National Connected Vehicle Field Infrastructure Footprint Analysis

Deployment Scenarios

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**Abstract**

This document, one of several products of the National Connected Vehicle Field Infrastructure Footprint Analysis, describes a set of scenarios illustrating how state and local agencies might deploy connected vehicle technology and applications. The scenarios build upon the prior Applications Analysis and the Deployment Concepts developed as part of this Connected Vehicle Infrastructure Footprint Analysis. The convergence of these scenarios into an emerging national connected vehicle footprint will be the subject of the next activity in the Footprint Analysis.

The deployment scenarios themselves describe the context and value proposition for connected vehicle infrastructure deployment; the system elements and steps by which deployment might proceed; funding strategies and other potential agency impacts; and some key challenges and limitations to deployment. A "base case" scenario is used to capture the assumptions and aspects of deployment that would be present in any particular scenario. Deployment objectives may vary among agencies, so individual scenarios are provided in response to those objectives:

- Urban Deployments
- Rural Deployments
- Multi-state Corridors
- DOT System Operations and Maintenance
- Commercial Vehicle and Freight Systems
- International Land and Border Crossings
- Fee Payments

In general, connected vehicle infrastructure is anticipated to be deployed organically as individual transportation agencies and deployment coalitions identify deployment objectives and projects. A NHTSA decision to proceed with rulemaking to deploy dedicated short range communications (DSRC) in light passenger and heavy commercial vehicles would facilitate scenarios using DSRC for safety applications. Mobility applications are likely to be developed using cellular communications and DSRC, if available, between public and commercial information services and individual vehicles and devices. Planning for individual projects would develop along the lines of comparable ITS projects.
Acknowledgements

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Executive Summary

The fundamental premise of the Connected Vehicle Environment lies in the power of wireless connectivity among vehicles, the infrastructure, and mobile devices to bring about transformative changes in highway safety, mobility, and in the environmental impacts of the transportation system. As key Federal policy decisions for connected vehicle safety approach, state and local transportation agencies need to understand what this will mean to them, what they need to know to prepare for the Connected Vehicle Environment, and what investments may need to be made. AASHTO, with the support of U.S. DOT and Transport Canada, has undertaken a Connected Vehicle Field Infrastructure Footprint Analysis to provide guidance to agency decision-makers.

This document, one of several products of the Footprint Analysis, describes a set of scenarios illustrating how state and local agencies might deploy connected vehicle technology and applications. The scenarios build upon the prior Applications Analysis and the Deployment Concepts developed as part of this Connected Vehicle Infrastructure Footprint Analysis. The convergence of these scenarios into an emerging national connected vehicle footprint will be the subject of the next activity in the Footprint Analysis.

The deployment scenarios themselves describe the context and value proposition for connected vehicle infrastructure deployment; the system elements and steps by which deployment might proceed; funding strategies and other potential agency impacts; and some key challenges and limitations to deployment. A “base case” scenario is used to capture the assumptions and aspects of deployment that would be present in any particular scenario. Deployment objectives may vary among agencies, so individual scenarios are provided in response to those objectives:

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In general, connected vehicle infrastructure is anticipated to be deployed organically as individual transportation agencies and deployment coalitions identify deployment objectives and projects. A NHTSA decision to proceed with rulemaking to deploy dedicated short range communications (DSRC) in light passenger and heavy commercial vehicles would facilitate scenarios using DSRC for safety applications. Mobility applications are likely to be developed using cellular communications and DSRC, if available, between public and commercial information services and individual vehicles and devices. Planning for individual projects would develop along the lines of comparable ITS projects.
Introduction and Purpose

As the key Federal policy decisions for connected vehicle safety approach, state and local transportation agencies need to understand what this will mean to them, what they need to know to prepare for the Connected Vehicle Environment, and what investments may need to be made. To provide guidance to agency decision-makers, AASHTO, with the support of U.S. DOT and Transport Canada, has undertaken a Connected Vehicle Field Infrastructure Footprint Analysis. Describing such a footprint satisfies many requirements in developing a policy foundation for the connected vehicle environment, including development of a set of desired outcomes:

- A description, for State and local investment and decision makers, of the justification for and value of deployment of connected vehicle infrastructure.
- A compilation of the possible data, communications, and infrastructure needs of the priority applications.
- A set of generic deployment concepts (at a high-level of engineering detail) that relate the infrastructure to the applications (or bundles of applications) and their needs under different operational conditions.
- A set of State- and local-based scenarios identifying how and where agencies might implement secure, connected vehicle infrastructure and what funding strategies they might use to support such deployment, and a synthesis of these scenarios into a preliminary national footprint of connected vehicle field infrastructure.
- A set of activities and timelines for deploying connected vehicle field infrastructure across and among State and local agencies.
- Estimates of potential costs for deployment, operations, and maintenance.
- Estimates of workforce and training requirements; and identification of policy and guidance needs.
- Identification of implementation challenges and institutional issues and identification of the timing by which those issues need to be resolved to achieve impactful deployment.

