ten years.

Heavy trucks generally use multiplex networks for gauges and other electronics, and generally they are configured to support a variety of aftermarket installed electronic equipment. The typical large truck also includes physical provisions for such equipment. As a result, it is much easier to add equipment to a truck, either as original equipment or as aftermarket equipment than it is to add such equipment to a passenger vehicle.

While comprising less than four percent of the overall vehicle population, the heavy vehicle industry is highly aware of the benefits and costs of technology, consequently they are much more proactive in making changes. The industry tends to support retrofit configuration much more easily than the passenger vehicle market, so it is a strong candidate for supporting early adoption of Connected Vehicle systems. Commercial vehicle operators have also demonstrated a willingness to participate in government-sponsored technology initiatives where it this will enhance their efficiency or productivity. Today, for example, about 400,000 trucks use PrePass and NORPASS tags for electronic pre-clearance at weight stations and ports-of-entry.

It should be noted that the Federal Motor Carrier Safety Administration (FMCSA) has recently published a proposed rulemaking requiring Electronic On-Board Recorders (EOBRs) for the purposes of recording drivers' hours. EOBRs have the potential to not only record drivers' hours, but to act as a potential enabling platform for other Connected Vehicle applications, such as safety checks, parking capacity prediction, and other important communications needs.

## **Bus Transit Vehicles**

According to 2006 data, there about 70,000 transit buses in the United States. There are also over 400,000 school buses. Transit buses account for about 2.2 billion vehicle miles per year, and according to the Federal Transit Administration (FTA) have a useful life of about 12 years. Transit vehicles are typically highly-customized with a variety of electronic equipment selected by transit operators to improve the monitoring of bus operations or better reporting of passenger usage data. All bus transit vehicles will fall under the same Connected Vehicle standards.

Transit vehicles represent a good target for early adoption of Connected Vehicle systems, as long as they can be shown to provide value to the operator. The cost of the equipment is relatively modest in comparison with other electronic systems typically deployed, so deployment of such equipment will generally depend on proving some level of operational benefits.

## **Emergency Vehicles**

There are about 75,000 fire trucks, 40,000 ambulances and about 90,000 police vehicles in the United States. There is limited information available about exactly how many emergency vehicles are produced each year. In general heavy fire equipment has a long lifespan, in some cases about 20-25 years. Fire equipment is typically built to order, and older equipment is often sold from wealthier municipalities to less wealthy municipalities as it ages. Ambulance equipment tends to follow a slightly faster obsolescence cycle as newer medical care and trauma equipment is developed. The average age of a police cruiser appears to be about four years after which specialized equipment is removed, and the police cars are sold publicly. This implies that about 25,000 new police vehicles are manufactured each year. Police vehicles are typically special models of conventional production

passenger vehicles. In all instances, emergency vehicles are equipped with specialized communications and other electronic equipment.

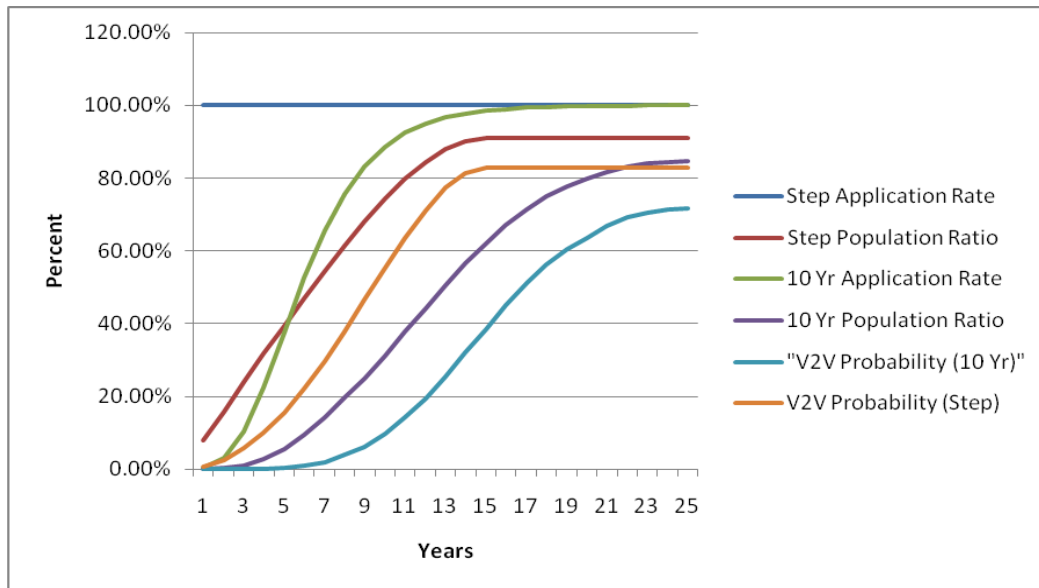
## Connected Vehicle Market Growth Projections

Projections of future market growth for Connected Vehicle systems are a core component of this deployment assessment. These projections depend heavily, however, on the presumed underlying market mechanics. Unlike, for example, safety-related anti-lock braking system (ABS) and traction control systems, V2V safety systems are fundamentally cooperative systems that require almost ubiquitous coverage for effectiveness. In contrast, airbags followed an initial organic curve that was then accelerated via mandate. The intent of this discussion is to describe the possible Connected Vehicle deployment scenarios (e.g. market-driven, new vehicle mandate, retrofit mandate) based on previous market experiences, in light of the deployment motivations and underlying market conditions.

The long life and large base of light vehicles in the U.S. means that change in the fleet occurs slowly. At the production rate of 15 million units per year, the fleet is theoretically replaced every 13 years. However, since some vehicles are retired early, and some vehicles last longer than the average, new features are not reflected in the overall population as quickly as might be expected. New features are also not adopted immediately across the entire annual build, so the rate of adoption of a feature in the vehicle population can lag substantially behind the introduction of such a new feature.

Figure 1 below illustrates this characteristic. In this model there is an assumed life span distribution with an average of about 13 years, and a power-law survival distribution in which a small fraction of vehicles do not survive the first year and some vehicles last more than 25 years. The figure shows the population ratio of a feature (the percentage of vehicles with the feature) based on a step function introduction (all vehicles built with the feature) and a more typical “S-curve” application rate characteristic.

The S-Curve growth rate used in the figure assumes that the application rate grows over time from zero to 90% in about ten years, with initial growth relatively slow, maximum growth in the middle years and then flattening out in later years. This application rate is slightly faster than most automotive features, so it is possible that the growth rate could be slower, and this would lead to longer time spans to reach the same fleet penetration rates.



**Figure 1: Potential Deployment Trends**

For example, anti-lock brake systems were first introduced on production cars in 1971 (on GM Cadillac and Chrysler Imperial models). Mercedes introduced an all-electronic version of the system on high-end vehicles in 1975, and the growth of ABS applications peaked in the early 1990's. By 1994, the growth rate had leveled off and it has remained relatively stable at about 60% of the fleet since that time.

Similarly, airbags for vehicles were first introduced in passenger production vehicles in the mid 1970's. Mercedes and Ford made them available as options in the mid 1980's, and Chrysler made them available as a standard feature on all vehicles in 1988. In 1991 the U.S. Congress passed a mandate requiring all production passenger vehicles to be equipped with airbags by the 1997 model year (mid 1996). So, even with a mandate, the airbag went from effectively zero penetration in 1980 to 100% in 1996, a period of 16 years, with substantial growth during the non-mandated middle period from 1986 to 1994.

These examples illustrate that a typical growth rate of zero to 90% over 10 years is somewhat optimistic, but could be realized. It is almost certain not to be faster than this.

As can be seen in the figure, a step feature introduction requires about 13 years (as expected) to result in 90% of the fleet being equipped (in this model it is assumed that 10% of the fleet is exempt from being equipped). In contrast, the more typical phased introduction over a 10 year period results in a delay of twenty years before 90% of the population is equipped. This same growth rate reaches 50% of the fleet in about fourteen years.

These characteristics of the automotive market have important consequences for Connected Vehicle system deployments. Specifically, any deployment that relies on automotive production will not see a sizable equipped population for more than a decade. For V2V safety this is especially problematic. While equipped vehicles would be able to produce (give and receive) benefits through V2I services,



V2V benefits can only be obtained when both interacting vehicles are equipped. As shown in the figure, the probability of obtaining benefits from a V2V system is less than 50% for over 17 years from the initial introduction. For a step-feature introduction, this point is reached at about 10 years, but this is still twice the average vehicle ownership period.

## Aftermarket Devices and Applications

Aftermarket devices have been suggested as an alternative to factory-installed equipment as a means of deploying Connected Vehicle applications as quickly as possible. If the objective is to deploy Connected Vehicle systems through consumer interest, deployment would likely occur through leveraging and extending existing product categories. Many of the postulated Connected Vehicle applications are already available or readily achievable as existing product extensions. Alternatively, an aftermarket consumer mandate could spur creation of a new category of products specifically designed for Connected Vehicle deployments.

The existing product categories relevant to Connected Vehicle deployments are diverse, but converging. The computing capabilities of small consumer electronics continue to expand. The number of consumer electronic devices with data connections has exploded in recent years. Both transportation agencies and commercial providers have come out with new software applications and data feeds for several transportation modes. This mix of data and devices creates so much opportunity that only a general review is possible in this report.

It is important to note that the potential for any Connected Vehicle applications or technologies to cause driver distraction will continue to be of utmost concern for both the U.S. DOT and AASHTO. Unlike mandated on-board equipment, aftermarket devices can potentially create serious safety problems in vehicles. Driver distraction is not explicitly addressed in this report because the report is primarily focused on infrastructure deployment. However, it is a significant issue worthy of note, and foremost in the minds of AASHTO and the U.S. DOT.

## Smartphones

Although there is no precise definition, a smartphone could generally be described as a mobile telephone handset with built-in personal computing applications and Internet data access. They frequently include GPS receivers and cameras. The newest smartphones are able to update and add new applications; have additional sensors for acceleration, ambient light, and compass direction; and have become a platform for independent software development and deployment.

Since their primary use is for personal communications by voice, email, and text messaging, smartphones are frequently present in vehicles. Add-on applications may include navigation and traffic information, and smartphones are increasingly used in place of other navigation devices. Even if applications that are useful in vehicles are present, their user interfaces are not typically designed for on-board traveler and vehicle information systems. Displays are generally smaller than those on devices designed for vehicular environments, though some of the newest smartphone displays are comparable to or larger than those on other navigation devices<sup>20</sup>.

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<sup>20</sup> The screen on the HTC EVO smartphone, for example, is a 480 x 800 4.3-inch TFT LCD; the screen on a TomTom Go 740 Live PND is a 480 x 272 4.3-inch LCD.

A smartphone's built-in data communications and ability to add third-party applications have created a dynamic market for new mobile data services. The data may flow in both directions between the service provider and the phone. Applications may download data for location-based services, for example, and provide probe or "crowd-sourced" data back to an aggregation service.

The history of smartphones (separate from the underlying mobile telephony) is generally dated to the "Simon" phone developed by IBM and marketed by BellSouth in 1993. Features and applications have advanced significantly since then, and the segment has behaved much like the personal computer market. Advances in features occur with enough regularity to keep pushing the product horizon ahead. Older mobile phones ("smart" or not) are replaced with units that have more features, in some cases capturing sales from other personal electronic categories. As such, the category is likely to grow until all mobile phones are smartphones. A recent Gartner Group study indicated that worldwide smartphone sales increased 24% from 2008 to 2009, whereas worldwide sales of all mobile phones together declined by 0.9%.

The combination of the extensible application platform and a growing population make smartphones a viable base for Connected Vehicle application deployment. "Apps" that provide many of the envisioned Connected Vehicle applications are already available on some smartphones. The use of smartphones as probe devices is a relatively common concept, and applications are readily available for users to provide, for example, traffic and pothole data. At the extreme edge, a recently released application for the iPhone provides "augmented driving" and real-time object recognition that demonstrates functionality similar to autonomous vehicle safety systems<sup>21</sup>. Similar applications, it could be speculated, might be able to dynamically recognize traffic signal phase changes and other roadway features.

## Personal Navigation Devices

Personal navigation devices (PNDs) are a class of portable electronic devices designed to provide location and navigation services. PNDs in use in North America use the Global Positioning System (GPS) to obtain the device's current latitude, longitude and elevation. GPS also provides a standard time reference. Features available on PNDs can vary widely. The simplest PNDs provide text location and directions, whereas more sophisticated units can provide voice and graphical interfaces. Units designed for automobile use may provide even lane-level navigation instructions. Most PNDs use local copies of geographical databases that can be updated.

Although PNDs can be used for any mode of travel, most are designed and used specifically in private automobiles. These units typically include mountings on the dashboard or windshield, displays that are readable in that position, and large simple controls. These features are designed to be easy to use without driver distraction.

Most PNDs enable users to add "waypoints" or "points of interest" to their geographical databases. This capability could be used to add roadway features and traveler information to the databases. New waypoints could be added through any of the device's standard means of updating the database.

Manufacturers have added applications beyond the PND navigation functions as communications have become less expensive and more widely available. Real-time traffic data, for example, can be received through FM radio-based signals from service providers such as FM TMC Traffic and XM

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<sup>21</sup> <http://www.imaginyze.com/Site/Welcome.html>

NavTraffic. Some newer PNDs are able to exchange traffic data with an information service provider through two-way data communications over cellular networks. These devices may even support “real-time” routing based on the vehicle’s current location and traffic data collected from other units. There have been to date a limited number of providers of this level of service (TomTom High Definition Traffic™, for example).

The first general-purpose satellite-based consumer navigation devices came to market in the early 1990s. Completion of the Block II GPS satellite deployment in 1993 improved the accuracy and reduced costs. Aftermarket automobile navigation devices appeared in the late 1990s, and sales growth expanded throughout the 2000s. All indications are, however, that sales growth is slowing or has peaked. Competition from navigation applications on other devices, particularly mobile phones, seems to be constraining further growth.

Although sales may have plateaued, PNDs could be a viable product category for enhancement as a potential aftermarket Connected Vehicle platform, at least for non-safety applications. The basic capabilities are all present, as are some of the simpler applications. Traveler information applications are already widely available on PNDs with cellular communications. In-vehicle signing and notification is present on many PNDs in the form of, for example, speed zone databases.

## Emerging Consumer Electronic Devices

The consumer electronics market has become so diverse that many devices that could be used in a vehicle do not fit the existing personal computing or telecommunications categories. Examples of these devices are included in the following:

- Netbooks are small personal computers designed for portability over power. They typically run the same operating systems and have the same networking capabilities as larger PCs, but have slower processors that consume less power.
- Electronic book readers (or e-readers) are devices designed specifically to provide an electronic means of presenting books, magazines, and other content for human reading. E-readers generally have wireless connectivity through Wi-Fi or 3G services for downloading new content, and are (as of this writing) starting to include other applications like Web browsers and games.
- Tablets such as the Apple iPad and those based on the Android operating system offer applications and connectivity in a physical package between a smartphone and a netbook (or laptop) computer. Like the e-readers, tablets may include Wi-Fi and 3G communications. Like the netbooks and smartphones, however, tablets have access to a wide variety of applications, some of which could be used in vehicles. Aftermarket equipment for mounting an iPad in a vehicle is readily available.

Again, driver distraction remains a critical concern, and these types of on-board aftermarket devices potentially create serious hazards. This is mentioned here to acknowledge the importance of the issue. However, driver distraction is not explicitly addressed in this report since its focus is primarily on infrastructure deployment.

The pattern of devices marketed to specific users and types of applications is not new or unexpected in digital processor-based consumer electronics. The PNDs discussed earlier in this paper are themselves a class of such devices. Personal digital assistants (PDAs) were a specific category until

their functions were absorbed into mobile telephones. The importance of these products and categories is that they demonstrate the value of their particular features and applications to the market. Valued features find their way into other similar categories. The original innovative products can adapt—Palm PDAs became Palm mobile phones—or disappear as their features are rolled into other devices. For this reason, Connected Vehicle applications developed for devices with established market presence would eventually be viable on these devices.

## Automotive Performance Monitoring Devices

Aftermarket automotive performance monitoring devices can access the vehicle's on-board information network for detailed display and analysis of the vehicle's performance. These devices connect to the vehicle's On-Board Diagnostic (OBD-II) port for vehicle data and may include a GPS receiver, supplemental sensors, and wireless communications. Configurations of these devices can vary widely and are generally specific to a consumer's particular needs. Some versions of these products can be used as on-board devices in fleet management applications.

Although automotive performance monitoring devices have certainly existed since invention of the automobile, such devices as consumer electronics owe their existence to the standard OBD-II port. Developments leading to the OBD-II standard began in California in 1982 as part of efforts to monitor vehicle emissions for air quality remediation. The OBD-II standard was incorporated into the 1990 U.S. federal Clean Air Act and required on vehicles sold in the U.S. in model years 1996 and following. Although focused on emissions data, the OBD-II specification created a consumer-accessible port to the vehicle data bus. The performance monitoring equipment category adapted itself to that feature. While the category has certainly grown since bringing OBD-II devices to market, it remains a hobbyist's niche category.

The ability to interface with the vehicle's data network makes these devices particularly interesting for Connected Vehicle applications that need probe data. The processing capabilities are generally consistent with data-oriented Connected Vehicle applications. The limitation, however, is that they have to be connected to the OBD-II port to do so. The connection is not technically difficult—the port is always located somewhere under the dashboard on the driver's side of a car or light truck—but may be intimidating to an average consumer. These devices generally use a cable for the connection between the port and the device itself, and the arrangement in the vehicle can be inconvenient for the driver. Some manufacturers also offer a Bluetooth® wireless connection option to replace the cable.

## Toll Tags

Toll tags are a unique form of consumer electronic device specifically designed for a vehicular environment. Electronic toll tags enable drivers to “pay” a toll by driving past a detection point. The identifying information on the tag is used to transact the toll from an account without having to stop to exchange currency. Most electronic toll tags are currently based on 915 MHz radio frequency identification (RFID) technologies, but DSRC-based tags have been successfully demonstrated. The tags are largely “passive” from the consumer's viewpoint—they are simply displayed in the vehicle and do not provide any active display or user interface.

The use of toll tags is a model of successful cooperation between consumer behavior and transportation operations. For those locations where consumers know that they will be paying a toll, they opt into using a toll tag as a means to simplify the transaction. Traffic flow is improved by eliminating the need for each vehicle to stop at a toll booth. The agency's operations are improved by reducing the net cost of tolling transactions. Consumer acceptance of electronic toll tags is a strong

indicator that consumers will be willing to use new technologies for applications where there is a clear personal benefit.