The purpose of this document is to describe a range of deployment scenarios that illustrate how different State, metropolitan and local agencies might approach deployment within their jurisdictions. The scenarios are based on the experience of agencies that have been substantially engaged in connected vehicle research and that have some level of deployment planned or in place, as well as agencies that are starting with no experience or existing connected vehicle infrastructure. The scenarios are intended to describe deployment by a particular agency (or coalition) of a set of applications within a particular context. They build upon the prior Applications Analysis and the Deployment Concepts developed as part of the Connected Vehicle Infrastructure Footprint Analysis. The aggregation of the scenarios into a national footprint will be the subject of the next task and deliverable, the Deployment Footprint.
Introduction and Purpose

Following this introductory section, the document consists of a discussion of deployment assumptions and a base case scenario and descriptions of the selected scenarios, including:

- Urban Deployments
- Rural Deployments
- Multi-state Corridors
- DOT System Operations and Maintenance
- Commercial Vehicle and Freight Systems
- International Land and Border Crossings
- Fee Payments
Deployment Assumptions and Base Case Scenario

As described in the Introduction section, the purpose of this document is to describe a set of scenarios by which agencies might approach the deployment of connected vehicle infrastructure for applications. The applications and concepts for infrastructure deployment have been described in previous Footprint Analysis deliverables. This section provides a base case deployment scenario and identifies key assumptions as a prelude to the individual deployment scenarios. This base case and the scenarios in the next section are all described in terms of:

- The deployment context: the state of the transportation system into which a connected vehicle deployment is being considered
- The value proposition: the operational objectives or expectation for which the deployment is being considered
- The deployment description: the capabilities, system elements and interactions, stakeholders, and steps by which deployment might proceed
- Funding strategies and other agency impacts: the processes within and by which a deploying agency would fund and support the deployment
- Challenges and limitations: gaps, roadblocks, and issues needing consideration, clarification, and resolution prior to and during any anticipated deployment

Deployment Context

The interaction of the transportation system with vehicles, communications networks, and the travelers using them is by definition complex. Describing the deployment of new technology and applications into this connected vehicle environment risks becoming either bogged down in more detail than is easily understood, or leaving the discussion at such a high level that it does not provide any new information. It is nonetheless important to have a common context for the deployment scenarios. Rather than attempt a completely new analysis, interested readers may refer to two other documents that may together provide a sufficiently detailed view.

The state of and trends in intelligent transportation systems (ITS) are summarized in the Deployment of ITS: A Summary of the 2010 National Survey Results.¹ This document provides a thorough description of the prevalence and distribution of ITS across the U.S. transportation system based on information provided by state and local transportation and emergency management agencies. The work was structured around seven surveys: Freeway Management, Arterial Management, Transit

Management, Transportation Management Center (TMC), Electronic Toll Collection (ETC), Public Safety – Law Enforcement, and Public Safety – Fire/Rescue. Some of these surveys correlate with categories of applications being considered as part of the connected vehicle deployment and demonstrate the potential functional evolution of the applications from an infrastructure-based to a cooperative (i.e., connected vehicle and infrastructure) deployment. The surveys also captured agency opinions about ITS and its ongoing deployment that may hint at attitudes toward similar connected vehicle deployments. This is important in setting the context for deployment scenarios; deployment of connected vehicle applications at signalized intersections, for example, depends and builds on the existing ITS deployments described in the Arterial Management survey results.

The history of and context for the connected vehicle environment was a major topic of the 2011 AASHTO Connected Vehicle Infrastructure Deployment Analysis, the precursor to this current study. That document provided a history of connected vehicle research; a review of the relevant U.S. DOT, state and local programs and Vehicle Infrastructure Integration Consortium (VIIC) initiatives at that time; an analysis of the deployment readiness of vehicles, communication devices, communications technologies, and traffic signal controllers. It also discussed, as a preview of the current work, potential applications of interest; a long-term view of deployment scenarios and strategies; and some key policy and business considerations. The discussion and conclusions of the Deployment Analysis are still relevant and provide a good historical basis for understanding the deployment context for the scenarios described in this document.

The context for deployment of the connected vehicle environment also includes an increasing number of pilot demonstrations. Federal, state, and local agencies have been working together and with vehicle and device manufacturers to demonstrate the technical viability and benefits of connected vehicle applications. Although an exhaustive presentation is beyond the scope of this document, it should be noted that public sector pilot demonstration test beds include, in no certain order:

- The Safety Pilot in Ann Arbor, Michigan, assessing V2V and V2I safety applications
- The I-66 test bed in Merrifield, Virginia supporting a variety of connected vehicle application research objectives
- The Anthem (Maricopa County), Arizona test bed, assessing arterial applications including emergency vehicle prioritization
- The Palo Alto, California, test bed, demonstrating signal system and arterial applications
- The Orlando, Florida test bed installed in support of the 2011 ITS World Congress
- The Oakland County, Michigan test bed supporting agency and private research and testing in security and signal system applications
- The Long Island, New York, test bed installed in support of the 2008 ITS World Congress and demonstration of commercial vehicle-infrastructure integration applications

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Value Proposition

The fundamental premise of the connected vehicle environment lies in the power of wireless connectivity among vehicles, the infrastructure, and mobile devices to bring about transformative changes in highway safety, mobility, and in the environmental impacts of the transportation system. Over the past decade, wireless technologies and wireless data communications have fundamentally changed the way people live. Nearly continuous access to information and the proliferation of apps—mobile software applications—have dramatically changed work, leisure, and social activities. The transportation system has not been immune to these changes.

The development of a connected vehicle environment is envisioned to leverage several types of wireless connectivity—cellular, Wi-Fi, and dedicated short-range communications (DSRC)—to serve the public good in a number of ways:

- The number and severity of highway crashes will be dramatically reduced when vehicles can sense and communicate the events and hazards around them;
- Mobility will be improved when drivers, transit riders, and freight managers have access to substantially more up-to-date, accurate, and comprehensive information on travel conditions and options; and when system operators, including roadway agencies, public transportation providers, and port and terminal operators, have actionable information and the tools to affect the performance of the transportation system in real-time;
- Environmental impacts of vehicles and travel can be reduced when travelers can make informed decisions about the best available modes and routes and when vehicles can communicate with the infrastructure to enhance fuel efficiency by avoiding unnecessary stops and slow downs.

The potential benefits of deploying V2I applications targeting safety improvements were described in some detail in a 2012 FHWA report on Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications. It provides estimates of the frequency and cost of crashes involving pre-crash scenarios addressed by V2I applications. The report concludes that “currently identified V2I safety applications could potentially target approximately 2.3 million crashes and $202 billion in costs,” assuming the applications are 100% effective in eliminating those crashes and deployed everywhere in the U.S.

Given this potential, the question to be addressed is less one of whether or not to build a connected vehicle environment than it is how to best realize that potential. Public agencies have a fundamental interest in assuring safe and efficient operation of the road network, but private enterprise is already deploying selected applications in order to capture the commercial advantages of connected vehicles. For example:

- Smartphone manufacturers, cellular network providers, and application developers work together to build and distribute location-aware applications that provide information services to mobile users. These applications already include mapping, navigation, and routing services used by millions of drivers.

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3 U.S. DOT Research and Innovative Technology Administration; Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications; Publication Number FHWA-HRT-11-040; November 2012.
• Various insurance companies are offering services and policies that tailor coverage to a driver’s behavior and vehicle mileage. Usage-based insurance (UBI) offers premium reductions in exchange for sharing a driver’s pattern of road use with the insurance company. In many cases data are taken from the vehicle’s on-board diagnostics port as well as from the insurance company’s mobile communications device.

• Many automakers are building always-on telematics into their new vehicles as a means of providing enhanced navigation, notification of required maintenance, emergency services and in-vehicle “infotainment” to buyers of their vehicles. These systems are generally also capable of capturing vehicle diagnostic data, locations, and driving history.

• Information service providers are using location and speed data from mobile devices acting as probes to generate aggregated and anonymized traffic information. The data may originate from captive vehicle fleets or from consumers that opt in to providing data in exchange for traveler and location-based information services.

Public agencies have a clear and coincident interest in much of this same information, both coming from and being made available to vehicles operating on their roadways. They also have unique access to and responsibility for the deployment of any roadway infrastructure that might be used to facilitate the connected vehicle environment. The value proposition for public agencies is then to leverage that infrastructure and its access to the greatest public good, irrespective of the particular means of deployment.

Deployment Description

The deployment description consists of several subsections that build on one another and set the stage for the subsequent discussion of funding, agency impacts, challenges and limitations.