## Communications

The core enabler of Connected Vehicle applications is providing effective data communications between vehicles and other sources and users of transportation and related data. The desire to deliver this capability in a focused and consistent manner was the primary driver behind the specification and development of DSRC. The communications networks, protocols, security, and messaging formats continue to be fundamental items of discussion and development for Connected Vehicle research, development, testing, and demonstration.

Communications technologies are also changing—and driving change—faster than any other area of technology. The transportation community's needs and opportunities are not unique among private or public industries. The communications products and services on the market are serving an immense range of applications. The diversity of needs has engendered a corresponding diversity of communication solutions, some of which might be applicable to the particular needs of a transportation systems opportunity.

This section of the report provides an overview of communication technologies that have potential for addressing some part of Connected Vehicle applications.

### 5.9 GHz DSRC

DSRC technologies were developed specifically for vehicular communications and have been closely associated with Connected Vehicle (and predecessor) initiatives. In the U.S., “DSRC” is used generically to refer to communications on a dedicated 5.9 GHz frequency band reserved using the Wireless Access in Vehicular Environments (WAVE) protocols defined in the IEEE 1609 standard and its subsidiary parts. These protocols build on the established IEEE 802.11 standards for Wi-Fi wireless networking. Standard messages for DSRC are described in the SAE J2735 standard. These standards continue to evolve, but have provided the basis for most Connected Vehicle DSRC demonstrations.

With this pedigree, DSRC is uniquely suited to mobile vehicular applications needing high bandwidth and low latency in short range communications (on the order of a few hundred meters). Security is managed through a certificate management scheme that issues new certificates to each radio at regular intervals. Radios are deployed in vehicles and in roadside equipment to provide V2V and V2I, or infrastructure-to-vehicle (I2V), communications.

Compared to other wireless communications technologies, however, DSRC is still early in its development and application life cycle. Proof-of-concept demonstrations have been deployed in Michigan and California, but there are to date no widespread deployments. Some private demonstrations by a DSRC system vendor of tolling applications have been provided to certain agencies. U.S.DOT is currently developing a Safety Pilot Program for a large demonstration of V2V and I2V safety applications in 2011-2013.

## Commercial Cellular Services

Commercial cellular communication services are available from a host of providers in the U.S. The technologies underlying those services vary among providers, but all provide similar voice and data services through phone handsets and cellular data modems. Commercial services are generally marketed as “3G” or “4G” connections that differ primarily in the bandwidth (“speed”) which is theoretically available for each connection. Geographical coverage also varies among providers, but all urban and most rural areas are served by at least one provider.

The ubiquity of commercial cellular services makes them valuable in vehicular environments for applications needing continuous connectivity over longer travel segments and trips. Smartphones, as noted earlier, now provide traveler information and entertainment options that were previously available only through AM/FM radio broadcast. Applications are not limited to receiving traveler information; cellular connections are increasingly being used for probe data collection and other telematics applications, especially on fleet vehicles. Bandwidth is generally sufficient for data-centric applications, though not necessarily for streaming video, and the networks are designed for secure transmissions.

Cellular network services are not generally appropriate, however, for real-time localized data exchange. Network latencies and the potential for dropped connections make cellular services inappropriate for real-time V2V and I2V safety applications.

Commercial cellular services have been used in a variety of commercial telematics deployments and Connected Vehicle demonstrations. The California SafeTrip-21 Connected Traveler Field Test Bed Mobile Millennium project used standard 3G Nokia phones as probe data sources. Cellular connections have been used for backhaul from RSEs in the VII California Test Bed and as one option in the VII POC Test Bed in Michigan. OnStar has used a dedicated on-board cellular connection for many years, and Ford is using a Bluetooth connection to a driver’s cell phone handset for its SYNC connection.

## WiMAX

WiMAX is a relatively new wireless technology designed to provide high-bandwidth data communications over a wide area. As with any wireless network, the practical bandwidth is reduced at longer ranges, but connections of up to ten miles are possible. The WiMAX standards (IEEE 802.16) support both fixed and mobile implementations.

Although WiMAX has been deployed in the U.S. by Clearwire as a 4G commercial cellular service, it can operate in unlicensed spectrum and can be deployed as a private network. It was used for backhaul purposes as part of the VII POC in the Michigan demonstration test environment.

## Wi-Fi

The Wi-Fi family of technologies was designed to provide wireless communications to replace wired connections for local area networks. Wi-Fi networking equipment is widely available, inexpensive and used in home, commercial, and industrial environments. The Wi-Fi protocols themselves are described by the IEEE 802.11 standards. Bandwidth has increased substantially from the original protocol implementations, and the most recent standards provide connections comparable to wired connections.

Wi-Fi is not specifically designed for vehicular applications, but has been used effectively to communicate between vehicles and fixed stations, such as parking lots and maintenance yards. Wi-Fi connections from vehicles to roadside collectors have been used in probe data collection applications in Michigan.

## Security and Certificate Management

The issue of security and certificate management often arises in any discussion of the need for a minimum deployment of DSRC RSEs. The topic is briefly introduced here to help provide clarity to these ongoing discussions.

DSRC security requirements are described in IEEE Standard 1609.2. The 1609.2 standard specifies that a private-key infrastructure (PKI) scheme be employed to secure DSRC messages. This discussion is not intended to completely describe the 1609.2 standard, but to note its relevance to the deployment analysis. Neither is it intended to be an exhaustive description of PKI or other contemporary telecommunication security processes.

Security in the context of DSRC information exchanges provides assurance that the messages originate from trusted parties (they are *authorized*) and that the messages are free from tampering (they are *authenticated*). Certificates are the devices by which we acknowledge mutual authority to exchange messages. Certificates also provide a means of encrypting messages to prevent tampering during transit. In other words, certificates say that a vehicle's messages are trustworthy.

The validity of certificates is assured by the establishment of a certificate authority. To prevent malicious use of certificates to falsify DSRC data exchanges, the certificate authority maintains a revocation list and re-issues new certificates at regular intervals. The identity and implementation of the certificate authority for DSRC deployment has not yet been determined.

Certificates are delivered from the certificate authority to the end DSRC device. The medium of the transmission is less important than the identities of the sender and recipient. For example, certificates could be delivered through a DSRC channel, other wireless communication means, or directly installed on the device.

For the case in which certificates would be delivered through DSRC, sufficient infrastructure to deliver updated certificates within a defined time period, between one day and one week, would need to be procured, deployed, and maintained. A study by the VIIC concluded that at a minimum 5000 RSEs across the United States would be needed to effectively deliver certificates over DSRC.

Alternatively, the certificates could be provided using other secure communication media. This case would not require agencies to deploy infrastructure for the purposes of certificate delivery. It would, however, require a 3G or 4G data connection to be provided by another party, such as the end user. The concern here is that neither vehicle manufacturers nor public agencies can require that consumers pay for cellular services.

## Communications Trends

The universal demand for communications services drives changes in technology and growth in markets at tremendous speeds. All market segments—wired and wireless, fixed and mobile—

continue to expand technologically, especially in increasing bandwidth. Prices continue to drop through economies of scale and competitive pressures.

Growth is particularly strong in mobile services. As shown in the figures below, the number of mobile cellular telephone subscriptions continues to increase, while fixed installations are flat or decreasing. Broadband connections are growing faster than those with lower data rates. In developed countries, the number of cellular telephone subscriptions is greater than the number of inhabitants. The cellular communication services market has moved beyond connecting people, to connecting devices.

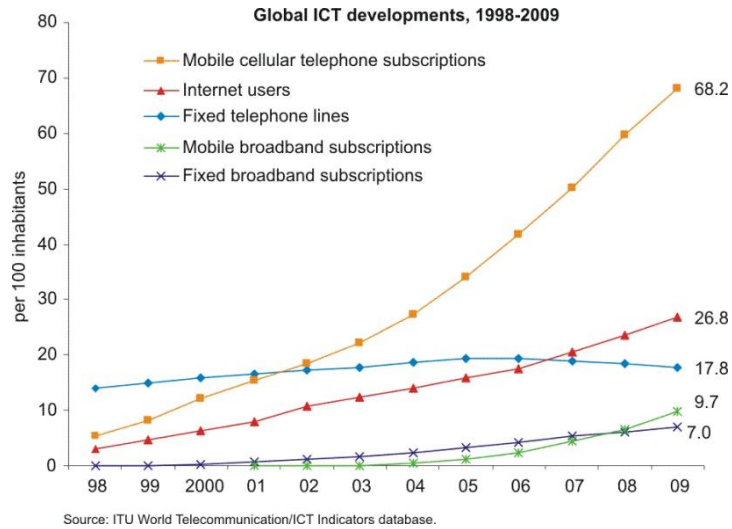


Figure 2: Global ICT Developments, 1998-2009

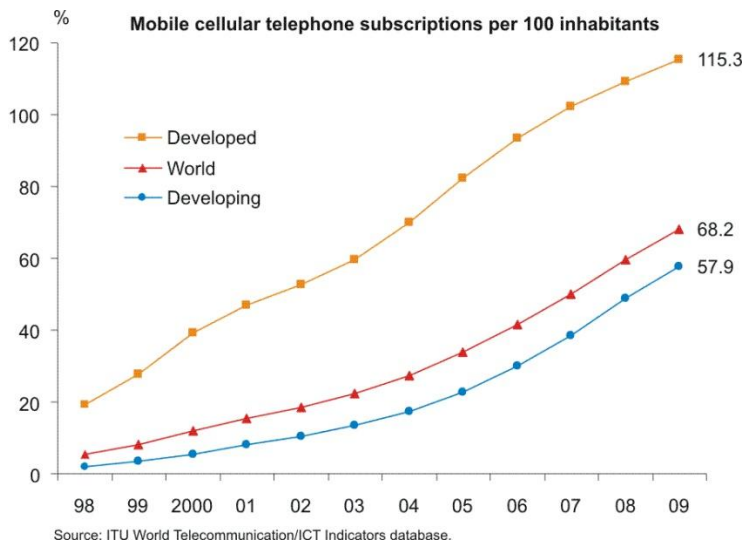
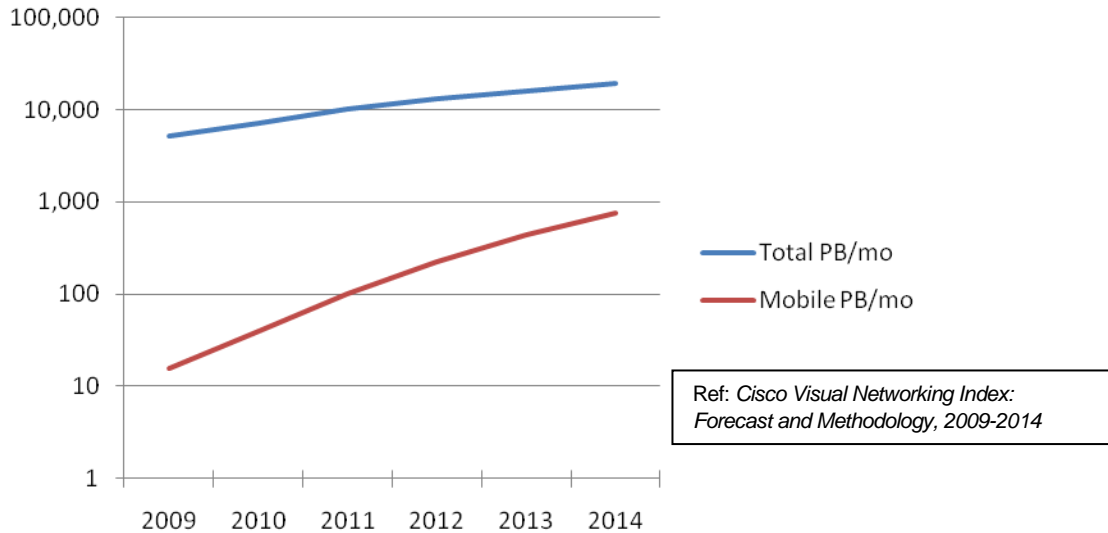


Figure 3: Mobile Cellular Telephone Subscriptions per 100 Inhabitants



The growth in mobile broadband connectivity is especially relevant to Connected Vehicle applications. As shown in Figure 4 below, Internet data traffic to and from mobile terminals—phones, consumer electronics, and connected devices—is expected to increase by factor of almost 100 between 2009 and 2014, an order of magnitude faster than the total volume of data traffic.



**Figure 4: Internet Data Volume Projections for North America**

The data demand associated with each Connected Vehicle will depend heavily on what applications are ultimately deployed on the vehicle. To provide some perspective, however, a demand of 150 MB per month per vehicle on a national deployment of 200 million vehicle terminals would create a total demand of 30 PB per month—a small fraction of the projected future data volumes.

## User Demand and Impacts

Market acceptance of and demand for Connected Vehicle systems will depend on the interaction between three factors: Availability; utility; and cost. The products and services that together make up a working Connected Vehicle deployment first have to be available to users. If the products and services are available, users will be able to assess their utility. If the products and services are useful, users will assess their willingness to pay for them.

Availability of Connected Vehicle products and services will depend greatly on the specific applications and supporting technologies to be deployed. As has been described earlier in this report, many of the types of applications that might be provided by Connected Vehicle systems are already, at least in part, available to users. There is already a market awareness and acceptance of these products. For example, navigation systems with location awareness and traffic data have become commonplace. OEM-provided telematics systems like OnStar and SYNC are well known to consumers. Autonomous crash avoidance systems for lane departure and adaptive cruise control are already available on certain vehicles. Connected Vehicle products that build off existing capabilities may be deployed more quickly and broadly than those dependent on new implementations.

The users' assessment of the utility of Connected Vehicle products is largely unknown at this time. Demonstrations thus far have been focused on proving or showcasing technical capabilities within the transportation community, and some applications have not yet been technically demonstrated. General public demonstrations have been limited to closed test populations (for example, the CICAS-V human factors studies) and self-selected groups (for example, the Mobile Millennium and E-470 tolling demonstrations). The U.S. DOT-sponsored Safety Pilot and others like the Minnesota DOT Safety, Mobility, and User Fee program will significantly expand the base of user experience with Connected Vehicle systems and applications.

Public acceptance of Connected Vehicle systems may not be an issue if the government chooses to mandate deployment for safety purposes. Availability, utility, and cost may still be factors to have been considered, but they will have been included in evaluations leading up to the mandate. In the absence of such a mandate, public acceptance and acquisition of Connected Vehicle systems would likely follow the pattern of other user-discretionary safety systems as described earlier.

## Traffic Signal Controllers

There are many types of existing field infrastructure within the jurisdiction of state and local transportation agencies that may be affected by the development and deployment of Connected Vehicle applications. Traffic signal controllers were called out for particular consideration within the scope of this study. As future analysis of deployment considerations are conducted, additional detail will be required in this area, and similar analyses will be required for other types of infrastructure, such as truck weigh and inspection facilities and toll facilities.

The Cooperative Intersection Collision Avoidance System (CICAS) program, developed jointly by U.S. DOT agencies and a consortium of automakers, identified substantial potential for reducing collisions at intersections using cooperative communications between the infrastructure and in-vehicle systems. In the case of CICAS for Violations (CICAS-V), the solution requires DSRC broadcast of SPaT data so that the in-vehicle system can warn the driver of a potential violation. Similar uses of SPaT data can be envisioned for CICAS-SLTA (Signalized Left Turn Assist) applications. Broadcasting the SPaT data in turn requires an interface between the DSRC radio and the signal controller.

Controller cabinets are furthermore logical places to consider deploying DSRC roadside equipment. Cabinets provide secure environmentally-protected enclosures with electrical power and often with backhaul communications. These features may enable a more efficient and cost effective DSRC deployment than would occur with new standalone installations. However, backhaul communications to signal systems may be limited in their capabilities and would need to be carefully assessed to ensure they were suitable for Connected Vehicle applications.

Integration of DSRC capabilities for Connected Vehicles with signal controllers may in many cases, however, require upgrade or replacement of the existing controllers. The scope, cost and scheduling of these changes are significant considerations in the deployment scenarios. This section provides an initial order-of-magnitude assessment of the effort required to implement the signal controller capabilities supporting Connected Vehicle applications across the U.S.

## Controllers in Service

The total number of traffic signal controllers in service in the U.S. is estimated to be 307,000. As shown below, this number includes a variety of models with differing capabilities relative to Connected Vehicle readiness.

	<b>Controller Type</b>	<b>Speed</b>	<b>Comm</b>	<b>OS</b>	<b>API</b>	<b>In Service</b>
1	ATC 5.2b	Yes	Yes	Yes	Yes	8,000
2	Model 2070LX	Yes	Yes	Yes	Yes	0
3	Model 2070E	Yes	Yes	Yes	No	0
4	Model 2070L	Yes	Yes	Yes	No	52,000
5	NEMA, Modern	Yes	Yes	33%	No	36,000
6	NEMA, Legacy	No	Adaptor	Yes	No	91,000
7	Type 170, Modern	Yes	Yes	No	No	12,000
8	Type 170, Legacy	No	Adaptor	No	No	102,000
9	Electromechanical & Other	No	No	No	No	6,000
<b>Total:</b>						<b>307,000</b>

**Table 7: Types of Controller in Service in the U.S.**

Definition of Controller Types listed in Table 7:

1. ATC 5.2b: Controllers compliant to the joint AASHTO/NEMA/ITE standard ATC 5.2b which includes a Linux- based Engine Board capable of running multiple software applications concurrently. Refer to the Institute of Transportation website for a no-cost download.
2. Model 2070LX: Controllers compliant to the AASHTO/NEMA/ITE standard ATC 5.2b as in (1), but with added provisions to be compatible with legacy 2070 controllers by substituting a 2070-1C Linux board in place of the 2070-1B OS-9 board. Refer to CALTRANS website for Transportation Electrical Equipment specifications.
3. Model 2070E: Compatible with 332 cabinet style. 2070L software compatibility with hardware improvements such as serial port indicator lamps and others.
4. Model 2070L: Controller for use in 332 or 336 cabinet with standard OS-9 operating system to run different software applications, such as signal control, ramp meter and others. About 10% of this total is 2070N controllers that include a NEMA base for use in NEMA TS-1 and TS-2 Type 2 cabinets.
5. NEMA Modern: Recent production controllers for NEMA TS-1, TS-2 Type 1 and TS-2 Type 2 cabinet styles. Differentiated from NEMA Legacy by inclusion of an Ethernet port and the power to run Connected Vehicle applications.
6. NEMA Legacy: Older production controllers for NEMA TS-1, TS-2 Type 1 and TS-2 Type 2 cabinets. Differentiated by the lack of an Ethernet port and power to run Connected Vehicle applications.
7. Type 170 Modern: Recent production controllers for 332 and 336 cabinets. Differentiated from Type 170 Legacy by inclusion of an Ethernet port and the power to run Connected Vehicle applications.
8. Type 170 Legacy: Older production controllers for 332 and 336 cabinets. Differentiated from Type 170 Modern by the lack of an Ethernet port and power to run Connected Vehicle applications.
9. Electromechanical: Synchronous-motor based controllers without software applications.