• The Connected Vehicle Environment describes the assumptions and constraints on deployment

• System Elements and Interactions identifies and describes the essential components of a connected vehicle infrastructure deployment

• Stakeholder Roles identifies the essential roles of stakeholders in the connected vehicle infrastructure deployment, including the transportation agency and those parties with whom it interacts

• Steps to Deployment describes the process by which the connected vehicle infrastructure deployment is likely to unfold within a transportation agency

The Connected Vehicle Environment

The connected vehicle environment will emerge from a complex and interrelated set of initiatives and decisions by transportation agencies, vehicle manufacturers, information service providers, and the traveling public. Agency initiatives to deploy connected vehicle infrastructure are only part of the environment’s development. Some fundamental assumptions about those decisions and initiatives need to be made in order to provide a context for the infrastructure deployment scenarios. The assumptions presented here are intended to describe a reasonable and likely set of conditions and constraints. Variations in these assumptions that would significantly change the scenarios are described here or within the relevant scenarios.
1. **NHTSA makes the decision in 2013 to pursue rulemaking for deployment of 5.9 GHz DSRC on-board equipment in light vehicles in support of V2V safety applications.** This assumption sets a base expectation that DSRC will eventually be deployed across the U.S. light vehicle fleet and available to interact with DSRC roadside equipment. Lack of such a decision could lead to opportunistic deployment for particular sets of applications, but would greatly reduce agency incentives to broadly deploy DSRC infrastructure.

2. **NHTSA makes the decision in 2014 to pursue rulemaking for deployment of 5.9 GHz DSRC on-board equipment in commercial vehicles in support of V2V safety applications.** Just as the light vehicle V2V decision incentivizes infrastructure deployment for potential V2I applications, a commercial vehicle decision would serve as a catalyst for deployment of freight applications. Lack of such a decision would likely result in opportunistic deployment of autonomous safety systems with minimal dependence on infrastructure rather than mandated cooperative capabilities.

3. **The FCC protects and preserves the 5850-5925 MHz DSRC spectrum for Intelligent Transportation Systems.** DSRC technology research and development have been based on availability of the specified frequency band, but there are competing interests in that part of the spectrum. Reduction or dilution of the available bandwidth could adversely affect the performance of some DSRC-based applications. It is nonetheless reasonable to assume that compensating research and development would enable the key applications that drove the spectrum allocation.

4. **Technical standards are in place to specify DSRC RSE form/fit/function and OBE function.** Developers and deployers will eventually need stable technology standards for DSRC equipment to justify their investment of resources in application development and deployment. Lack of such standards could result in a reduced pace of deployment, or in variations in technical specifications among vehicle manufacturers and agencies.

5. **Technical standards are in place to specify interfaces and messages between vehicles and infrastructure.** A minimum set of messaging standards will need to be implemented to support the connected vehicle applications. The vehicle will provide basic information about its location and speed; its sensed vehicle and road environmental conditions; and relevant requests for interactions with the infrastructure (e.g., traffic signals). The infrastructure will provide traveler information; maps and roadway geometries; and signal phase and timing. The infrastructure may also provide requests for data sensed by vehicles; roadside traffic and weather alerts; reference positioning corrections, and reference time corrections. Lack of such standards could result in a reduced pace of deployment, or in variations in technical specifications among vehicle manufacturers and agencies.

6. **Technical standards are in place to specify interfaces and messages between the roadside infrastructure and network information services.** It would certainly be possible to build a set of closed systems where the roadside infrastructure was linked only to specific network nodes and services, but it would severely limit the opportunities for third-party application development and sharing of the roadside infrastructure among multiple applications. The alternative is, as assumed here, to establish standardized interfaces.

7. **Automakers and roadway owner/operators reach an agreement of intention to deploy and maintain a base set of capabilities in complete compliance with the technical standards in support of V2I safety and mobility applications.** The cooperative nature of

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4 A description of the potential connected vehicle applications relevant to this assumption is provided in the Connected Vehicle Infrastructure Footprint Analysis Applications Analysis

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office
connected vehicle applications requires that interfaces be present on both vehicles and infrastructure for V2I applications to function. Agencies are unlikely to proceed with development and deployment of infrastructure without evidence of complementary development and deployment on vehicles.

8. **DSRC equipment certification capabilities are available.** As demonstrated in the Safety Pilot, standards are subject to interpretation, and certification to an objective test of compliance is necessary to assure interoperability in complex open systems. Deployment could be significantly slowed by recursive field testing and modification if appropriate certifications are not available.

9. **DSRC equipment manufacturers are providing certified RSEs in complete compliance with the technical standards in support of V2I safety and mobility applications.** Even with established standards and certification testing, vendors have to be providing compliant equipment before it can be deployed.