Traffic signal controllers as identified above can be evaluated according to the following four criteria: computer processing speed, communications support, standard operating system, and application programming interface. In the following paragraphs, a short analysis of each criteria is presented.

### ***Computer Processing Speed***

Adequate computing power would be needed to run any Connected Vehicle software applications on the signal controller without adverse effect on traffic signal control and communications. The ATC 5.2b standard compliant Model 2070LX requires a minimum of 400 MIPS (Millions of Instructions per Second), but some deployed 5.2b controllers typically run at 600 MIPS or greater. As a comparison, 2070L and 2070E controllers run at 4 MIPS. It has previously been determined that processing speeds of at least 60 MIPS will be required for Connected Vehicle applications. The processing speed of ATC 5.2b, Model 2070L and Modern NEMA controllers are therefore considered suitable for Connected Vehicle applications (based on experience with those installed on the VII test beds). The processing speed of legacy Type 170 and legacy NEMA controllers are not considered suitable for Connected Vehicle applications (based on parallel experience with installing basic VII applications on those legacy controllers). However, since there has been limited experience to date through existing Connected Vehicle test beds, additional analysis of processing capabilities maybe required as new Connected Vehicle applications are developed.

### ***Communications Support***

Modern traffic signal controllers include Ethernet and Internet Protocol (IP) that is well-adapted for connection to DSRC-based roadside equipment (RSE). Legacy NEMA and Type 170 controllers lack Ethernet support and require the expense of an environmentally-hardened Ethernet adaptor to convert the controller's serial communications port to Ethernet port of the RSE. A more detailed analysis of communications suitability is included in "Controller Interfaces" section below.

### ***Standard Operating System (OS)***

In this context, the "standard" OS refers to either OS-9, required by the ATC 2070 Standard, or Linux 2.6 required by the ATC 5.2b Standard. Use of a standard OS allows interoperability of software applications among controller types and manufacturers. As shown in Table 7 above, modern NEMA controllers vary in that some manufacturers chose to use a standard OS while other did not. For this analysis, one-third of Modern NEMA controllers are estimated to use a standard OS, while two-thirds of modern NEMA controllers do not. Proprietary controllers using a non-standard OS will run applications developed specifically for that controller, but would not run the library of standard applications developed for OS-9 and Linux 2.6 such as those running on the USDOT-funded test beds. As shown, modern Type 170 and 67% of modern NEMA controllers using non-standard operating systems are considered suitable for Connected Vehicle applications, but may result in added time and cost to port standard applications to non-standard operating systems.

### ***Application Programming Interface (API)***

A controller API allows several software applications to run at the same time, analogous to adding "apps" to a smartphone without altering the basic function of the phone. For example, ATC 5.2b controllers would allow applications, such as those for transit, collision avoidance and weigh-in-motion, to be added without altering the signal control software. As shown, the API is not a requirement for Connected Vehicle applications, but the API would enable an agency to add

applications without loading and testing a new version of the signal control software specifically configured for those applications.

## Controller Upgrades and Replacements

Based on the controller profiles described above, Table 8 presents an initial assessment of the need for controller upgrade or replacement to support Connected Vehicle applications.

Line	Controller Type	Upgrade Necessary for RSE
1	ATC 5.2b	None
2	Model 2070LX	None
3	Model 2070E	None
4	Model 2070L	None
5	NEMA Modern	Standard OS (33%): None Non-Standard OS (67%): Port App, Cross-compile, Test
6	NEMA Legacy	Replace Controller
7	Type 170 Modern	Port App, Cross-compile, Test
8	Type 170 Legacy	Replace Controller
9	Electromechanical controllers	Replace Controller

**Table 8: Need for Controller Upgrades**

### ***Controller Hardware Upgrade Cost***

For the purposes of this preliminary analysis, the data presented in the previous sections can be used to estimate controller upgrade costs. This cost estimate includes the following:

- The cost of replacing legacy controllers
- The cost of upgrading traffic signal control software
- Installation cost of new controllers and software

These estimated controller hardware replacement costs are shown in Table 9 below. These estimates, however, include a number of assumptions and are acknowledged to exclude certain costs (such as cabinet replacements) that may be required when a signalized intersection is being upgraded to support Connected Vehicle applications. The assumptions and identified exclusions are discussed in the text after Table 9.

	<b>Controller Type</b>	<b>Replaced</b>	<b>Cost Range Ea.</b>	<b>Cost Total Range</b>
1	ATC 5.2b	0	\$ 0	\$ 0
2	Model 2070L	0	\$ 0	\$ 0
3	NEMA Modern:			\$ 0
	Standard OS (33%)	0	\$ 0	\$ 0
	Non-Standard OS (67%)	0	\$ 0	
4	NEMA Legacy (Shelf)	91,000	\$ 1,350 - \$2,350	\$ 122,850,000 - \$213,850,000
5	Type 170 Modern	0	\$ 0	\$ 0
6	Type 170 Legacy (Rack)	102,000	\$ 2,200	\$ 224,400,000
7	Electromechanical controllers	6,000	\$ 900	\$ 5,400,000
			<b>Totals:</b>	<b>\$352,650,000 - \$443,650,000<sup>22</sup></b>

**Table 9: Estimated Controller Upgrade Costs (equipment only)**

***Basis of Cost Estimates and Effects of Procurement Size***

Cost data used in this estimate is drawn from publicly-awarded procurements for signal controller replacements as follows:

- Rack-mount controller cost shown is from a publicly-awarded contract for 2070L controllers that included the 2070-1C module for ATC 5.2b compliance
- Shelf-mount controller cost shown is from a publicly-awarded contract for NEMA TS-2 Type 1 controllers compliant to ATC 5.2b compliance

The effects of procurement volumes and methods are outside the scope of this study, but should, however, be taken into consideration. Note that the “Cost EA” column includes cost awards on high-volume contracts that would be expected to be the minimum cost if the replacements are funded by multiple stakeholders using pooled funding for large-volume procurements.

For example, the Electromechanical controller Cost EA originated from a high-volume procurement of NEMA TS-2 Type 1 controllers that do not include the connectors for parallel wiring required for TS-1 or TS-2 Type 2 cabinets. This example may not necessarily be representative of the lower purchasing power of other, smaller agencies. Nor does it take account of the need for complete intersection overhaul that may be required that could include new cabinets and other support equipment.

Other statewide contracts for modern NEMA TS-2 Type 2 controllers have been recently awarded with costs of \$1,850 and \$2,350 per controller.

***Traffic Signal Software Cost***

The cost estimate assumes that no additional traffic signal control software cost is included for the replaced controllers. Additional assumptions include the following:

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<sup>22</sup> The cost estimate presented in this table includes only the direct costs for controller upgrade. Other assumptions and exclusions exist in this estimate, and care should be taken when quoting this number without due consideration of the accompanying text in this section. Additional costs could be significant.

- For purposes of this study, the Legacy NEMA controllers of Line 4 above are assumed to be replaced with shelf-mount ATC 5.2b controllers with signal control software included.
- For purposes of this study, the Legacy Type 170 controllers of Line 6 above are assumed to be replaced with rack-mount Model 2070LX controllers containing 2070-1C module compliant to ATC 5.2b standard. The signal control software is assumed to be pre-licensed, meaning developed by the agency purchasing the controllers, or software license that carries forward and recompiled for use on the Model 2070LX.

### ***Controller Installation Cost***

It is acknowledged that different agencies will have different approaches to controller replacement for Connected Vehicle applications: some agencies will consider the installation cost of the new controller to be part of the capital purchase; others may view that cost as a maintenance activity. In either case, the labor cost to test new controllers after shipping, and the labor to install and then test intersection data in the field must be taken into account when developing an overall cost estimate. While an installation cost has not been specifically included in the cost estimates presented in this section, it has been suggested that the labor cost for controller replacement would be comparable to the labor cost incurred to place the intersection in FLASH during an agency's controller inspection activities.

### ***Cabinet Replacement Cost***

For purposes of this study, we assume the existing cabinets will remain in place and are not part of the replacement cost for the following reasons:

- The Model 2070 controller design includes interface modules for 332, 336, NEMA TS-1, NEMA TS-2 and ITS cabinet styles.
- The ATC 5.2b standard also includes interfaces and standard connectors for 332, 336, NEMA TS-1, NEMA TS-2 and ITS cabinet styles.

For simple estimating purposes, it has been suggested that cabinet replacement costs where required could be in the range of \$10,000-\$11,000.

## **Controller Interfaces**

Traffic Signal Controllers typically include one or more built-in communications interfaces, as well as the option to add plug-in or external communications interfaces. This section describes the communications interfaces typically found on traffic signal controllers by type, as well as the suitability of each communications interface for Connected Vehicle applications.

It should be noted that other methods to interface with a controller, especially older microprocessor-based controllers, could be developed. The discussion in this section is not intended to constrain progress in this program area.

## ***Asynchronous Serial Port***

### Description

Asynchronous Serial Ports transmit and receive individual characters one at a time, at data rates typically ranging from 1200 to 9600 bits per second in traffic control applications. These individual characters are typically converted to audible tones on phone lines connecting the traffic signal controller to the traffic management center. The binary values of “1” and “0” are created (modulated) by shifting between the two frequencies, using a Frequency Shift Keying (FSK) modem (modulator/demodulator). Communications media other than phone lines is supported by standard EIA-232 connection to an external modem, such as EIA-232 to fiber optic modem. Note that serial communications is often added to the oldest electromechanical controllers in service using an external Remote Terminal Unit (RTU), which senses the states of the controller inputs and outputs, then transmits those states to the traffic management center via serial communications.

### Availability

Serial communications interfaces are widely-deployed and available on all traffic signal controllers as built-in, available as a plug-in option or available by external RTU.

<b>Line</b>	<b>Controller Type</b>	<b>Serial Communications</b>
1	ATC 5.2b	Rack-Mount: Option Board for EIA-232 and FSK Shelf-Mount: Built-In
2	Model 2070LX	Option Board for EIA-232 and FSK
3	Model 2070E	Option Board for EIA-232 and FSK
4	Model 2070L	Option Board for EIA-232 and FSK
5	NEMA TS-2 Ethernet (modern)	Built-In Port 3 for EIA-232 and FSK
6	NEMA TS-1 (legacy)	Built-In Port 3 for EIA-232 and FSK
7	Type 170 controllers (modern)	Built-In EIA-232 and FSK
8	Type 170 controllers (legacy)	Built-In EIA-232 and FSK
9	Electromechanical controllers	External Remote Terminal Unit (RTU), EIA-232 and FSK

**Table 10: Controller Serial Communications**

### Suitability

Serial Ports are not well-suited to Connected Vehicle applications. Serial Ports have been successfully used to interface both Legacy Type 170 and legacy NEMA controllers to Connected Vehicle RSEs. Although the serial connection successfully sent and received characters representing the controller SPaT, the Serial Port connection was unacceptable due to the following:

1. Latencies between actual signal state and the SPaT message exceeded the 50 mS maximum delay on the Control Channel required for Connected Vehicle safety applications, such as collision avoidance and automatic braking.
2. Serial Port transmitting at 1200 to 9600 bps limited the usefulness of the Service Channel for exchange of long messages between the vehicle and roadside infrastructure.
3. Expense of an environmentally-hardened EIA-232 to Ethernet converter provided the End User less value than investing in an upgrade to ATC 5.2b with Ethernet and computational speed to support Connected Vehicle applications anticipated over the next decade.



## ***Synchronous Data Link Control (SDLC)***

### Description

SDLC is a mature communications standard originally deployed to connect mainframe computers to data-entry terminals in an office environment. SDLC is an improvement over Serial Ports in that SDLC transmits and receives long blocks of data, versus the single characters of Asynchronous Serial Ports. In traffic signal control applications, SDLC is used to connect subassemblies within the roadside cabinet at data rates of 153 K bps in NEMA cabinets, or 614 K bps in ITS cabinets.

### Availability

<b>Line</b>	<b>Controller Type</b>	<b>SDLC Communications</b>
1	ATC 5.2b	Rack-Mount: 614 K bps to Input File and Output File Shelf-Mount: 153 K bps to Detector Rack and Load Bay
2	Model 2070LX	Rack-Mount: 614 K bps to Input File and Output File Shelf-Mount: 153 K bps to Detector Rack and Load Bay
3	Model 2070E	Rack-Mount: 614 K bps to Input File and Output File Shelf-Mount: 153 K bps to Detector Rack and Load Bay
4	Model 2070L	Rack-Mount: 614 K bps to Input File and Output File Shelf-Mount: 153 K bps to Detector Rack and Load Bay
5	NEMA TS-2 Ethernet (modern)	Shelf-Mount: 153 K bps to Detector Rack and Load Bay
6	NEMA TS-1 (legacy)	None
7	Type 170 controllers (modern)	None
8	Type 170 controllers (legacy)	None
9	Electromechanical controllers	None

**Table 11: Controller SDLC Communications**

### Suitability

Although included in both 2070 ATC and ATC 5.2b standards, SDLC is not well suited for Connected Vehicle applications. NEMA controllers use SDLC Port 1 as an interface between internal electrical cabinet subassemblies. Standards 2070 ATC and ATC 5.2b have an optional EIA-485 board to communicate using SDLC. But like Serial Ports, the expense of adding this EIA-485 board as well as adding an environmentally-hardened EIA-485 to Ethernet converter will provide the end user less value than investing in an upgrade to ATC 5.2b with Ethernet and the computational speed to support Connected Vehicle applications anticipated over the next decade.

### ***Ethernet***

### Description

Ethernet is compliant to IEEE 802.3 standards and widely-deployed in computer applications. Ethernet transmits long blocks of data at rates of 10 M bps and above.

Availability

2070 ATC, ATC 5.2b, modern NEMA controllers and modern Type 170 controllers include one or more Ethernet ports, each with Internet Protocol (IP) address. Although both 2070 ATC and ATC 5.2b require a minimum data rate of 10 M bps (10 Base-T), the ATC 5.2b controller deployed to date will also support data rates of 100 M bps (100 Base-T).

Line	Controller Type	Ethernet Communications
1	ATC 5.2b	ENET1: 10 Base-T to Traffic Management Center ENET2: 10 Base-T to Roadside Equipment
2	Model 2070LX	ENET1: 10 Base-T to Traffic Management Center ENET2: 10 Base-T to Roadside Equipment
3	Model 2070L	ENET: 10 Base-T to TMC & RSE using Ethernet Switch
4	Model 2070E	ENET: 10 Base-T to TMC & RSE
5	NEMA TS-2 Ethernet (modern)	ENET: 10 Base-T to TMC & RSE using Ethernet Switch
6	NEMA TS-1 (legacy)	None
7	Type 170 controllers (modern)	ENET: 10 Base-T to TMC & RSE using Ethernet Switch
8	Type 170 controllers (legacy)	None
9	Electromechanical controllers	None

**Table 12: Controller Ethernet Communications**

Suitability

Ethernet is most suitable for Connected Vehicle applications. In fact, the ATC 5.2b standard includes a second Ethernet port (ENET2) dedicated to a local area network (LAN) for roadside equipment. Ethernet has the added advantage of being electrically isolated from the controller electronics to provide a measure of immunity to radiated noise picked up by the Ethernet cable. Ethernet supports both the sub-50 mS latencies required by a Connected Vehicle Control Channel, as well as the ability to communicate the long messages of the Service Channel.

**Universal Serial Bus (USB)**Description

USB is the modern replacement for Serial Ports on laptop computers and other commercial devices. Whereas Serial Ports are physically Point to Point, USB topology is Multipoint, meaning that one computer can be connected to multiple peripheral devices using a USB hub. USB data rates supported include the following:

- USB 1.0: Low Speed of 1.5 M bps
- USB 1.1: Full Speed of 12 M bps
- USB 2.0: High Speed of 480 M bps

Availability

Line	Controller Type	USB Communications
1	ATC 5.2b	USB 1.1
2	Model 2070LX	USB 2.0
3	Model 2070E	None
4	Model 2070L	None
5	NEMA TS-2 Ethernet (modern)	None
6	NEMA TS-1 (legacy)	None
7	Type 170 controllers (modern)	None
8	Type 170 controllers (legacy)	None
9	Electromechanical controllers	None

**Table 13: Controller USB Communications**Suitability

Although possessing high data transfer rates and inclusion in the ATC 5.2b standard, USB is not well suited for Connected Vehicle applications. USB is not electrically isolated from the controller electronics, which allows the USB cable to provide an adverse receiving antenna that can allow radiated noise to enter the controller. The ATC 5.2b USB port is intended to be used for memory sticks and Bluetooth devices that have no external wires, or have an external antenna that is isolated from the controller circuitry. The ATC 5.2b standard intends that all networked communications application be implemented via ENET1 or ENET2 that are electrically-isolated from the controller electronics.

**Procurement Issues**

As part of the Deployment Analysis, guidance is offered here to assist agencies in specifying Connected Vehicle-compatible traffic signal controllers for future procurements.

***ATC 5.2b: USA National Standard***

It is recommended that new controller procurements reference the ATC 5.2b (or later) Standard, which is the top-level, overarching traffic signal controller standard compatible with widely-deployed cabinet styles. ATC 5.2b standard is balloted and approved by NEMA, ITE and AASHTO including Caltrans and incorporates several key features required by current and future Connected Vehicle applications as follows:

- Dedicated ENET2 Ethernet connection to RSE
- ATC 5.2b Standard, Minimum of 60 MIPS computational speed Connected Vehicle software applications
- Model 2070LX minimum of 400 MIPS
- Model 2070LX with Embedded Linux 2.6.18 Kernel or later
- ATC 5.2b Standard, Embedded Linux 2.6 operation system for interoperability of Connected Vehicle software applications among controller manufacturers

- Minimum of 60 MIPS computational speed for Connected Vehicle software applications
- Engine Board interchangeable among manufacturers that consists of the microprocessor and memory components most prone to obsolescence. As electronic components become obsolete, the older Engine Board containing obsolete parts can be replaced with a newer Engine Board with modern components.

The ATC 5.2b standard is available as a no-cost download from [ite.org/standards](http://ite.org/standards).

Agencies adopting the ATC 5.2b Standard should also be explicit in requiring the use of the ATC Application Programming Interface (API). This approach should reduce the cost of developing Connected Vehicle software on the ATC 5.2b platform and enhance the likelihood of software interchangeability from different vendors.

### ***Caltrans Transportation Electrical Equipment Specification (TEES)***

TEES is not a Standard, but rather a Procurement Specification for equipment purchased by Caltrans, as well as by other agencies. Currently Caltrans procurements are compliant to TEES 2009, plus Addendums. The TEES 2009 references the ATC 5.2b Standard, specifically with the Model 2070LX with a 2070-1C module that provides ATC 5.2b compliance. The Model 2070LX can be used to replace existing Model 2070L and Model 2070Es to an ATC 5.2b compliance as a retrofit. Agencies procuring to the Caltrans TEES may specify use of the 2070E or Model 2070LX in place of the 2070L, as well as specifying the Linux version of their traffic signal control software for the 2070L.

### ***National Electrical Manufacturers Association (NEMA) TS-2 Standard***

NEMA TS-2 is not an agency procurement specification, but rather a standard that is referenced in procurement specifications. Several manufacturers currently produce NEMA TS-2 standard controllers that are also compliant to the ATC 5.2b standard, including Engine Board, ENET2, Linux 2.6 operating system and 60 MIPS computational speed for Connected Vehicle software applications. Agencies procuring to the NEMA TS-2 standard may specify either TS-2 Type 1 or TS-2 Type 2, depending upon cabinet used, and would also need to specify ATC 5.2b compliance, if desired. Since NEMA traffic signal control software is included in the controller, the Linux version of traffic signal control software is supplied without special provisions.

### ***Special Provisions***

Procurement specifications typically include Special Provisions to provide functions and features needed by the agency, beyond the minimums listed in the ATC 5.2b Standard as shown in the following:

- **Memory Requirements:** The ATC 5.2b Standard lists the minimum memory required to be ATC 5.2b compliant. When specifying controllers for Connected Vehicle applications, be sure to include a Special Provision for any additional memory required by the software applications. This information is available from the software vendor, just as software purchased for personal computers lists the memory requirements needed.
- **Libraries:** Annex A and Annex B of the ATC 5.2b standard lists the minimum library and tool set required to be included in the controller. When specifying controllers for Connected Vehicle applications, be sure to include a Special Provision for any additional libraries or tools

required by the software applications. This information is also available from the software vendor.

## Software Costs and Impact

### ***Traffic Signal Control Software Impact***

#### Intersection Status Message

Connected Vehicle-equipped intersections issue a continuous, periodic Intersection Status message acting as a “heartbeat” containing FLASH status. Approaching vehicles use this message to enable collision avoidance strategies for that intersection.

#### Signal Phase and Timing (SPaT) Message

The SPaT message is derived from the traffic signal control software, transmitted by the RSE to nearby vehicles. Vehicles use the SPaT message to identify the state of each signal phase as well as a countdown time to the next signal phase. SPaT messages were developed and successfully tested on the U.S. DOT test beds with < 50 mS latency between roadside signal and navigation screen display.

#### Effects on Control Strategies

1. Pre-timed Control has no Connected Vehicle deployment cost associated with software development or changes to the controller database. Pre-timed intersections provide approaching vehicles with a continuous SPaT countdown to the next phase change without need to modify the controller timing plan.
2. Actuated Control has no Connected Vehicle deployment cost associated with software development or changes to controller database. For example, when the RSE picks up an approaching side street vehicle, a SPaT countdown to main street RED is initiated, until the vehicle passes and the signal is back to main street GREEN. No further SPaT messages will be issued until other vehicles arrive.
3. Pedestrian phases have no Connected Vehicle deployment costs associated with software development or changes to the controller data base. Pedestrian phase changes are transmitted in the SPaT message as they occur.
4. Coordinated “Green Wave” corridors have no Connected Vehicle deployment cost associated with software development, but do incur a small Connected Vehicle deployment cost of changing the controller data base to realize the Connected Vehicle safety benefits.

### ***DSRC Roadside Equipment Software Impact***

#### RSE Software Applications

RSEs are assumed to have no additional software deployment costs. It is believed that the cost of an RSE will typically include an embedded microcontroller, Linux operating system and at least the following software functionality:

- Software to translate the controller Ethernet SPaT message to J2735 wireless message

- Software to create the wireless Intersection Status message to vehicle (heartbeat)
- Software to create the wireless Vehicle Pre-emption and Priority messages
- Software to create the wireless Map messages, indicating intersection geometry
  - For example, a driver knows which facing traffic signal to obey, depending upon which lane the vehicle occupies. Likewise, the vehicle computer receives all signal phases and needs to know the intersection lane locations to determine which signal phase applies. This information is supplied to the vehicle via the Map message.

#### RSE Software Updates and Maintenance

Because the J2735 Message Set includes a wide and ever-growing array of vehicle messages, agencies can expect to periodically update the software in each RSE. To that end, each RSE includes a FLASH memory drive used to receive message set updates via the Ethernet connection, from either roadside or central.

#### **Source of Data**

##### Total Installed Base

No comprehensive, agency-by-agency data exists for the total number of signalized intersection in the U.S. A 2004 Institute of Transportation Engineers (ITE) project, "Signal Timing Practices and Procedures: State of the Practice", included a survey of a large number of jurisdictions of all sizes, to estimate the total number of signalized intersections in the U.S., that report concluded that a very accurate "rule of thumb" is one signalized intersection per 1,000 populations. That would mean that, as the U.S. has an estimated 2009 population of 307 million, the U.S. has 307,000 signalized intersections. For verification, this "rule" was tested using data from 75 urban areas with a total population 168,895,184. The total number of signals in these metropolitan areas was 153,228, meaning that the ratio of traffic signals to population is one signal per 1,102 of population.

##### Categorization by Technology

No comprehensive, agency-by-agency data exists for categorization of traffic signal controller by technological readiness for Connected Vehicle RSEs. For this study, the ATC Joint Committee was tapped to provide a best estimate, being organized under a Memorandum of Understanding among ITE, NEMA and AASHTO with strict anti-trust guidelines. Short of a comprehensive, agency-by-agency survey, the Joint Committee voted to proceed by querying the sales and distribution organizations of the NEMA manufacturers for the following reasons:

- NEMA manufacturers have nation-wide sales and distribution, covering each agency.
- NEMA manufacturers are familiar with the technology used in the design of each type of traffic signal controller as it relates to Connected Vehicle readiness. For example, controllers in service may include the necessary communications ports to connect to a Connected Vehicle RSE, but still lack the computational power for Connected Vehicle applications.

The information was collected under strict anti-trust guidelines prohibiting information relating to market share, sales price, manufacturing cost or vendor of the deployed equipment. The only data collected related to number of signal controllers in service, categorized by technology.

Cost of Traffic Signal Controller Replacements

The cost estimate for traffic signal controller replacements was taken from publicly-awarded contracts for ATC 5.2b controllers as follows:

NEMA TS-2 Type 1:	New York City ASTC Award = \$900
NEMA TS-2 Type 2:	City of Toronto = \$1,350
2070 Controller including 2070-1C module:	Harris County TX Service Contract = \$2,200

# Applications of Interest

During the course of the VII and Connected Vehicle programs, a very broad set of potential applications have been identified. For the deployment assessment, it is important to focus on those applications that have the greatest applicability to state and local transportation agencies.

In earlier work during the VII program, applications were generally divided into “public” and “private.” This earlier segmentation is useful and is revisited here for several reasons. First, it can be seen that there has been a particular shift in a number of application areas from the public side to the private side. In the last few years, application areas that might have been considered the traditional role of the public sector, such as traveler information, have been taken over by both commercial service providers and free web-based services. Second, in some instances, there may be no absolute division between a private and public application. For instance, an application developed and offered to consumers by the private sector may be enhanced by input from the public sector. Finally, the potential set of applications has grown, and indeed continues to grow, since the earlier development work. These factors are considered in the identification of appropriate applications that will form the basis of the deployment analysis.

To identify which applications may best serve the interests of the state and local transportation agencies and their constituents, it is useful to examine the objectives behind any Connected Vehicle deployments by the public sector. General descriptions of the Connected Vehicle programs developed by U.S. DOT state that if successfully deployed, such programs will enhance safety and mobility, while helping to reduce the environmental impact of surface transportation.

In addition, AASHTO’s Connected Vehicle Strategic Plan 2009<sup>23</sup> provided a mission statement for these programs as intending “to dramatically improve safety and mobility, facilitate electronic payment, improve operational performance, and reduce the environmental impact of road travel.” This identifies two additional objectives. Collectively, five objectives can be considered in the selection of applications by state and local agencies included in the following:

- Improve safety
- Enhance mobility
- Reduce environmental impacts
- Facilitate electronic payments
- Improve operational performance of agencies

These objectives are frequently interconnected—for example, improving safety implicitly reduces crashes and other incidents that could reduce mobility. Similarly, some applications may contribute to

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<sup>23</sup> American Association of State Highway and Transportation Officials (May 2009). *IntelliDrive<sup>SM</sup> Strategic Plan 2009*. Washington, D.C. (Document prepared by Mixon Hill, Inc.)



achieving multiple objectives. These applications, therefore, do not fit neatly under a particular objective. Exploring the nature of each objective a little further, however, can help provide a greater understanding of what expectations state and local agencies may have from these applications.

**Improve Safety** - Improving transportation safety has become the keystone opportunity for Connected Vehicle deployment. As described in the approach in the U.S. DOT Policy Paper<sup>24</sup>, a recent NHTSA analysis concluded that:

“Up to 79 percent of all crashes by unimpaired drivers could potentially be addressed by V2V technology. If V2V were in place, another 16 percent of crashes could potentially be address[ed] by V2I technology.”

Crashes contributing to these estimates for V2V cases included forward collisions, lane change and merge collisions, and intersection collisions; and for V2I cases, road departure and intersection crashes. In terms of more specific objectives, applications contributing to improved safety would, for example, create results that include the following:

- Reduce the likelihood of collisions at intersections
- Reduce the likelihood of forward and lateral (lane change and merge) collisions
- Reduce the likelihood of secondary crashes
- Reduce the likelihood of road departure crashes
- Provide more accurate and timely road condition alerts

**Enhance Mobility** - The societal economic incentives to improve mobility are well known. Traffic congestion costs the U.S. economy millions of hours and billions of dollars every year. Improved utilization of the existing infrastructure would take pressure off the need for construction of new facilities and increase attention to rehabilitation and improved maintenance of existing facilities. Objectives contributing to enhanced mobility would include the following:

- Make more efficient use of capacity (e.g., implement adaptive flow control)
- Provide more accurate and timely traveler information
- Reduce impacts of incidents on traffic flow

**Reduce the Environmental Impact of Road Travel** - Current economic and global environmental conditions are turning attention to the impacts of travel on the environment. Operational objectives for reducing the environmental impacts coincide with and reinforce some of the objectives noted above. Operational objective include the following

- Reduce excess emissions from inefficient traffic operations that otherwise reduce mobility

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<sup>24</sup> U.S. Department of Transportation, Research and Innovative Technology Administration, ITS Joint Program Office (April 2010). *Achieving the Vision: from VII to IntelliDrive<sup>SM</sup>*. Washington, D.C.

- Reduce excess treatment materials (e.g., salt), further reducing costs and improving operational performance

**Facilitate Electronic Payment** - Improving the speed and accuracy of electronic payments within the transportation infrastructure could contribute to enhanced mobility and reduced cost of operations. The focus here is on those payments made to transportation agencies, but the technologies could facilitate other payments as well included in the following:

- Automate toll payments
- Automate fee payments

**Improve Agency Operational Performance** - Although much of the focus in Connected Vehicle discussions has been on safety and traveler benefits, the transportation agencies could benefit more directly from these deployments. Agencies could, for example, seek improvements that include the following:

- Reduce dependence on DOT traffic monitoring infrastructure
- Improve transportation asset condition monitoring
- Reduce resources needed for system maintenance
- Increase the availability of information for performance measurement.

Beyond these key objectives, there are additional practical considerations that help identify the relevance of particular applications to state and local agencies. These topics help differentiate the role of the public sector versus that of the private sector in the delivery of an application. These topics include the following:

- The need for a roadside infrastructure for the successful operation of an application
- The need for access to publicly-gathered or generated data to create an effective application
- The need for devices to be installed in publicly maintained vehicle fleets for the successful operation of an application.

Finally, selection of related applications should also consider programmatic criteria that may affect a successful deployment. Highly desirable applications would be those designed to satisfy key functional objectives *and* to advance related programmatic benefits. Higher priority might be given to applications that, for example, include the following:

- Create additional opportunities for Connected Vehicles to interact with the infrastructure
- Provide functionality not currently in place or achievable through established technologies
- Maintain and apply standards for interoperability of hardware and software
- Show near-term or local benefit to stakeholders, rather than depending on broad deployments

- Are achievable without depending on integration of Connected Vehicle components with vehicle systems as original equipment

## Sources of Information

The *Background* section of this report documents the original list of VII applications, together with the subsequent “Day One” applications. Since that time, however, there has been significant work undertaken to define and develop applications for the Connected Vehicle programs. Additional sources of information that have been used to identify potential applications for consideration in this report include the following:

- Interviews with U.S. DOT personnel and reviews of Connected Vehicle roadmaps
- Review of a draft report on crash data analyses<sup>25</sup> prepared for U.S. DOT, and subsequent collaboration between members of the U.S. DOT V2I safety team and the AASHTO Connected Vehicle Working Group
- A review of projects conducted by state and local transportation agencies
- Current projects performed under the Pooled Fund Study
- Candidate Dynamic Mobility Applications identified at [http://www.its.dot.gov/intellidrive/app\\_template/DMAcandidateAppsSummaryAug.htm](http://www.its.dot.gov/intellidrive/app_template/DMAcandidateAppsSummaryAug.htm)
- The reported outcomes of the TRB Workshop on Research Needs for IntelliDrive<sup>SM</sup> Applications for the Public Sector, September 21-22, 2010

These sources provide a rich set of potential applications that can be considered in the development of the deployment scenarios described later in this report.

## Applications Analysis

The intent of this analysis is to provide a core set of potential applications that are suitable for incorporation into the deployment scenarios. Applications to be evaluated must both relate to one or more of the deployment objectives and have a clear connection to the Connected Vehicle framework—the exchange of information among vehicles and infrastructure. A wide range of applications is possible within these constraints.

Prior lists of potential use cases have included applications directly related to the deployment objectives (e.g., electronic toll payment) and those which provide general capabilities (e.g., in-vehicle signing or probe data); applications involving a single mode (e.g., transit vehicle signal prioritization) and multiple modes (e.g., highway/rail intersection warnings); and applications for any one or combination of stakeholders (e.g., drivers, transportation system managers, commercial vehicle operators, emergency services dispatch, or commercial services of all types). Applications discussed

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<sup>25</sup> U.S. Department of Transportation, Federal Highway Administration (June 2010). *Crash Data Analyses for IntelliDrive<sup>SM</sup> Vehicle-Infrastructure Communications for Safety Applications*. Washington, D.C. (Document prepared by Vanasse Hangen Brustlin, Inc.)

here may contribute to one or more use case, and represent only a fraction of those that might be enabled by a complete Connected Vehicle deployment.

## Intersection Safety

Intersection safety applications attempt to reduce the likelihood and severity of incidents between vehicles at intersections. Historically, safety “applications” have been in the form of intersection traffic controls—predominantly signs and signals. V2I safety applications will largely be extensions of or supplements to those controls. Intersection safety applications received significant attention in the early stages of VII use case identification and were the focus of several Cooperative Intersection Collision Avoidance Systems (CICAS) applications. Parallel efforts in Europe have been represented by the Intersafe project.

While the potential for intersection incidents depends primarily on driver/vehicle behaviors, it is further enabled or constrained by the physical arrangement of the intersection, any traffic controls that may be present, and interactions with other modes (pedestrians, transit, and emergency vehicles). This diversity of interaction between passenger vehicles and other modes, traffic controls and the infrastructure at an intersection, led to classifying solutions specific to the types of interaction. The CICAS applications developed in parallel with the VII program covered three specific cases shown below:

- **CICAS-Violation (CICAS-V)** would warn drivers of the potential for violation of a traffic signal or stop sign using in-vehicle indicators.
- **CICAS-Stop Sign Assist (CICAS-SSA)** would inform drivers on a minor roadway of unsafe conditions associated with insufficient gaps in traffic at an intersection with busier roadway using a dynamic message sign (DMS).
- **CICAS-Signalized Left Turn Assist (CICAS-SLTA)** would inform drivers of unsafe conditions for making an unprotected left turn at a signalized intersection using DMS or in-vehicle indicators.

A more recent preliminary analysis of crash data in support of safety applications<sup>26</sup> refines and expands the CICAS categories as follows:

- **CICAS–Signalized Left Turn Assist (CICAS-SLTA)** application area is intended to assist vehicles waiting to turn left at signalized intersections with permitted left turns. The application area assists the driver with gap acceptance. The relevant crash type is a multi-vehicle crash involving a left turning vehicle and a through vehicle.
- **CICAS–Traffic Signal Violation (CICAS-TSV)** application area is intended to address crashes that result from signal violations. This application area provides a warning to both the driver who is in danger of violating the signal and the driver on the conflicting approach.
- **CICAS–Traffic Signal Adaptation (CICAS-TSA)** application area is similar to the CICAS-TSV system in that it is intended to address crashes that result from signal violations. However, this application is intended to address crashes that occur at the onset of the red

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<sup>26</sup> *ibid*

interval at signalized intersections from signal violations. Upon sensing that a vehicle is about to violate the signal at the onset of the red interval, the application would adapt the traffic signal timings so the conflicting approach would be held at a red signal instead of being released with a green signal.

- **CICAS–Stop Sign Assist (CICAS-SSA)** application is intended to address crashes that result from poor gap acceptance at two-way stop-controlled intersections. This includes stop-controlled vehicles that are going straight or turning at the intersection.
- **CICAS–Stop Sign Violation (CICAS-SSV)** application is intended to address crashes that result from stop sign violations at stop-controlled intersections. This includes two-way, four-way, and other stop-controlled intersections.

This recent analysis documents the potential impacts of current intersection safety applications (including extensions thereto to address conflicts with pedestrians and cyclists)<sup>27</sup>. The potential impacts assume 100 percent effectiveness of the application and 100 percent deployment. The results are presented below in Table 14.

Application	Estimated Annual Crashes (Weighted)	Annual Cost (\$)
CICAS-SLTA	200,212	\$9,759,131,692
CICAS-SLTA Extensions	5,013	\$579,571,248
CICAS-TSA	229,333	\$12,261,025,825
CICAS-TSV	234,013	\$12,511,250,841
CICAS-SSA	250,997	\$15,880,166,220
CICAS-SSV	74,693	\$3,807,849,579
CICAS-SSV Extensions	3,843	\$444,938,193

**Table 14: Potential Impacts of Current Intersection Safety Applications**

### ***Applicable Development Efforts***

Successful deployment of intersection safety applications will require information about the roadway, vehicles (and potentially, pedestrians and cyclists), and control state for signalized intersections. The work done on the CICAS applications has already established some of the data and interface standards for each of these components.