10. **A Security Certificate Management System (SCMS) with standardized interfaces is available to support trusted connected vehicle infrastructure deployments.** The SCMS is an essential and necessary component of a connected vehicle deployment in order to ensure trusted and secure data exchange. It is assumed here that an SCMS is available to support the field infrastructure, and that its availability does not directly depend on the infrastructure deployment or on actions by deploying agencies.

11. **Deploying agencies will seek to preserve and enhance their existing infrastructure and ITS investments.** Connected vehicle technology deployment is here assumed to complement existing ITS capabilities, and need not be presumed to replace equivalent existing ITS solutions.

12. **Connected vehicle investment decisions may include evaluation of non-connected-vehicle alternatives providing equivalent benefits.** Decisions to deploy new safety, mobility and environmental enhancement applications will not necessarily default to connected vehicle technologies. The investment decision may include an analysis of alternatives that include traditional fixed infrastructure and ITS technologies as well as connected vehicle solutions.

13. **Commercial 4G LTE services continue to expand so as to meet or exceed the prior-generation 3G footprint with similar subscription and pricing models.** Analysis of non-DSRC connected vehicle alternatives should recognize that cellular communications networks are continuing to evolve as well.

14. **Telematics services driven by commercial interests will continue to develop along current trajectories (e.g.: traffic crash/work zone icons on Google Maps; usage-based insurance).** Connected vehicle applications are being developed outside the transportation system-based initiatives, and there are no reasons to believe that they will not continue to do so. Realistic deployment scenarios will recognize and potentially leverage these developments to advance safety, mobility and environmental objectives.

15. **Vehicle manufacturers will continue to offer autonomous safety systems for applications such as adaptive cruise control, lane departure warnings, blind spot warnings, etc.** Just as traditional traffic control and ITS solutions may offer
infrastructure-based alternatives to connected vehicle systems, it should not be assumed that connected vehicle systems would necessarily replace current or future autonomous systems.

16. **Research on automated vehicles continues (or accelerates) along current trajectories.** Development of “self-driving” vehicles is likely to continue, and seems likely to need some level of connected vehicle capability to reach its full potential. The research needs to be monitored for potential impacts on connected vehicle deployment.

**System Elements and Interactions**

It is generally assumed in the deployment scenarios that connected vehicle communications directly between two mobile elements in vehicles are carried out using DSRC/WAVE technology. The need for very low-latency communications makes DSRC the default choice for V2V safety applications.

It is generally assumed in the deployment scenarios that connected vehicle communications directly between connected vehicle mobile elements and field elements at the roadside are carried out using DSRC/WAVE technology. Low latency communications are important for some local V2I safety and mobility applications with rapidly changing local road conditions and traffic controls, such as at signalized intersections.

It is generally assumed in the deployment scenarios that connected vehicle communications directly between connected vehicle mobile elements and center elements are carried out using cellular or other non-DSRC wireless communications, or DSRC infrastructure with appropriate backhaul connections. Applications based on interactions between a vehicle or a mobile device and a network information service—for example, gathering probe data or providing traveler information—typically do not require low latencies or interaction with the roadside infrastructure. In such cases, a cellular data connection over an established commercial network provides a proven means of data transfer. A DSRC-based alternative, sending messages from the vehicle or mobile device to an RSE that relays the messages over a backhaul connection, is also possible.

Connected vehicle applications will both drive the need to develop the essential system elements and depend on their deployment. The Applications Analysis identified and provided a synthesis of a large number of potential applications from the connected vehicle literature. For the purpose of describing the deployment scenarios, it is helpful to postulate a subset of application that are more likely to see early deployment and from which the connected vehicle environment could grow. Early applications are likely to develop around the deployment of DSRC for V2V safety and around enhancements to existing applications. These “launch” or “day one” applications could include:

- **V2I safety applications**
  - Red Light Violation Warning (similar to the earlier CICAS application)
  - Curve Speed Warning
  - Stop Sign Gap Assist (similar to the earlier CICAS application)
  - Spot Weather Impact Warning
  - Reduced Speed / Work Zone Warning

- **Mobility applications**
  - Motorist Advisories and Warnings (emergencies, weather, variable speeds, curve speed, oversize vehicle)
  - Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles (WX-INFO)
Deployment Assumptions and Base Case Scenario

- Advanced Traveler Information System (ATIS)
- Freight Real-time Traveler Information with Performance Monitoring (F-ATIS)
- Transit Signal Priority
- Emergency Vehicle Preemption
- Agency Operations and Maintenance
  - Enhanced Maintenance Decision Support
  - Information for Maintenance and Fleet Management Systems

The deployment of these applications as part of a connected vehicle environment is described in the particular scenarios to which they might apply.