SPaT information is common to several intersection safety applications. Two of the Year-1 applications in the Connected Vehicle PFS: *Connected Vehicle Traffic Signal Control Algorithms* and *Investigating the Potential Benefits of Broadcast SPaT Data under Connected Vehicles* represent current research in this area. In addition, the U.S. DOT is undertaking work to identify the necessary interfaces for two-way communication of traffic signal information between the traffic signal controller and a mobile device; provide the concept of operations for use of the interfaces; and develop prototypes of the interfaces using traffic signal controllers from two different manufacturers. These interfaces and prototypes are intended for use by applications that require SPaT and related messages. Michigan DOT is also engaged in SPaT development including upgrades to roadside equipment on Telegraph

<sup>27</sup> *Ibid* Table 100.

Road, and development and testing of a multi-phase traffic signal broadcast system for in-vehicle use in which SPaT information will be broadcast from a traffic signal controller, using DSRC and an alternative technique to extend the broadcast range of the SPaT information.

Many transportation agencies have been upgrading their traffic signal installations to be compliant with the Americans with Disabilities Act (ADA). This includes Accessible Pedestrian Signals (APS), which provide a means for a blind person to locate the pushbutton and provides an audible and tactile indication as to whether the walk light is on. Since the agency is already required to spend money for the upgrade and do work at the location, there is an opportunity to install an RSE at the signal, broadcasting the SPaT information, including the pedestrian timing. A handheld DSRC device would receive the message and provide the information to the pedestrian. In addition, the pedestrian could enter a pedestrian call using the handheld device.

A challenge to deploying pedestrian applications would be resistance to the idea that the pedestrian needs to carry a device to utilize the service. Also, unless the RSE is deployed at all signals, conventional pedestrian assistance will still be required at many or most signals.

### ***Synergy between Applications***

Other applications that address conflict at intersections would be conceptually similar to these intersection safety applications. Signal preemption for emergency vehicles and signal priority for transit vehicles could, for example, result in a change in signal timing that could be passed to other vehicles through the SPaT message. Pedestrian signal calls could likewise initiate a change in signal state. Non-intersection safety applications could use similar in-vehicle driver interfaces and local V2I communications.

## **Speed Warnings**

Speed warnings attempt to alert drivers that they are entering a reduced speed zone or that they are approaching a specific location where a higher-than-posted speed may be unsafe. Speed zone and spot speed warnings are applications that will be provided through some form of in-vehicle signing.

Speed warnings can be used in a variety of situations included below:

- Curve speed warnings - provide a warning to vehicles approaching horizontal curves on segments or interchange ramps above a threshold speed to address crashes that are speed related
- General speed zone warnings – provide a warning to speeding drivers approaching reduced speed zones
- School zone speed warnings - provide a warning to speeding drivers when reduced speeds are in effect in school zones
- Work zone speed warnings - provide a warning to speeding drivers when approaching active work zones

In-vehicle signing has been a consistently-identified application throughout the Connected Vehicle programs. In the broadest sense, in-vehicle signing could provide a visual driver-vehicle interface for any application. Most discussions thus far, however, have referred more specifically to applications

that would supplement existing fixed or mobile roadside signage and provide new capability for more specific and targeted messaging than can be effectively deployed on the roadside.

In concept, any message that is currently displayed on a traditional fixed sign or a dynamic message sign could be routed to an in-vehicle display. Messages could be presented for traffic control, to advise drivers of roadway conditions, or to provide more general traveler information (landmarks, directions, or services). The locations to which an in-vehicle sign applies could range from fixed geospatial coordinates and direction, to a route of travel, to a broadcast region.

The majority of in-vehicle signage applications considered in prior Connected Vehicle discussions is advisory. These messages notify drivers of traffic, roadway, or weather conditions that may affect their travel, but which do not constitute an immediate threat.

The previously-referenced crash data analyses<sup>28</sup> also assess the potential impacts of current speed warning applications, and their extensions (such as response to weather conditions on horizontal curves)<sup>29</sup>.

Application	Estimated Annual Crashes (Weighted)	Annual Cost (\$)
Speed Advisory and Warning Approaching Horizontal Curves	167,092	\$28,225,375,843
Speed Advisory and Warning Approaching Horizontal Curves Extensions	7,647	\$850,534,111
Speed Zone Applications	360,694	\$27,707,024,945
Work Zone Applications	16,364	\$1,300,714,358

**Table 15: Potential Impacts of Current Speed Warning Applications**

### ***Applicable Development Efforts***

Many navigation systems already provide the ability to display speed limits and “points of interest” that could be made to correspond to roadside signage. Irrespective of whether in-vehicle signage applications, including speed warning systems, are provided to drivers by the private sector, state and local transportation agencies will be a primary provider and continuing stakeholder in identifying and locating appropriate signage, including that already deployed to the roadside.

Minnesota DOT is currently implementing a demonstration of speed warning in-vehicle signing applications, including school speed zones and work zones. This project will utilize a commercially-available aftermarket navigation system enhanced to present speed warnings to participating drivers.

### ***Synergy between Applications***

The capabilities inherent to an in-vehicle signage application—the display and link to the vehicle’s current location—are common to any application needing visual interfaces for the vehicle’s driver. The display for in-vehicle signing will likely be provided either as part of the vehicle’s embedded driver interface, an aftermarket device, or some other mobile consumer electronics device, but in any case

<sup>28</sup> U.S. Department of Transportation, Federal Highway Administration (June 2010). *Crash Data Analyses for IntelliDrive<sup>SM</sup> Vehicle-Infrastructure Communications for Safety Applications*. Washington, D.C. (Document prepared by Vanasse Hangen Brustlin, Inc.)

<sup>29</sup> *Ibid* Table 100.

should conform to specifications consistent with the intent of the *Manual on Uniform Traffic Control Devices*.

## Fee Collection

Existing transportation payment systems are almost exclusively oriented toward the collection of tolls and fares. Manual collection at transaction booths along the roadway has steadily given way to automated cash collections, to station-based electronic transactions, and more recently to open-road tolling.

Payment systems have been part of the Connected Vehicle solutions suite since the inception of VII. Applications considered within this category have included the VII “Day-1” use cases for “Gasoline Purchases”, “Parking Fees”, and “Toll Roads”; other similar transportation fees and commercial transactions have been discussed. In the more recent plans, “electronic payment systems that support transformational system performance” are categorized with mobility applications<sup>30</sup>. Elimination of on-road tolling structures, for example, would greatly benefit mobility in areas where tolls are currently being collected. Connected Vehicle technologies may accelerate the transition to open road tolling systems.

It should be acknowledged that current RFID technologies and deployment approaches have proven to be both cost and operationally effective for the collection of highway tolls. However, the use of Connected Vehicle technologies in fee collection applications provides benefits beyond their function as a simple payment system. The Metropolitan Transportation Commission (MTC) of the San Francisco Bay Area has posited that the use of Connected Vehicle technologies on HOT lanes<sup>31</sup> will provide significant benefits to drivers in support of their decision to use the HOT lane rather than the free general purpose lane. In particular, Connected Vehicle applications will provide the driver with current dynamic pricing information for use of the HOT lane, as well as information on the potential travel time savings between the HOT and general purpose lanes.

Connected Vehicle technologies could also facilitate the collection of mileage-based user fees (MBUF) based on vehicle miles traveled (VMT). Interest in MBUF has accelerated as other sources of funds for transportation funding have stagnated. The Minnesota DOT analysis of and plans for a demonstration of an MBUF system identifies the importance to road user acceptance of accurately and effectively gathering, accumulating, and presenting mileage-based fees to drivers.<sup>32</sup>

### **Applicable Development Efforts**

MTC has previously developed a white paper on the application of Connected Vehicle technologies to HOT lane applications and was ready to perform a technology and application assessment on both test track and operational HOT lane facilities during 2011; however that plan is no longer being considered for contractual reasons. Minnesota DOT will conduct a demonstration of Connected Vehicle technologies for MBUF collection during 2011-12.

### **Synergy between Applications**

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<sup>30</sup> [http://www.its.dot.gov/intellidrive/intellidrive\\_research.htm](http://www.its.dot.gov/intellidrive/intellidrive_research.htm) accessed 1 June 2010.

<sup>31</sup> Metropolitan Transportation Commission (October 2009). *IntelliDrive<sup>SM</sup> Technologies to Support HOT Lane Operations*. Oakland, CA. (Document prepared by Mixon Hill, Inc.)

<sup>32</sup> Minnesota Department of Transportation (October 2009). *Vehicle Infrastructure Integration (VII) for Safety, Mobility, and User Fee Concept of Operations*. Roseville, MN. (Document prepared by Mixon Hill, Inc.)



Payment systems as used in transportation operations fundamentally depend on identification of a payer (in the form of a person, vehicle, or tag) at a location within the transportation network. Adding a time stamp to that data provides enough information to facilitate travel time estimation and other traffic management applications.

Payment applications being discussed in the Connected Vehicle context are “point-of-sale” (POS) technologies in the sense that they facilitate the transaction of payment at the location where the service is provided. Interfaces from payment systems to back office financial systems will be needed to fully integrate the capabilities with agency operations.

## Weather and Road Condition Information

The value to be derived from gathering weather observations at the surface for integration with atmospheric weather information has been well documented over the last ten years. Transportation agency operations can see tremendous operational benefits from data gathered at the roadway surface, rather than inferred from observations at thirty thousand feet. U.S. DOT has invested heavily in this premise through the development and operation of the *Clarus* system, and efforts to create *Clarus*-enabled user services that utilize both the collected surface observations and atmospheric weather data to support a variety of applications for state and local agencies. These applications currently include non-winter maintenance activity planning, traveler information, multi-state road closure coordination, and monitoring road conditions during spring thaw. Weather-related probe data would increase the coverage, spatial resolution, and accuracy of the weather observation fields, and enhance and expand the variety of Connected Vehicle applications.

Direct weather-related applications of probe data generally have fallen into two categories: those that generally improve the collection of weather observations and forecasting (and thereby broadly assist agencies in their system operations), and those that more specifically target the effects of weather on particular parts of the transportation system. FHWA's Road Weather Management Program is currently investigating opportunities to collect weather-related data directly from vehicles for synthesis with traditional meteorological observations.<sup>33</sup> This approach has the potential to dramatically expand the scale of weather data coverage over the roadway network, and perhaps to identify data sets that cannot be easily collected by other means.

The effects of weather on road conditions at specific locations are also well-known. Drivers are familiar with the fact that bridges and overpasses will typically freeze ahead of the rest of the roadway. However, there are many other situations where road conditions can create unsafe or challenging situations – the combination of deteriorating weather conditions and substandard horizontal curves is a good example. Current Connected Vehicle applications can gather data on vehicle performance at specific locations on the roadway to provide alerts or warnings to drivers.

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<sup>33</sup> U.S. Department of Transportation, Federal Highway Administration (January 2007). *Weather Applications and Products Enabled Through Vehicle Infrastructure Integration (VII): Feasibility and Concept Development Study*. Washington, D.C. (Document prepared by National Center for Atmospheric Research.)

### ***Applicable Development Efforts***

Under contract to U.S. DOT, the National Center for Atmospheric Research (NCAR) is developing a Vehicle Data Translator (VDT) that will gather vehicle-based data to supplement other road weather and atmospheric weather observations. NCAR has conducted research using data gathered at the Detroit Test Bed during 2009 and 2010, to good result.

Michigan DOT, through its Slippery Roads and VIDAS programs, will use Connected Vehicle data gathered from vehicles to directly synthesize weather condition and provide guidance, alert, and warnings through traveler information systems.

### ***Synergy between Applications***

Position and time data are inherent to the Connected Vehicle concept, but collection of any other probe data from vehicles depends on what sensors are available on the vehicle and accessible from the vehicle's data bus. An aftermarket on-board unit would need an interface (e.g., an OBD-II connector) to access the vehicle's data. Interpretation of the data types available through that interface generally requires knowledge of the vendor's parameter IDs (PIDs) for data types of interest. Investigation of this topic will be shared between any applications where vehicles serve as sources of probe data.

Once gathered, accurate, up-to-date weather and road condition information will be a vital input to a number of safety and mobility applications. The potential extension to speed warning systems for horizontal curves noted earlier is a logical use of road condition information gathered from -equipped vehicles. However, other intersection safety, traffic control, and traffic management applications could also be enhanced through the availability of these data.

## **Pavement Condition Information**

Connected Vehicle probe data could provide agencies with a view of road surface conditions as experienced by vehicles riding on pavement in near real time. Current industry practices provide incidental surveys of the pavement by maintenance personnel, but depend on annual (or even less frequent) inspections for performance measurement and reporting. Gathering pavement-related data from even a small population of vehicles would provide significantly more data than are currently available. Data such as accelerometry, tire pressure, and steering angle, for example, may be able to be correlated with pavement defects and roughness. When state and local transportation agencies have accurate, up-to-date estimates of pavement quality for specific roadway sections they can better plan their response and better manage their maintenance resources.

### ***Applicable Development Efforts***

The Connected Vehicle PFS<sup>34,35</sup> is conducting a Year-1 (2010) research project to investigate a Pavement Maintenance application. Michigan DOT has recently equipped vehicles in its own fleet to

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<sup>34</sup> American Association of State Highway and Transportation Officials (November 2009). IntelliDrive<sup>SM</sup> Pooled Fund Study: Program to Support the Development and Deployment of Infrastructure IntelliDrive<sup>SM</sup> Applications – Scope of Work for Year 1 Applications.

<sup>35</sup> Auburn University (undated). Pavement Maintenance Support Application.

gather relevant probe data, and through its DUAP program<sup>36</sup> is measuring the correlation between these data and International Roughness Index (IRI) results determined through pavement profilometry.

### ***Synergy between Applications***

The same issues relating to the availability and interpretation of sensor data as described for weather and road condition information exist in this application area.

## **Traffic Control and Traffic Management**

Traffic control and traffic management are traditional core functions of transportation agencies. They are the front line means to enhanced mobility and provide system-wide support to improved safety by reducing opportunities for conflict. The need for better traffic controls has always been a driver of technological innovation in surface transportation systems. It is not surprising that Connected Vehicle programs present significant opportunities to enhance traffic management and controls.

The components common to all traffic management and control functions are monitoring, decision analysis and driver messaging. For traditional traffic signals, intersections are monitored for vehicle presence and demand for passage through the intersection; signal phase is determined from the demand data and timing patterns; and the phases are communicated to drivers through the signal indications. The pattern holds for freeway traffic management systems as well: monitor the traffic flow, evaluate speeds and travel times, and inform travelers of current conditions through roadside dynamic message signs and through media feeds.

Connected Vehicle applications for traffic management and control can affect all three components. The on-board equipment facilitates gathering information on vehicle location, speed and heading. The roadside and network services provide situation analysis and generate appropriate controls and messages. The in-vehicle systems can present messages to vehicle operators. The Connected Vehicle components can work both in tandem with each other and with other intelligent transportation systems. For example, the Connected Vehicle “HIA” messages could be synthesized into speed/volume/occupancy data for use in existing traffic management systems.

The range of traffic control and management applications that have been proposed and discussed over the courses of the Connected Vehicle programs is extensive. Leaving aside those already described in the context of “Intersection Safety”, a list of traffic applications could include the following:

- Adaptive signal controls, monitoring approaching traffic streams to create phase and timing plans that optimize flow
- Traffic signal prioritization for transit vehicles and preemption for emergency vehicles that work with the adaptive signal controls
- Arterial network signal coordination
- Active traffic management applications<sup>37</sup> such as variable speed management

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<sup>36</sup> Michigan Department of Transportation (August 2007). VII Data Use Analysis and Processing Concept of Operations, Version 1.02. Lansing, MI. (Document prepared by Mixon Hill Inc.)

- Automated highway applications such as cooperative adaptive cruise control for managing headway and capacity
- Adaptive ramp metering
- Corridor and regional management applications that integrate adaptive strategies across intersections and facilities
- Weather-responsive adaptive controls

### ***Applicable Development Efforts***

The U. S. DOT has made DMA one of the keystone efforts in the Connected Vehicle programs. Although the DMA research area is early in its formal development, it is likely to include many representative traffic control and management applications.

Interactions between vehicles and traffic signal controllers are a significant focus of intersection safety application development. As described earlier, provision of signal phase and timing data is the focus of several development efforts.

Traffic signal preemption is a primary consideration in the Arizona Emergency VII (E-VII) program by the Arizona DOT, Maricopa County DOT, FHWA and other partners.<sup>38</sup>

### ***Synergy between Applications***

As has been previously noted, applications around traffic signal control support intersection safety as well as arterial mobility. Since both purposes are to be served by selection of appropriate signal phase and timing plans, they are inextricably linked.

Messaging for traffic management purposes is supported by in-vehicle signing similar to that discussed in the context of speed warnings and intersection safety applications. Like the signal phase and timing, the design of the driver interface will have to support messages from multiple applications.

Any weather-responsive adaptive controls for mobility enhancement will depend on weather data and road condition information. Algorithms supporting a weather response may draw from local condition information and from road weather forecast applications that in turn depend on that local condition data.

## **Commercial Vehicles and Freight**

Stakeholders in commercial vehicle operations have been longtime proponents of the potential benefits of wireless communications between vehicles and the roadside infrastructure. Motor carriers, their associations and their transportation agency counterparts have together been responsible for tremendous improvements in safety and operating efficiency through new technology deployments. The alignment of these interests with Connected Vehicle programs is a natural next step.

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<sup>37</sup> Federal Highway Administration (March 2010). *Synthesis of Active Traffic Management Experiences in Europe and the United States*. Washington, D.C. (Document prepared by Parsons Brinkerhoff.)

<sup>38</sup> Arizona Department of Transportation (February 2008). *Arizona Emergency VII (E-VII) – Program Overview and Focus Areas*. Phoenix, AZ. (Document prepared by Kimley-Horn and Associates.)

Potential Connected Vehicle applications for commercial vehicles include most (if not all) of the applications useful to light vehicle operations and those that are more specific to commercial vehicle operations. Safety, payment, in-vehicle signing, and probe data applications have already been described in this report and apply to heavy as well as to light vehicles. Their implementation in commercial operations and on heavy vehicles will vary somewhat from those used on passenger vehicles and light trucks, but can use similar architectures and services.

Beyond these shared needs, commercial vehicles operations have a series of unique needs that can be supported or accommodated by Connected Vehicle applications. U.S. DOT, under the leadership of the Federal Highway Administration (FHWA) and the Federal Motor Carrier Safety Administration (FMCSA), is developing the Smart Roadside initiative as part of the V2I program. Major desired capabilities of the Smart Roadside initiative have been identified in a recent white paper<sup>39</sup> and include the following:

- Real-time traffic, weather, special event, and truck parking information shared with driver
- Vehicle sensor data collected at the roadside shared with private vehicle maintenance providers
- Unique vehicle identifier shared with the enforcement agencies
- Routing clearance information shared with driver
- Vehicle size and weight shared with enforcement agencies
- Origin/destination information shared to determine routing information
- Construction and time restriction information shared with driver
- Real-time driver/carrier/truck information shared with enforcement agencies for inspection decisions
- Roadside inspection results (violation and non-violation) shared with Federal enforcement agencies
- Emissions data shared with carriers and agencies to assess operating efficiencies, including those involving emissions, energy use, and carbon footprint

### ***Applicable Development Efforts***

Commercial vehicle applications will largely share technologies with other applications previously discussed in this paper, but have additional needs with respect to inspection, verification and enforcement, security, and fleet management. It is likely that these applications will require additional on-board and back office components, and may require specific roadside and communications features.

The I-95 Corridor Coalition's Commercial Vehicle Infrastructure Integration (CVII) program in New York has already been demonstrating foundational work on potential Connected Vehicle applications for

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<sup>39</sup> U.S. Department of Transportation (April 2010). White Paper: Scope of the Smart Roadside Initiative.

commercial vehicles.<sup>40</sup> The current I-95/New York CVII program includes the development and prototype testing of applications for the following:

- In-vehicle signage, traveler information, road conditions, weather information, etc.
- Commercial vehicle driver identification and verification, and possibly EOBR hours reporting using V2I communications
- Wireless vehicle safety inspection information using V2I communications
- Commercial vehicle to maintenance vehicle communications

### ***Synergy between Applications***

As already noted, commercial vehicles will use many of the same types of applications as are used in light vehicles. Some of the applications developed for commercial applications, however, may also be useful in other heavy vehicle fleet applications—emergency and transit vehicles. Routing of transit vehicles, for example, shares many of the time-critical and destination-dependent characteristics of commercial vehicles.

## **Emergency Vehicles**

Emergency vehicles provide a strong opportunity for deploying Connected Vehicle applications. Emergency vehicles are high-value assets that tend to be highly customized. Emergency vehicle fleets may already consist of “Connected Vehicles” if they have deployed automated vehicle location (AVL) systems providing core functions similar to the probed data applications.

Many jurisdictions may furthermore provide some form of emergency vehicle preemption of traffic signals. Emergency vehicle signal preemption allows an emergency vehicle to request right of way from traffic signals in its direction of travel. Typically the agency provides the equipment on the traffic signal while the emergency responder is responsible for procuring the equipment on the vehicles. Preemption has been provided using optical or infra-red strobes on vehicles, using GPS and radio communications on vehicles, with pushbuttons in a fire station, and by detecting the siren of an approaching emergency vehicle.

Since the approach to preemption can be agreed to within a region, there is an opportunity for DSRC-based preemption. In this instance, the intersection-mounted roadside unit would verify that the request has been made by an authorized source and alters the traffic signal and timing to provide right of way to the emergency vehicle. This application would need to be integrated with other intersection safety applications

Emergency vehicle signal preemption in a multiple traffic signal network is implemented by intersection mounted, stationary, RSE communicating with each other and with emergency vehicle mounted, mobile on-board equipment as they approach. As a stationary RSE collects data to identify an approaching emergency vehicle, it sends information to the local signal controller and the surrounding stationary RSEs that allow the emergency vehicle to proceed through its' intersection and others in its path with a green light.

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<sup>40</sup>I-95 Corridor Coalition website:

<http://www.i95coalition.org/i95/Projects/ProjectDatabase/tabid/120/agentType/View/PropertyID/247/Default.aspx>

A challenge to DSRC-based preemption is the installed base of other approaches in certain regions. However, many jurisdictions do not have an installed base of preemption.

### ***Applicable Development Efforts***

Like commercial vehicle applications, emergency vehicles will largely share technologies with other applications previously discussed in this paper. They may also need features consistent with their existing dispatch, security, and system/fleet management systems.

As described earlier, Maricopa County and the Arizona DOT have developed and prototyped a signal preemption application for multiple emergency response vehicles at an intersection in the field. They also tested applications to support vehicle-to-vehicle communications, and traveler information in a laboratory environment. The County plans to perform corridor level testing of emergency vehicle preemption and transit vehicle priority in the summer of 2011. The County is also interested in using Connected Vehicle data to develop speed maps and improve signal coordination. ADOT also recently completed a study to develop a Concept of Operations for dynamic routing of emergency vehicles using the Connected Vehicle platform. This body of work will be an essential reference for other agencies looking to specify and develop similar sets of applications.

### ***Synergy between Applications***

Emergency vehicle will use most applications developed for light vehicles and some developed for commercial or transit vehicles. Future integration with operations centers could use incident detection results to further extend dynamic routing capabilities, or even provide anticipatory staging of vehicles in areas and circumstances more likely to see accidents.

## **Agency Data Applications**

Most of the Connected Vehicle applications considered in this report—and generally in other Connected Vehicle forums—are driven by a need to improve real-time or near-term operations. Intersection safety applications, for example, are expected to respond immediately to new conditions and data. Traffic management and weather response applications will demonstrate their value within minutes of data being provided. Even pavement condition applications are intended to speed up the operational response to observed conditions.

At the other extreme, some transportation agency processes are focused not on the timeliness of response, but on the completeness and accuracy of the data products themselves. Agencies go to great lengths to identify performance measures by which the agency's own processes can be evaluated. Transportation planning processes depend on stores of archived traffic and asset data as the basis for projections of future maintenance and development needs.

Connected Vehicle system capabilities will provide tremendous opportunities to improve the density, accuracy, completeness, and timeliness of data collection for system management applications. The increased quantity and diversity of Connected Vehicle-generated data may also drive new analyses of what performance measures can be derived from the data. Analyses may also be needed to assess what new planning applications might emerge.

Although the potential of Connected Vehicle data to enable new applications is significant, it may also be constrained by the very nature of the data. Data privacy and reuse issues may limit, or at least complicate, applications of the data. For example, current standards-based probe data

implementations do not support key-on to key-off tracking of a vehicle's travel path. While intended to protect the driver's privacy, this limitation precludes direct application of the probe data to origin-destination studies that are valuable to transportation planning.

While there are still many questions about the use of Connected Vehicle data in agency performance measure studies and planning, areas of known interest would include the following:

- Traffic and transportation management performance measures
- Vehicle classification-based traffic studies
- Origin-destination studies
- Intersection turning movement analysis
- Traffic model base lining
- Predictive traffic studies

### ***Applicable Development Efforts***

Analysis of Connected Vehicle data to transportation agency data-centric applications is still being developed. The most significant near-term input to these analyses is likely to come from the U.S. DOT Real-Time Data Capture and Management program. Although the focus of that program is on data capture, it will more specifically identify the data to be captured and provide an assessment of the limitations of use.

### ***Synergy between Applications***

Performance measurement and planning applications, by their nature, are drawing on the same data that is being generated and used in other Connected Vehicle applications.

## **Recommendations**

Based on the preceding assessments, applications that could form the basis of the AASHTO deployment scenarios can include the following:

- Traffic signal prioritization for transit vehicles, benefiting intersection safety and enhancing mobility
- Traffic signal preemption for emergency vehicles, benefiting intersection safety
- Commercial vehicle wireless roadside vehicle inspection, routing, clearance and weight warnings, enhancing safety and mobility
- Curve speed and run-off-road warnings, supporting safety enhancements and utilizing in-vehicle signing



- Payment applications demonstrating alternative highway funding options, such as VMT, and understood to include potential tolling/HOT applications, likely to be based on probe data
- Pavement condition data synthesis, benefiting agency operations and utilizing maintenance and other vehicle probe data

Each of these recommendations supports one or more of the applications previously endorsed by the AASHTO community and has a high likelihood of successful demonstration in the near future without necessitating a large population of vehicles with factory-installed DSRC OBEs.

## Application Development Considerations

There are likely as many particular application development scenarios as there are potential applications of Connected Vehicle capabilities. The scenarios will be driven by factors including the following:

- The characteristics of the application. Complex applications that involve interfaces between multiple systems (e.g., vehicles, traffic signal controllers, and traffic management systems) are more likely to need government sponsorship and coordination than simpler applications routing data to a particular user community (e.g., traveler information to iPhones).
- The target end user community. A large end user community will attract more commercial development interest than a smaller market.
- The sponsoring organization. Applications sponsored by larger organizations with more resources tend to attract more potential developers.
- The developing organization. Developer business models vary widely and will have an impact on ownership of intellectual property, implementation of standard interfaces, and competitive innovation.

Nonetheless, successful development scenarios are likely to fall somewhere within a more limited set of parameters. Four generalized scenarios encapsulate most of the development factors likely to result in successful development: market-driven commercial applications; industry-standard applications; agency-specific applications; and government-sponsored application frameworks. Development scenarios that might be appropriate for particular applications will be described as part of the overall deployment scenarios.

**Market-Driven Commercial Applications** - Some applications could be developed competitively to serve a market demand. Development is driven largely by the perceived size of the market for new products and, eventually, by services to support those products. Many of the consumer needs that could be met by anticipated Connected Vehicle applications are already being addressed in some form by commercial applications. Traveler information, traffic alerts, and routing applications, for example, are available throughout North America on both aftermarket and in-vehicle devices from multiple vendors. Applications needed by transportation agencies might be developed commercially if the perceived market is large enough. Autonomous and V2V safety systems would be subject to market drivers unless there is a regulatory mandate.

**Industry Standard Applications** - Some Connected Vehicle applications will be broadly useful across the industry, but may not have a large enough market to directly incentivize commercial development. Alternatively, significant investment for research and development relative to the size of the market may create a barrier to entry for any but the largest developers. Interoperability requirements and over-specification of features can constrain innovation and further reduce competitive commercial incentives. In these cases, it may make sense to directly fund development of applications that benefit the industry as a whole. Agency coalitions and pooled funds have successfully used this development model for ITS applications and demonstrated its effectiveness under similar constraints.

**Agency-Specific Applications** – Connected Vehicle applications fulfilling specific transportation agency needs might not be candidates for coalition or pooled fund sponsorship. Technical and institutional aspects of transportation operations within and between agencies can result in needs that may not be perceived to be applicable to other agencies or situations—though the broader applications may become clearer after the system has been demonstrated in practice. Application development in these circumstances may be best addressed through means used for any other ITS systems development at the state or local level.

**Government-Sponsored Connected Vehicle Application Frameworks** - Application frameworks, including interface standards, can help assure interoperability and consistency in development of complex systems. This may be particularly important for Connected Vehicle applications designed to deliver safety benefits and for applications supporting data aggregation for system planning and management. In such cases, the diversity of stakeholders and system components may be best supported by coordination through federal agencies.

# Deployment Scenarios

Much of the analysis of Connected Vehicle systems and applications has attempted to describe *alternative* scenarios to achieving agencies' safety, mobility, and operational objectives. The magnitude of the opportunities and breadth of implementation options—for data, applications, technologies, standards and policies—has inspired a similarly wide range of research and demonstrations. This body of knowledge is useful and significant, but appears to demand that agencies make specific choices among alternatives.

This plan will instead approach the deployment as a set of likely sequential scenarios. It recognizes that technologies and events will continue to impact agency operations even without intentional decisions on the part of those agencies. The focus is on articulating the needs of the agencies and anticipating the context in which agencies will make specific deployment decisions.

The scenarios that follow describe the progressive deployment of Connected Vehicle systems out to a twenty-year horizon. They start with an assessment of the current state, touching on key drivers and activities. Each step in time corresponds to a new deployment goal—a particular emphasis for that phase of development. Anticipated external events and policy decisions are described, and the most likely arc of technology developments is projected from the current state.

## Key Observations and Assumptions

The scenarios presented in this report are based on a set of observations about the current conditions and assumptions about the future that may affect the decisions and approaches to Connected Vehicle infrastructure deployment by the agencies. The most important observations and assumptions are described below.

Government spending on surface transportation is constrained, and will continue to be so, and this will further encourage a shift from new highway construction to solutions that provide operational and safety improvements on the existing infrastructure. However, within this environment there will be strong competition for funding within state and local agencies between alternative approaches for providing operational improvements. Connected vehicle solutions will only be favored where compelling arguments based on solid, documented benefits, costs, and deployment schedules demonstrate the advantage of these approaches over the alternatives.

As a general guiding principle in the development of the scenarios, it is assumed that public agencies will be motivated to deploy the field infrastructure for Connected Vehicle systems to achieve near-term benefits from applications that enhance mobility, provide localized safety improvements, or enhance the operational performance of the transportation system or agency in some manner. Public agencies will deploy DSRC field infrastructure in recognition of its long-term value in Connected Vehicle active safety applications but will leverage that investment to support a variety of applications in the near-term.

The scenarios presented in this report assume actions by NHTSA in 2013 and 2014 to somehow result in DSRC-equipped vehicles. If NHTSA takes no actions in this direction, then the anticipated actions of AASHTO and the state and local agencies are likely to change dramatically from those presented here. Even a delay in actions by NHTSA could negatively impact the anticipated actions and commitments of the state and local agencies.

The scenarios acknowledge that “deployment” can have several different aspects in the context of a Connected Vehicle system, and it can be sometimes challenging to define the roles of AASHTO and its members in some aspects of deployment. To achieve all of the applications desired, the deployment path facing state and local agencies will include both DSRC and non-DSRC components.

Based on consultations with members of the VIIC, the scenarios assume a specific deployment timeframe for the availability of factory-installed DSRC onboard equipment. If NHTSA, in some fashion, decides to move forward with requirements to mandate factory-installed DSRC equipment on-board both light and heavy vehicles, prior experience would suggest that on-board equipment will first appear in 2019 in newly-manufactured light vehicles for the 2020 model year.

This timing assumption has a major influence on the deployment approach presented in the scenarios. While it can be said that the benefits to drivers of OBE-equipped passenger cars will increase as the deployment of RSEs increases, it is also true that there are no benefits to the deployers of RSEs if there are no OBE-equipped vehicles with which to communicate. Therefore, in order to encourage near-term deployment of DSRC roadside infrastructure, the state and local agencies must pursue approaches that do not rely on the presence of a growing population of factory-equipped passenger vehicles before the end of the current decade.

The scenarios address this problem by placing early deployment emphasis in the following areas:

- Focus on the deployment approaches and appropriate applications that meet the needs of potential early deployers, such as commercial vehicles, transit vehicles, and emergency and public safety vehicles
- Focus on the deployment approaches and appropriate applications that can satisfy operational objectives of an agency and can be met by using equipped vehicles that are controlled by the agency, such as agency fleet vehicles, maintenance vehicles, and other specialized vehicles
- Focus on applications that are of interest or importance to agencies and where the end users have a strong incentive to obtain the necessary devices to participate. These may include location-specific safety applications or fee collection applications
- Focus on approaches that lead to the early deployment of retrofit, aftermarket, and other consumer devices that operate within Connected Vehicle systems and emphasize applications that are of interest to state and local agencies and that will function effectively with these devices

The scenarios begin with a focus on activities that will provide benefits directly to the state and local agencies and their customers and therefore give an initial incentive to start infrastructure deployment. However, the scenarios also support AASHTO’s dual roles of leadership and partnership in the national Connected Vehicle program, as defined in the 2010 Strategic Plan. As such, the scenarios

identify a number of activities that are most effectively accomplished through collaboration between AASHTO, the carmakers, and U.S. DOT.

In particular, the scenarios recognize that commitment to the Connected Vehicle program by the carmakers requires the need to address broader governance, liability, security, and privacy issues, including the need to establish certificate authority processes. The scenarios acknowledge the position of the VIIC that at least 5,000 DSRC RSEs will be required nationwide for effective certificate management.

It is recognized that the overall Connected Vehicle research program of work currently underway or planned by U.S. DOT will affect the infrastructure deployment decisions and approaches taken by the state and local agencies. Therefore, the scenarios seek to provide ways in which AASHTO and its members can effectively support, participate, and influence these activities as appropriate. In particular, the scenarios assume that state and local agencies will favor deployment approaches that provide compliance with a national Connected Vehicle system architecture and national standards.

Finally, the scenarios recognize the existence of a number of external influences in the areas of technology, commercial product and service development, and consumer response. While public agencies have invested significantly and will remain committed to the provision of traveler information, the private sector has clearly identified market opportunities in this space and is currently providing and expanding services to collect, process, and redistribute traffic data and value-added traveler information. Availability of these services from the private sector will increase for the foreseeable future, and at a rate that will outpace the public agencies. The public agencies must determine the appropriate balance of publicly-collected data versus the acquisition of private data that is necessary to conduct their business. Commercial applications dominate the distribution of traveler information, and will continue to do so as long as it is profitable. Agencies must be prepared for future scenarios where the business model is no longer profitable and commercial providers retreat from this space.

Travelers are already exposed to the opportunities to use their own carry-in electronic devices for obtaining travel-related information (including traffic conditions, weather, etc.). Their reliance on these devices as their primary source of up-to-date information will increase. However, the effects of national and state policies on driver distractions must be considered in the long-term viability of this model.

Similarly, in-vehicle aftermarket telematics terminals are currently available as standalone devices and as applications on consumer electronic devices. These products will continue to become more available, more sophisticated and less expensive.

## Deployment Scenarios

This section of the report paints a picture of the development and deployment activities associated with Connected Vehicle systems that are known or anticipated to occur over the next twenty years. The specific actions that will help shape and promote deployment in the states and that will be the responsibility of AASHTO and its members are described in the next section.

The deployment scenarios emphasize the needs and objectives of the state and local transportation agencies. It will be through AASHTO's leadership role in the national Connected Vehicle program that these needs and objectives will be satisfied. The scenarios also describe related activities being undertaken or planned by U.S. DOT and the VIIC. This information is included for two principal purposes. First, the federal and VIIC activities described here provide relevant context and in some

instances will affect or influence the deployment direction pursued by the agencies. Second, in its role as a partner in the national Connected Vehicle program, it is incumbent upon AASHTO to support the needs of both U.S. DOT and the carmakers where these will help resolve longer-term challenges and impediments to full deployment.

## **2011 – Setting the Direction**

The activities and decisions of 2011 set the direction of Connected Vehicle system development and deployment for many years to come. Numerous research and development programs and early deployment activities at the federal, state, and local levels are in process or about to begin, all contributing to the base of knowledge and experience on which future planning will depend.

2011 is the time that AASHTO and its members define their general concept for deployment. The general deployment concept is developed in response to the assumption that new light vehicles with factory-installed DSRC equipment will not begin to emerge until 2019 following a some type of NHTSA agency decision in 2013. The AASHTO general deployment concept therefore focuses on an early deployment of DSRC RSEs for selected applications and users; the development of applications that can be served by DSRC capabilities available through aftermarket and mobile consumer devices; and the deployment of additional mobility and improved agency operations applications supported by either DSRC or non-DSRC communications systems.