Stakeholder Roles

Each of the stakeholders in the connected vehicle environment will be associated with a set of system components that they provide as part of or operate within the environment.

A **Transportation Agency** (or an organization operating on its behalf) provides infrastructure and data supporting the connected vehicle environment including, but not necessarily limited to:

- V2I roadside equipment (for example, DSRC RSEs)
- Interfaces from V2I roadside equipment to roadside transportation equipment (for example, traffic signal controllers) and/or local roadside networks
- Supporting roadside infrastructure (for example, pole and mounting, power)
- Backhaul from the roadside to network information services
- Data from roadside equipment for DSRC-based applications
  - Traveler information and alerts, including advisory speed limits and lane closure information
  - Intersection and roadway geometric data
  - Signal phase and timing data
  - Positioning system and time corrections, if needed
- Network information services as needed by particular applications

A **Traveler** operates their vehicle (for example, a car, light truck, motorcycle or bicycle) with its mobile unit and its software within the connected vehicle environment. A pedestrian with a personal mobile device could also participate in the connected vehicle environment.

- Equipped vehicle
  - DSRC OBE unit (embedded or aftermarket)
  - (Optional) Cellular/LTE device (embedded, aftermarket, or carried in)
- (Optional) Interfaces to the vehicle from a personal device
- Personal mobile device for non-vehicular applications
  - (Optional) Applications and data services on personal device

A **Vehicle Manufacturer** provides vehicles that are equipped to operate within the connected vehicle environment. Within the vehicle itself, they provide:
Deployment Assumptions and Base Case Scenario

- Embedded communications units (for example, DSRC OBEs or cellular units), if applicable
- Interfaces from the vehicle to (embedded, aftermarket, or personal) communications units
- Data services on embedded units
  - Basic Safety Message (BSM) for DSRC
  - Probe data as needed to support V2I applications
  - Requests for information from roadside (DSRC) or remote (cellular) services as needed to support V2I applications
- Application software on embedded units, if applicable

Aftermarket Equipment Manufacturers provide communications units that are not embedded into vehicles by the vehicle manufacturers. The aftermarket units are functionally the same as embedded units.

- Aftermarket units, if applicable
- Interfaces (wired or wireless) to vehicle from communications units
- Data services on aftermarket units
  - Basic Safety Message for DSRC
  - Probe data as needed to support V2I applications
  - Requests for information from roadside (DSRC) or remote (cellular) services as needed to support V2I applications
- Application software on aftermarket units, if applicable

Roadside equipment manufacturers and certification services provide the equipment to be deployed at the roadside to support local V2I communications. Equipment in this context could include but is not limited to DSRC roadside equipment (RSE), traffic signal controllers supporting V2I data exchange, and "black boxes" that might be used to enable V2I data exchange with legacy signal controllers.

Third-party information services provide data to user applications within the connected vehicle environment. They do not otherwise own or operate any part of the environment itself. Value-added traveler information services, for example, could provide applications and data for use on mobile devices or within vehicles.

A Governing Body for Security Services, to be formed from among transportation agencies, vehicle manufacturers, and DSRC equipment manufacturers, will need to be established to define procedures and administer connected vehicle network security across the entire geography of connected vehicle operations. The Governing Body would also charter and license the Security Certificate Management System (SCMS) Service Providers. It is assumed in the deployment scenarios that transportation agencies would not be acting as their own SCMS service providers. The SCMS service provider will:

- Provide DSRC security certificates
- Maintain and distribute DSRC security certificate revocation lists
Steps to Deployment

The process by which connected vehicle infrastructure and applications will be deployed by transportation agencies is similar to that for any other transportation infrastructure and is generally an extension of existing ITS practices. The primary distinction is that the evidence of a successful deployment requires a cooperative deployment of the mobile infrastructure—vehicles that also participate in and support the applications—that is generally outside the control of the agency deploying the infrastructure.5

The first step in connected vehicle deployment, as in any other infrastructure program, is to identify the needs and appropriate deployment opportunities. The Applications Analysis developed earlier in this project provides a survey of potential connected vehicle applications, and the NCHRP 03-101 Deployment Plan6 provides a tool for assessment of opportunities. Since connected vehicle applications are still maturing, it will be helpful at this phase to scan for comparable deployment experiences and review pilot demonstrations.

It will be important in this needs identification stage to develop institutional awareness and support for local and regional deployments. While many of the connected vehicle applications are intended to address very local operational problems—intersection violations, for example—the benefits of the connected vehicle environment are much broader. Awareness and cooperation within and between agencies will be necessary to deploy infrastructure and applications that are useful to vehicles operating across agency jurisdictions.