The DSRC component of this concept starts with applications that improve current systems and that can quickly lead to a limited nationwide RSE footprint, with localized pockets of dense RSE deployment for applications that focus on fleets and systems over which the state and local agencies have some influence or control. Efforts to broaden this initial nationwide footprint will be accomplished through deployment of high-value, high-priority applications at isolated locations. In the early years, this means emphasis will be placed on the following

- A focus on commercial vehicles applications where DSRC can be used as a replacement or enhancement to the communications mechanism in existing systems (such as transponders used for roadside screening or through the Commercial Vehicle Information Systems and Networks (CVISN) program)
- Research and implementation of methods that use DSRC for emergency vehicle pre-emption (EVP) and transit signal priority (TSP) systems that would replace existing systems
- The identification and deployment of DSRC-based safety applications at isolated high volume, high accident locations where they will provide demonstrable benefits

In 2011, AASHTO and its members will establish the specific applications to be pursued during the early deployments, shape the desired outcomes, and begin to educate and inform based on initial results.

At the federal level, 2011 sees the U.S. DOT Connected Vehicle activities continue the necessary fundamental research and development but with an emphasis on supporting initial deployments of Connected Vehicle infrastructure and applications. A major aspect of the federal program will be the initiation of the Connected Vehicle Safety Pilot. Demonstrating V2V and V2I safety benefits on a large scale and using multiple vehicle types supports NHTSA's plans to make agency decisions in 2013 and 2014. This approach also raises awareness within both the transportation community and the general public of Connected Vehicle technologies. Coupled with the results of National Cooperative Highway

Research Program (NCHRP) project 03-101 to measure the costs and benefits of public sector Connected Vehicle infrastructure deployments, state and local DOTs will be able to incorporate solid and reliable data into their decision-making and programming processes by 2014.

2011 also see additional focus on V2I communications within the federal program. U.S. DOT will develop a safety applications concept of operations in 2011 with stakeholder input gathered in the latter half of year. The concept of operations will support the selection of safety applications to be prototyped in 2013. However, the purpose of the V2I data exchange is to not only mitigate crashes through safety applications, but also enable a wide range of other applications that enhance mobility and provide benefits to the environment.

As the representative of the owners and operators of the infrastructure side of the V2I equation, AASHTO will seek to take a leadership role in V2I program – assisting in prioritizing safety and mobility applications; defining system hardware, software and back-end needs; and potentially undertaking system development through the Cooperative Transportation Systems Pooled Fund Study or individual agency efforts, with AASHTO providing overall coordination, or with assistance from U.S. DOT.

The U.S. DOT Safety Pilot also provides the opportunity to explore both the role of original equipment and aftermarket devices in vehicles. The results of the Pilot along with retrofit analyses by the VIIC and the Cooperative Transportation Systems Pooled Fund Study will help refine the anticipated timeline in which suitably equipped vehicles will be present on the nation's roadways. The likelihood of a strong retrofit market will further support positive deployment decisions by the state and local agencies.

U.S. DOT will also create Qualified Product Lists (QPL) for the Basic Safety Message Broadcast Device (the so-called "Here I Am" device); Roadside Equipment; and Aftermarket Safety Devices. These could be of particular significance to the state and local agencies. The ability to procure approved products will give further confidence to state and local DOTs to proceed with deployment decisions. However, AASHTO members will again need to provide leadership in this area to ensure that the resulting products meet the needs of state and local agencies. For example, it may be most useful for state and local agencies to see the development of an RSE on the QPL with an interface to a traffic signal controller.

The federal program will also begin to expand the coverage of Connected Vehicle testbeds during 2011. The existing Michigan testbed will be enhanced and expanded, and new testbeds will likely emerge in California, Florida, and New York. In addition to providing venues for all Connected Vehicle stakeholders to develop and evaluate new technologies and applications, the testbeds also serve as initial pockets of deployed infrastructure and provide seeds from which broader deployments can grow. A new Transportation Operations Laboratory at FHWA's Turner Fairbank Highway Research Center will include a Connected Vehicle-Highway Testbed for evaluating new concepts that are not ready for deployment on the public highways. This continuing commitment to new R&D by U.S. DOT will provide a steady flow of new approaches and applications that will be picked up by the state and local agencies in the years to come.

The federal program, however, is not exclusively focused on Connected Vehicle safety applications during this period. High-priority Dynamic Mobility Applications were announced at the beginning of the year, and development of prototypes in the areas of signal control, corridor, management, emergency management, traveler information, freight, and transit will proceed over the course of 2011. The findings from these prototyping projects will influence the selection of applications for assessment or

deployment, or help enhance initial deployments by state and local agencies in the coming years. Environmental applications will be identified through the AERIS program later in 2011, providing even more information and options to the state and local DOTs to support their deployment decisions.

In 2011, the topic of Connected Vehicle technologies in traffic signal control will be an early priority to AASHTO. Through the Connected Vehicle Pooled Fund Study, AASHTO members will guide the development of prototype dynamic mobility applications in the area of signal control. AASHTO members will also develop additional related research agendas to address topics such as the placement and installation of DSRC RSEs at signalized intersections. AASHTO will also address the potential for and develop recommendations for the deployment of RSEs during regular signal upgrades. Topics to be addressed will include the need for deployment guidance, adopted standards, and a plan for outreach to the responsible state and local agencies across the U.S.

State and local agency Connected Vehicle programs will continue to provide some the most important information on the practical aspects of infrastructure and application deployment. Initial implementations will be the foundation from which small deployments expand geographically, and which provide the approaches, guidance, and lessons-learned to peer deployers in other states. Early deployment opportunities will emerge from the following:

- Arizona and Maricopa County DOTs' emergency vehicle and transit priority field study for Connected Vehicles<sup>41</sup>
- Caltrans' Connected Vehicle test bed upgrade and expansion
- Minnesota DOT's Safety, Mobility and User Fee program
- Michigan DOT's work on real-time data capture and management through the Vehicle-based Information and Data Acquisition System (VIDAS) and Data Use and Analysis (DUAP) programs
- The I-95 Corridor Coalition's Commercial Vehicle initiatives led by New York State
- Florida DOT's activities to deploy infrastructure and host demonstrations as part of the 2011 ITS World Congress

Consistent with AASHTO's general deployment concept for DSRC RSEs, particular emphasis will be placed on leveraging experience from the state and local agency Connected Vehicle commercial vehicle, emergency vehicle pre-emption, and transit vehicle priority initiatives. AASHTO will establish a taskforce of the Connected Vehicle Working Group to define specific applications that are candidates for further development and broader deployment in each area. As deployment of these capabilities is likely to use state and local funding, the taskforce will also identify and document the benefits of DSRC-based commercial vehicle, EVP & TSP applications that will satisfy the decision makers in the responsible agencies, and will also develop accurate cost estimates for deployment, operations and maintenance.

In recognition of AASHTO's role as both a leader and partner in the national Connected Vehicle program, the development of applications for heavy trucks will have to address the needs of federal as

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<sup>41</sup> Maricopa County Department of Transportation (December 2010). Scoping Study: E-IntelliDrive<sup>SM</sup> Field Test – Emergency Vehicle and Transit Priority,



well as state and local stakeholders. The program will also acknowledge that in many instances the needs of commercial vehicles from Connected Vehicle systems are consistent with those of personal vehicles, although the deployment approaches and locations may differ. AASHTO will work with its members to consider Commercial Vehicle applications in the following areas:

- Intersection safety for commercial vehicles
- Curve speed and run-off-the-road warnings for trucks
- Low bridge warnings
- Electronic screening and inspection processes
- Border crossing processes
- Tolling, in-vehicle signage, and traveler information
- Truck parking information

In addition, the Cooperative Transportation Systems PFS will continue to generate research findings that will inform deployment opportunities and approaches by the state and local agencies, including the current work on SPaT and pavement monitoring, and the upcoming research on aftermarket onboard equipment and a certification process for Connected Vehicle devices.

As these technical activities advance, AASHTO will communicate progress to U.S. DOT on a regular basis to ensure this information is incorporated into the federal program initiatives.

Other reference activities that will be important to the state and local agencies during 2011 will include the completion of the Connected Vehicle system architecture, and the preparation of design, procurement, and operations and maintenance guidance documents that is being led by Michigan DOT for U.S. DOT. As these efforts advance, AASHTO will seek formal input to their development to ensure they meet the needs of the state and local agencies, including enforcement agencies. Once they are completed, establishing a mechanism that encourages use of these resources by the agencies will be an important continuing role for AASHTO.

In addition, further work by the U.S. DOT and vehicle manufacturers to analyze the requirements for security and certificate authority will also be monitored by AASHTO to determine the impact on DSRC RSE deployment decisions by the state and local agencies. The expressed desire for an initial national footprint of 5,000 DSRC sites for certificate authority purposes will be considered by AASHTO and its members as they define a specific early deployment strategy and timeline. AASHTO will maintain ongoing communication with the VIIC to report the approach and progress being made by the state and local agencies with their RSE deployment plans.

Conscious of its partnership in the national Connected Vehicle program, AASHTO will coordinate with U.S. DOT and the VIIC to lay out a plan and schedule for addressing governance issues and for revisiting the privacy principles established in 2007. AASHTO will also begin collaboration with the VIIC to develop funding plans as appropriate.

Several technology trends through 2011 could have significant impacts on Connected Vehicle programs. Consumer telematics services are set to greatly expand this year; OnStar, for example, has announced aftermarket devices and services operating on commercial wireless networks for vehicles

beyond those produced by GM. Commercial wireless communications providers will accelerate the growth of 4G network services this year, driven by consumer demand for higher-bandwidth data and video applications. On the horizon for later this year: smartphone-based on-premise transaction services for Apple's iPhone.

## 2012 – Showing Success

Many of the programs active in 2011 will continue into 2012. The U.S. DOT Connected Vehicle Safety Pilot, the prototyping of V2I safety applications, dynamic mobility applications, and environment applications, and the expansion of national testbeds will be in the middle of their development cycle. Planning for the integration of multi-modal safety and dynamic mobility applications into future U.S. DOT-sponsored regional demonstrations will also be underway. AASHTO and its members will stay closely involved with these activities to provide input and ensure that individual state and local development efforts remain aligned with the national approach to the greatest extent possible. Coordination on these activities will also help AASHTO identify the opportunities for leveraging the investment being made by others in a deployed field infrastructure to the benefit of the state and local agencies.

The individual state and local agency programs will similarly advance during 2012, with increasing emphasis on the broader deployment needs and approaches that will follow demonstration and testing activities shown below:

- Michigan DOT's VIDAS program will have deployed and be gathering a variety of probe data from a controlled fleet of test vehicles, and will be considering broader deployment on state vehicles to provide the breadth of data needed to deploy the Connected Vehicle applications identified in its DUAP-2 program.
- Caltrans will be providing a test bed section of thirteen consecutive DSRC-equipped intersections along a major arterial corridor in Palo Alto for "green wave" and transit studies.
- Minnesota DOT's Safety, Mobility and User Fee program will be using aftermarket devices and both commercial wireless and DSRC to gather data from participant users drawn from the general public and will be beginning its formal evaluation.
- The I-95 Corridor Coalition, New York State DOT and New York State Energy Research and Development Authority (NYSERDA) will have developed and evaluated an aftermarket on-board DSRC device with a wireless roadside inspection application for commercial vehicles.
- The Maricopa County test facilities will have been demonstrating traffic signal prioritization in an arterial section with five DSRC-equipped intersections, and may also have begun some expansions to demonstrate ramp metering and incident location applications.

The programs in the states will include both DSRC-based and non-DSRC-based approaches, providing results and experience that will inform the national program and support information sharing between the early adopter agencies. Overall, these state and local efforts will be providing a broad base of initial experiences in Connected Vehicle applications. The benefits of these applications to agency operations will be demonstrable, begin to be published, and provide a basis for expanding the functionality and geographical coverage. Applications that are winners—those that are improving infrastructure-related safety, mobility, and efficiency and effectiveness of operations—will become naturally attractive to agencies looking for those benefits. In 2012 AASHTO will begin to plan and

implement education and outreach efforts to its membership on Connected Vehicle applications and infrastructure deployment approaches, beginning with these individual state and local initiatives. Education and outreach activities will include scanning tours for AASHTO members.

Focus will remain, however, on AASHTO's initial general concept for deployment. Work will continue on the identification of both DSRC and non-DSRC based early deployment identified during 2011 (i.e., commercial vehicle, EVP, TSP, and isolated safety locations), and on conducting the necessary research and development work required to advance these systems and applications to deployment. To support this effort and broader national deployment goals, AASHTO will begin to develop a national footprint plan for DSRC RSE infrastructure.

The primary purpose of the national footprint plan is to provide specific direction to the infrastructure deployment efforts of the individual state and local agencies and to provide AASHTO with a blueprint that can be used to encourage coordination between states to achieve viable regional, multi-state, and, ultimately, nationwide deployment of RSEs. Initially, the national footprint plan will focus on laying a national freight RSE network that will be used to identify and encourage Interstate corridor-level early deployments in future years. The initial national footprint plan will also provide an analysis of where the denser pockets of urban RSE deployment will emerge over time, as agencies pursue EVP, TSP, and other signal control applications. The development of the national footprint plan may also require AASHTO policy action that encourages the minimum desired deployment levels by its members.

The secondary purpose of the national footprint plan is to support larger national deployment goals, including those of the VIIC. The RSE growth strategy identified in AASHTO's general concept of deployment will likely not satisfy the VIIC's desired deployment of 5,000 RSEs for certificate management; either in terms of number of RSEs or geographic distribution of RSEs. The initial national footprint plan will be provided to U.S. DOT and the VIIC for review and future collaboration on additional RSE build out across the country. While AASHTO members are unlikely to undertake the deployment of "security-only" RSEs, the national footprint could be further expanded by identifying viable isolated locations for appropriate DSRC-based safety and mobility applications that can also support certificate management goals. The national footprint plan will continue to evolve under AASHTO's direction over the period until OBE factory-equipped light vehicles begin to arrive in 2019. The national footprint plan, as defined here, will also support AASHTO's ongoing participation in national program efforts to advance the definition and development of security and certification processes during 2012.

As this work advances during 2012 and 2013, increasing coordination with U.S. DOT will be required to ensure that any additional infrastructure deployment through pilot projects and testbed expansions supports the early deployment needs identified in the national footprint plan.

2012 will also be a period of opportunity during which AASHTO can conduct final reviews and analyses of the completed Connected Vehicle system architecture and the initial design, procurement, and O&M guidance documents sponsored by U.S. DOT. Through these reviews AASHTO will determine the needs and develop a strategy for developing more formal guidelines for its members, similar perhaps to the AASHTO Green Book.

It should be noted that when viewed across the broad spectrum of public and private sector interests, development of applications is likely to proceed on multiple communications paths in 2012. Telematics probe and traveler information applications based on 3G/4G services are likely to expand while DSRC-based safety application research continues.

## 2013-2014 – Jumpstarting Deployments

Presuming that the U.S. DOT Safety Pilot demonstrates the potential benefits of V2V and V2I safety applications, 2013 and 2014 also see key milestones in the Connected Vehicle program: NHTSA agency decision points about DSRC in light and heavy vehicles. A decision that somehow encourages deployment of DSRC in both light and heavy vehicles would create a demand for DSRC infrastructure to support the V2V applications and create an additional means of implementing V2I applications. This deployment scenario assumes that following a positive decision and subsequent action, factory-equipped light vehicles begin to emerge in 2019. However, retrofit and aftermarket analyses being performed by the VIIC and related activities to be conducted during the Safety Pilot could accelerate the deployment timeline. AASHTO must remain closely aligned with these efforts and be prepared to factor the results into its deployment strategy and the deployment plans of its members.

Any NHTSA actions in the 2013 and 2014 timeframe will also inform AASHTO's national footprint plan for the deployment of DSRC field infrastructure. As noted earlier, the footprint plan is anticipated to evolve through 2019, but additional information on schedules for deployment of in vehicle systems and any other external processes will require particular attention to the proposed national deployment footprints. Depending upon these issues, which are hard to predict at this stage, AASHTO may need to develop formal policy statements relating to RSE deployment by its members and implement more aggressive efforts to identify funding sources to support implementation activities in the states.

In parallel with the Safety Pilot, U.S. DOT will define public agency deployment requirements for V2V and V2I safety applications and develop a Practitioner Toolbox for Deployment. These activities are very compatible with other AASHTO efforts to develop deployment guidance for its members, and so will seek active participation in the development process.

In addition, U.S. DOT is considering conducting Regional Pilots in multiple implementation areas that will provide an opportunity to pilot a variety of applications tailored to the needs of an area. Such Pilots would likely begin around 2014. These Regional Pilots would help develop implementation experience using the newly-adopted Connected Vehicle system architecture and the lessons learned from the Safety Pilot. These projects would accelerate deployment of DSRC and leverage available wireless communications networks for non-safety applications. AASHTO will engage with U.S. DOT to ensure this potential program is compatible with the national footprint plan.

With an ever-growing library of successful demonstration and testing results from the state and local agencies, and the research products from the Cooperative Transportation Systems PFS, AASHTO and its members can jumpstart growth of Connected Vehicle systems by enabling, facilitating, and sponsoring on-the-ground activities that expand the initial key localized and regional deployments. Through 2013 and 2014, one component of this effort will mean providing forums for presentation and discussion of project results and lessons learned; continuing to sponsor research through Pooled Fund Studies; participating in scanning tours of working test beds and applications; coordinating plans and development efforts with like-minded agencies; and actively supporting deployment programs. Some agencies may want to accelerate their own deployment by leveraging the plans and models implemented by other agencies.

To accomplish this, AASHTO will establish a two-pronged Deployment Support Initiative. The first component of this would focus on outreach and education intended to broadly raise the awareness and participation level in Connected Vehicle initiatives by all AASHTO members. This would ensure that there is a common level of understanding and commitment across the nation that would be necessary for the deployment of an initial DSRC infrastructure footprint. This may involve executive-

level briefings, scanning tours, and efforts to carry the results of NCHRP 03-101 to decision-makers in the agencies. An adjunct to this effort would be a coordinated program to collaborate with other organizations such as the National Association of Counties, the Association of Metropolitan Planning Organizations, and the National League of Cities to carry a common message to their constituents.

The second aspect of the Deployment Support Initiative would be a Peer Deployers Forum. This group would be an action-oriented organization where AASHTO sponsorship would allow early deployers to provide leadership and guidance to encourage the implementation of their successful deployment strategies and applications in other geographic areas.

## **2015-2019 – Expanding the Field**

Depending on NHTSA actions in 2013 to mandate DSRC in all new light vehicles for V2V safety applications, model year 2020 light vehicles would begin to appear with mandated DSRC equipment in mid-2019.