The planning phase should also consider the externalities of and alternatives to a connected vehicle application deployment. Since the applications require connected vehicles to be effective, deployment planning will need to address the prevalence of enabled vehicles within the population. While many vehicles are already capable of some level of cellular connectivity, growth of DSRC and cellular connectivity within the target vehicle fleets will directly impact both the timing and effectiveness of infrastructure deployment.7 Many connected vehicle applications provide benefits similar to more traditional ITS deployments, so a benefit-cost analysis of alternatives may be appropriate where applications are similar. There may also be synergies between the potential connected vehicle and existing ITS deployments that could affect the effectiveness and costs of the new projects. For example, integration of connected vehicle traveler information applications with existing 511 and advanced transportation management systems (ATMS) would have clear functional and cost advantages.

Depending on the particular application(s) being considered, it may be appropriate at this point in the process to consider a local demonstration pilot project. If the scan of deployment research, pilot projects, and experience did not discover any similar applications, it may be difficult to identify the benefits or costs for planning purposes without sufficient information. Although the benefits of V2V applications have been the subject of much research, establishing believable safety and mobility

5 The exception to this concern is the case of an agency deploying connected vehicle applications in support of its own management and operations, as is described in one of the scenarios in the next section of this document.
6 NCHRP 03-101: Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies Deployment Plan; Version 1.0; August 30, 2013
7 An analysis of the likely rate of deployment among the vehicle population will be part of the next Deployment Footprint deliverable under this project.
benefit estimates for V2I will be a large part of agency acceptance of the value proposition. A pilot project specific to the application context and conditions can significantly enhance the technology base, awareness and effectiveness of connected vehicle applications. Several state and local agencies are in the process of deploying connected vehicle technology pilot demonstrations in conjunction with the U.S. DOT, and the Research and Innovative Technology Administration’s (RITA) Affiliated Test Bed initiative is coordinating information on these pilot demonstrations and testing opportunities.

When an agency decides to deploy, that intent becomes part of the agency’s planning process. Although the details may vary, the stages and products of the process are fairly consistent among agencies. Connected vehicle deployments will at this point track closely with an agency’s ITS deployment practices except that, as noted earlier, the cooperative nature of the connected vehicle environment will require closer attention in planning to external factors.

**Long-range Transportation Planning** will capture the intent to deploy; provide schedules and budgetary estimates for the deployment; and identify the funding strategies and sources, potentially including consideration of public-private partnerships. Long-range plans can provide twenty to thirty-year views into the future, renewed every five to ten years, and in this case would reflect the connected vehicle environment’s development from its initial planning to relative maturity. The effects of an increasing population of connected vehicles would be considered in regional models for congestion, traveler behavior, and greenhouse gas emissions.

An agency’s 5(-7)-year Program would include any near-term connected vehicle application deployment plans as they relate to its objectives and performance measures. Funding may be identified and allocated in this planning process. Projects identified in the five-year program are scheduled and committed to development in the Transportation Improvement Plan (TIP). This process is not expected to differ from other ITS projects for connected vehicle deployments.

Actual project development and deployment should proceed as with any other ITS program, with some differences.

- Deployments may vary substantially across settings and applications. Each DSRC RSE radio is licensed for a particular site and the radio frequency (RF) characteristics will vary from site to site. The Deployment Concepts document can provide more information on this subject.
- As mentioned earlier in the bases for deployment, project deployments will also depend on the availability of supporting systems provided by others (e.g., SCMS, RSEs with applicable software, data provided by OBEs). These considerations will have had programmatic attention and planning before getting to the project stage, but will require continued monitoring and some additional specific project activities. For example, RSEs will need to be registered with the SCMS and have active certificates before being tested and deployed in a live environment.
- CV programs and projects may depend on having sufficient (private) vehicle deployments to operate and measure the performance benefits of the deployment.

Connected vehicle deployments will also depend on the eventual development of **design and procurement standards** (special provisions). These standards will likely come in part from the connected vehicle infrastructure deployment guidance to be developed by FHWA in 2015, and from the deploying agency’s existing procedures and provisions for ITS.
**Staff development and training** will be needed for deployment, operations and maintenance of connected vehicle systems insofar as they differ from typical ITS deployments. Personnel development should proceed in parallel with planning and research to assure capacity is consistent and mature prior to and during deployment.

**Funding Strategies and Other Agency Impacts**

It is assumed in the deployment scenarios that there will be no Congressionally-designated funding to support the deployment of connected vehicle field infrastructure. As such, it is unlikely there will be a centrally-coordinated nationwide infrastructure roll-out. The implementation of the SCMS is a potential exception.