Depending on NHTSA's actions, its actions may provide another opportunity to review and update the national footprint plan by AASHTO. The initial deployment concept for AASHTO and its members will have seen key freight corridors and selected urban areas deploy denser networks of RSEs for EVP and TSP, the focus will shift to deploying a nationwide network of RSEs over this four-year period. Through increasing collaboration between AASHTO and the VIIC the footprint plan will address both the operational needs of the agencies and support for security and certificate authority needs through the deployment of dual-use RSEs.

From the perspective of AASHTO and its members, this period of time will focus on the most logical locations for DSRC implementations beyond the initial freight corridors and urban EVP and TSP applications in order to build out a nationwide RSE network. Roadside DSRC equipment may be deployed at high-priority intersections with traffic signal controllers supporting a SPaT interface. Drivers of vehicles equipped with retrofit and aftermarket DSRC devices would see an immediate impact from these V2I installations, prior to factory-installed OBEs being widely available. Other intersections and safety zones—for example, curves with speed warnings, school zones, sections subject to occasional extreme weather conditions—could be deployed as studies indicated appropriate levels of cost and benefit. Additional locations would be those that leverage federal investment in infrastructure provided for pilot projects or testbeds. State and local agencies would likely install and operate the roadside equipment following AASHTO's Connected Vehicle infrastructure design guidelines at this time.

Applications supporting agency operations will also be maturing in this phase. The increasing experience base and continued support through the AASHTO Peer Deployers Forum will reduce the barriers to deployment in other agencies. Widespread availability of commercial 4G data services and DSRC-based wireless communications will enable agencies to select the optimal alternatives for the particular applications to be deployed.

## **2020-2023 – Taking Solutions to the Market**

With 2019 designated as “year zero” for estimating the number of equipped vehicles in the fleet for subsequent years, the portion of the U.S. vehicle fleet with manufacturer-equipped DSRC on-board units could then rise to about 30% over the subsequent four years.

Widespread 4G (and newly-available 5G) commercial services and increasingly widespread DSRC installations will make it easier to gather and share data. Greater data availability—covering larger regions with higher spatial and temporal resolution—will create opportunity for new applications and data products. Data will increasingly be available from multiple providers, both public and private. Mixed data ownership and security for value-added products will require additional management of data flows and redistribution.

The private sector will by this time have the data and systems to support a wide variety of traffic information products for consumers and agencies. Many of these products will have integrated roadway safety data for road geometry and weather conditions. The availability of these products from commercial sources will then enable agencies to focus more specifically on applications directly benefitting agency operations. To say it another way—the issue will have moved from getting data to using data to improve operational effectiveness.

## **2024-2029 – Growing to Meet Demand**

Agencies will have many alternatives for obtaining traffic and roadway data by this time. Commercial data service providers will work alongside the agencies' own systems to generate broad coverage and high data quality. Applications of the data will be fully integrated into the agencies' operations.

DSRC OBE deployment in the U.S. light vehicle fleet would rise from about 30% to 70% between 2024 and 2029. V2V benefits would start to become apparent during this phase.

Agencies will have continued to deploy appropriate V2I roadside equipment until in this phase it is a routine part of roadway design for safety and operations. The infrastructure issue will be coverage, working to assure that data and services are available across all parts and modes of the transportation network where needed. Some early V2I deployments will need to be upgraded or replaced by this time.

The benefits of V2V applications will be apparent. Applications of V2V communications for operational benefit—for capacity improvements and incident response, for example—will become viable when a majority of vehicles are equipped.

## **2030 and Beyond – Connected Vehicles Everywhere**

Projecting the future state of technology is notoriously difficult, even more so after multiple generations of technology. It is both easier and more useful when looking into the distance to describe what is to be achieved rather than how to achieve it. Based on the state of the systems in 2011 and on the trajectory described in these scenarios, it seems likely that in 2030 and beyond connected vehicles will be everywhere as described below:

- Anything in the transportation system—cars, trucks, trains, transit vehicles, emergency vehicles, bicycles, pedestrians, signs, traffic controls—can be location-aware.
- Anything can be on a network.
- Data is collected and processed by both public and private service providers.
- Information is available from both public and private service providers.

- Safety and mobility on the transportation system are significantly enhanced.
- Environmental impacts of travel are reduced.

# Deployment Strategies

This section of the report synthesizes the specific strategies and associated actions that would be undertaken by AASHTO and, as appropriate, the state and local transportation agencies under the preceding deployment scenarios.

## 2011 Strategies

- To provide a common direction for Connected Vehicle application development and infrastructure deployment by the state and local agencies, the AASHTO Working Group will begin to define and document a General Concept for Deployment. This Concept will begin with identification of the specific systems and associated applications that should be deployed; the remaining research and development needs for these systems; and a general geographic phasing of deployment. The resulting document will then be used to engage the necessary state and local agencies in the process of further developing and refining the Concept. Initial focus will be placed on Connected Vehicle freight, EVP, TSP, enhanced agency operational activities, and isolated safety applications using DSRC. The benefits of deploying these systems will be documented in the Concept in form that is meaningful to agency decision-makers.
- To provide leadership in the Connected Vehicle V2I program, the AASHTO Working Group will collaborate with U.S. DOT to develop a strategy through which AASHTO will assist in prioritizing safety and mobility applications, define hardware, software, and backend needs, and identify system development needs.
- To maximize the potential benefits of the Connected Vehicle Qualified Product List, the AASHTO Working Group will establish a formal process for providing input to the product development process, with a focus on the development needs of DSRC RSEs.
- To facilitate rapid and simplified deployment by its members, AASHTO will develop guidance on the procurement of DSRC Roadside Equipment from the U.S. DOT Qualified Product List.
- To generate the greatest value for the Connected Vehicle development, testing, and evaluation projects that are being conducted by state and local agencies, the AASHTO Working Group will establish an Information Exchange Forum with responsibility for conducting a semi-annual workshop and preparing and distributing technical briefs.
- To ensure that state and local agencies with an interest in early Connected Vehicle development and deployment are aware of and can provide feedback on federal efforts, the AASHTO Working Group's Information Exchange Forum will monitor relevant U.S. DOT activities (e.g., pilot tests, application development, reference implementation activities), conduct briefing and discussion sessions with members, and provide feedback to U.S. DOT.



- To ensure that U.S. DOT is similarly aware of and taking account of development and deployment progress by the state and local agencies, the AASHTO Working Group will establish a formal mechanism and schedule for briefing U.S. DOT on activities, findings, and direction being pursued by AASHTO members.
- To leverage the operational knowledge of state and local agencies, the AASHTO Working Group will establish a task force to address the relationship between Connected Vehicle systems and traffic signal control systems. The Task force will establish a plan for the development of relevant applications, RSE siting and interface issues, recommendations for deployment of RSEs during regular signal upgrades, development of appropriate standards and specifications, deployment guidance needs, and outreach and education needs.
- To ensure broad awareness and dissemination of U.S. DOT-led efforts to develop an updated Connected Vehicle system architecture and DSRC RSE design, procurement, and O&M guidance documents, the AASHTO Working Group will develop and implement a plan for suitably promoting these products to AASHTO members.
- To ensure a strong and successful national Connected Vehicle program, AASHTO will encourage U.S. DOT and the VIIC to join with AASHTO and establish the appropriate forum through which the three parties can explore the resolution of governance, liability, security, and privacy issues in a collaborative manner.
- To ensure complimentary and mutually beneficial deployments of DSRC field equipment, AASHTO will establish a formal mechanism and schedule for briefing the VIIC on its activities and progress in developing the General Concept for Deployment and subsequent related activities.

## 2012 Strategies

- To broaden awareness across the entire AASHTO membership, the AASHTO Working Group develops a plan for a Connected Vehicle Education and Outreach Program, including the initiation of scanning tours to states with programs that are well-advanced.
- To prepare for initial infrastructure deployments by the state and local agencies, the AASHTO Working Group will establish a task force to begin work on the development of a national footprint plan for DSRC RSE infrastructure. Initial activities will include developing the scope, approach, and basic requirements of the footprint plan to meet the needs of state and local agency deployment plans and schedules.
- To support early DSRC RSE deployment efforts, the AASHTO working group will continue to refine and expand the General Concept for Deployment initiated in 2011. Specific actions will include the identification and recommendation of desired Connected Vehicle freight corridors across the U.S., and detailed deployment guidance for EVP, TSP and isolated safety applications.
- To support the future successful implementation of the General Concept of Deployment and the national DSRC footprint, AASHTO will begin development of policies that would encourage AASHTO members to adopt the recommended Connected Vehicle freight corridors, begin migration from existing commercial vehicle screening technologies to DSRC,

and support the minimum desired deployment levels of DSRC RSEs as promulgated in the national footprint plan.

- To support the nationwide DSRC RSE deployment objectives of all partners in the national Connected Vehicle program, AASHTO will engage U.S. DOT and the VIIC in the review and comment on its national RSE footprint plan. AASHTO will establish a mechanism by which ongoing discussion and collaboration on RSE density and placement can be pursued with the VIIC as the AASHTO Working Group continues to expand and refine the national footprint plan in response to the needs and deployment progress of state and local agencies.
- To further support deployment efforts by the state and local agencies, the AASHTO Working Group will assess the need and provide recommendations on the development of formal Connected Vehicle Infrastructure Design Guidelines.

## 2013-2014 Strategies

- To support deployment of the national DSRC footprint, particularly following any NHTSA agency decisions which will help bring further clarity to the timing of the presence of DSRC factory-equipped light and heavy vehicles, AASHTO will pursue adoption of a policy encouraging minimum levels of RSE deployment in each state.
- To ensure that minimum deployment levels can be accomplished in a timely fashion, AASHTO develops a national funding strategy, collaborating with other partners as appropriate.
- To ensure consistency between federal and state deployment efforts, AASHTO will seek a role in the development of the Regional Pilots and Practitioner Toolbox for Deployment to be undertaken by U.S. DOT.
- To assure sufficient awareness among state and local agencies, the AASHTO Working Group will implement a Deployment Support Program that includes the following:
  - A member education and outreach program
  - Formal collaborative education and outreach efforts with other relevant associations
  - The creation of a Peer Deployers Forum

## 2015-2019 Strategies

- To support the local, regional, and multi-state deployments of its members and to help direct a nationwide build out compatible with the needs of its other partners in the national Connected Vehicle program, AASHTO will finalize the national DSRC RSE footprint plan.
- To support deployments in the states, AASHTO will adopt the Connected Vehicle Infrastructure Design Guidelines.

## 2020-2023 Strategies

- To facilitate smooth and rapid expansion of Connected Vehicle capabilities and to encourage market growth, AASHTO will develop guidance on public-private relationships for infrastructure-based applications.

# Policy and Business Considerations

Through this deployment analysis, a number of policy and business issues have emerged that may require discussion and consideration by the AASHTO leadership. These topics are discussed below.

## National Program Coordination

At the current time it is appropriate for the state and local transportation agencies to be looking for approaches that can accelerate deployment of Connected Vehicle systems and applications. This emphasis on near-term deployment solutions in the early years of the deployment scenario is achieved through a focus on approaches that are more easily controlled or influenced by the AASHTO members. While core research and development tasks remain at the center of the federal program, the efforts by the state and local agencies will continue to gather practical deployment experience and help put in place an initial level of DSRC RSE coverage on the nation's highways. Once NHTSA makes a decision take agency actions in 2013 and 2014 about the future of DSRC in light and heavy vehicles, the results of the federal and state experiences will have an opportunity to converge.

However, representatives of the VIIC suggest that while a successful Safety Pilot is necessary, it is not sufficient for an affirmative decision regarding the future of DSRC in light vehicles. It will also be essential to define how the required DSRC security infrastructure and necessary governance structures will be established and put in place. The VIIC continues to question how and who will deploy a nationwide network of DSRC RSEs of sufficient size and within the necessary schedule to support certificate management.

Representatives of the VIIC also argue that public privacy remains a significant issue that must be resolved. The VIIC calls for a review and reaffirmation of the Connected Vehicle privacy principles originally developed in 2007.

It is important for the success of the national Connected Vehicle program for the three principal partners – AASHTO, U.S. DOT, and the carmakers – to address these issues in a collaborative manner, and sooner rather than later. A decision to advance these topics and seek resolution in the near-term should be considered by the AASHTO leadership through the appropriate forum, such as the Connected Vehicle Executive Leadership Team.

## DSRC Licensing

There is a very fundamental assumption that the Connected Vehicle program will be built in-part around DSRC systems operating near 5.9 GHz. However, there has been limited discussion regarding the availability of the frequency nationally. The current situation may be concerning to AASHTO and its members.

Licenses for the DSRC channels are currently granted on a non-exclusive basis with each licensee required to resolve issues with interference between themselves. Each license is granted based on geo-

political boundaries for governmental agencies, meaning each state receives one license for all locations they will install throughout the state. Cities, counties, tribal, and other authorities operate under the same guidelines. Their license is for their geo-political boundaries only. Commercial licensees, such as vehicle manufacturers receive a license for nationwide operation. In addition to the connected vehicle program, two other entities also have access to the frequencies at fixed locations. The frequencies are used by some earth stations as uplinks to satellites while the third entity having authorization to operate on the same frequencies is the department of defense at specific locations. DOTs and other users must avoid causing interference to stations already operating within their licensed area. This includes not only the DoD radars, but satellite earth stations and any previously installed DSRC equipment.

Installation of any infrastructure supporting the Connected Vehicle program such as V2V and V2I is, by its very nature low power. Being low power, it is also limited in its coverage area. On average, infrastructure has a maximum range of approximately 800 meters; the coverage area from vehicles will be less due to antenna height and placement. As currently stated in the FCC rules (47 CFR §§90.371-90.383), the issue of mitigating interference is the responsibility of the latter installed station and not the incumbent, *i.e.* he who installs first rules the roost. This will have its greatest impact in urban areas as governmental, non-governmental agencies and commercial deployers will have to share not only spectrum, but the physical areas as well.

The lack of deployed units using the DSRC frequencies is one reason the FCC has not assigned a Band Manager or Managers to oversee the deployment of fixed or RSE equipment. One function of a Band Manager will be to resolve interference complaints from authorized users by ensuring the licensing of deployed units is both uniform and in compliance with FCC rules and regulations. AASHTO sees a need for three entities to be certified as Band Managers, one for governmental entities, one for non-governmental agencies, and one for commercial entities. It would be incumbent upon the band managers to develop procedures for the siting of units, areas of both exclusive and non-exclusive operation and interference mitigation processes.

Only 16 states currently hold licenses for the frequency, and not all of these are held by the transportation agency within the state. There are also several local agencies (city and county) and toll authorities which also hold licenses. This raises a question of how will a national program be implemented which is targeting state DOTs when most do not currently have access to the frequency, and where they do, there may be possible conflicts with its use by other local agencies?

Further, it is significant that currently there are over 100 companies nationally that have license to the frequency which could present possible conflicts with its use by DOTs depending on location. The majority of companies are telecommunications providers or television stations.

It is clear that frequency access is a significant topic that needs to be discussed and understood among the states. AASHTO executive leadership may wish to direct additional research to be performed on this subject, develop an action plan for addressing this issue, and inform member agencies of the need to resolve this issue. For example, AASHTO may want to strongly encourage all of its members to obtain a license for the DSRC channels and actively support the concept of a Band Manager or managers. In addition, it is important to note that an upcoming NCHRP 20-01 project will more closely examine the issues around DSRC infrastructure deployment, specifically looking at equipment capabilities, spectrum licensing, acquisition requirements, as well as operations and maintenance guidelines, which will be of great help and interest to AASHTO members.

## **Commercial Vehicle Applications and Corridor Designation**

The Connected Vehicle deployment scenarios developed in this report call for an early focus on the deployment of DSRC infrastructure to support commercial vehicle applications, such as electronic screening and driver identification. This area has the potential to demonstrate early successes in the Connected Vehicle program and to help accelerate the initial deployment of DSRC RSEs on the nation's roadways. AASHTO members, particularly New York State DOT in cooperation with the I-95 Corridor Coalition, have demonstrated early leadership in this area.

Commercial vehicle applications were and continue to be an early success of the larger national ITS program. As a result, states across the U.S., most often through the leadership of the state transportation departments, have made significant investment in the systems, technologies, operational procedures, and interactions with both the federal government and motor carriers required to implement these applications. It should be noted that the Federal Motor Carrier Safety Administration (FMCSA) has recently published a proposed rulemaking requiring Electronic On-Board Recorders for the purposes of recording driver's hours which, if implemented, could help provide a strong enabling foundation for Connected Vehicle applications.

The use of DSRC in these applications will provide enhancements and capabilities that could otherwise not be realized. However, these benefits will come with a commitment on the part of the state DOTs to transition from existing systems to new DSRC equipment and to work with motor carriers to upgrade equipment onboard trucks. Coordination with FMCSA is critical to ensure compatibility of new systems with existing federal systems.

Furthermore, the proposed approach for achieving early deployment of Connected Vehicle DSRC-based commercial vehicle applications calls for identifying specific freight corridors targeted for initial implementation. There are several corridors that could be considered, and the recommended next step of identifying a National Footprint for DSRC RSEs will shed light on which corridors might be most advantageous to start.

Together, these issues will require support and commitments by state DOTs across the country. AASHTO executive leadership may wish to direct the development of an implementation strategy identifying the anticipated levels of commitment, defining the specific actions that will be required of the state DOTs, and describing the recommended methods for informing and raising awareness of AASHTO members.

## **Implementation of a DSRC National Footprint**

A key component of the deployment scenarios presented in this report is the development of a plan for a national footprint of DSRC RSEs under the direction of the AASHTO Connected Vehicle Working Group. This national footprint plan will include the recommended freight corridors described above, as well as denser pockets of DSRC equipment in urban areas for EVP and TSP, and isolated deployments of infrastructure for other safety and mobility applications focusing initially on high volume, high accident locations. It is anticipated that there will be additional collaboration with the VIIC in the development of the national footprint plan to maximize the opportunities for deploying an RSE network that can also support security and certificate management processes.

Implementation of the national footprint plan will therefore be essential to realizing both early benefits of Connected Vehicle infrastructure deployments and for achieving the full potential of a nationwide

Connected Vehicle system as DSRC-equipped light vehicles begin to roll off the production line toward the end of this decade.

Once again, the implementation of the national DSRC footprint will require commitments to planning, design, funding, deployment, operations, and maintenance on the part of all state DOTs, as well as many local transportation agencies. AASHTO executive leadership may wish to inform and raise awareness with its members of the need and benefits of the proposed approach. On completion of the national footprint plan, AASHTO leadership may wish to develop policy statements that encourage the minimum levels of deployment in each state.

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