Connected vehicle field infrastructure deployment and associated operations and maintenance costs will nonetheless have broad eligibility under various federal-aid funding programs in the same manner as ITS field infrastructure. The same processes for identifying funding sources and allocating funding that involve MPOs, state and local agencies will be adopted.

In parallel with the development of deployment guidance by FHWA in 2015, AASHTO could encourage the creation of an incentive program (similar to the 511 planning and deployment assistance program) that would provide grants to deploying agencies. This might motivate agencies to begin the necessary deployment planning activities; deepen understanding of standards, core system components, and available guidance; and encourage consistent deployment approaches in the absence of a coordinated nationwide roll-out.

Deploying agencies will look to public-private partnerships (P3), including relationships with data service providers and commercial application developers, to support infrastructure deployment and ongoing O&M. These relationships could involve a variety of financial arrangements from direct transaction-based user fee payments to innovative incentive and concessionary finance programs. AASHTO will develop appropriate resources including best practices and model contracts and data sharing agreements. Development of alternative funding strategies (e.g., P3 or commercial arrangements) will be highly dependent on state and local development priorities and policies, and could require legislative action at federal, state and local levels to enable and implement.

As mentioned earlier, agencies will need to actively participate in the governance and implementation of security measures due to the cooperative nature of connected vehicle communications. The establishment and operations of the SCMS service providers will necessitate creating a governing body for security services in which some representatives of the transportation agencies should be included.

Connected vehicle policies and institutional issues, including the governance of security services and other topics beyond the scope of this document, are the subject of extensive ongoing research by RITA's Joint Program Office. More information and resources are available at the JPO's Connected Vehicle Policy and Institutional Issues web page at http://www.its.dot.gov/connected_vehicle/connected_vehicle_policy.htm.
Challenges and Limitations

The cooperative nature of the connected vehicle environment generally precludes traditional top-down central planning of connected vehicle application deployments. For example, V2I safety applications using DSRC will not provide benefit until both vehicles and infrastructure have been enabled with DSRC communications. As such, it becomes difficult to justify the benefits of infrastructure deployment until a certain number of vehicles with V2I capabilities have been deployed—a condition which is outside the control of the agency deploying the infrastructure. On the other hand, the vehicles will not necessarily be equipped with V2I safety applications until the infrastructure is deployed—a condition which is outside the control of the vehicle and aftermarket manufacturers. Solutions to this deployment challenge could come from taking advantage of opportunities where public agencies control the vehicles as well as the infrastructure—for example, in transit fleets, or among their own maintenance vehicle fleets. The DOT Operations and Maintenance scenario advances this opportunity with specific connected vehicle applications. Agencies might also initiate connected vehicle application deployment partnerships with private fleets—commercial vehicle operators or rental car fleets.

Although there have been several demonstration deployments of V2V safety applications, most notably in the Safety Pilot in Ann Arbor, Michigan, there have been only very limited field demonstrations of V2I safety and mobility applications. All of the connected vehicle infrastructure applications will need additional research and pilot demonstrations to be deployment-ready.
Scenarios

As described in the Introduction, the purpose of these deployment scenarios is to illustrate how transportation agencies might approach the deployment of connected vehicle capabilities within a state, metropolitan or rural area. Each scenario is intended to illustrate a pattern of deployment for a generalized set of characteristics typical of an agency, its policies, transportation facilities, traffic conditions, and operations. All of these characteristics vary from agency to agency, and variability within each scenario is described insofar as it might materially affect deployment strategies and planning.

The scenarios themselves are based on surveys of connected vehicle experience to date, projected to larger scales based on experience with similar ITS deployments. Agencies interviewed as part of developing the scenarios had a range of familiarity and experience with connected vehicle programs, technologies and applications. Some interviewees had already deployed test beds and demonstration applications, whereas others had awareness but no practical experience. Reference documents describing connected vehicle programs, architectures, and deployments were consulted and incorporated as applicable.

The scenario descriptions presume that the deployment assumptions and platform described earlier in this document are available as a foundation for specific deployments. Those common elements are essential components of each scenario and are included by reference rather than being repeated in the particular scenarios. As such, the scenario descriptions are focused on deployment considerations and components specific to that scenario, and on exceptions to the underlying common bases.

Each of the scenario descriptions follows the common template established in the deployment platform description. After a brief introduction of the particular scenario’s intent, the agency and application context is described. This is followed by a statement of the value proposition for deployment in familiar terms of its intended effect on safety, mobility and the environment. The deployment itself is described in terms of both its system interactions (based on the deployment concepts developed earlier in this project) and the steps to deployment. An analysis of potential funding strategies, acknowledging transportation planning processes, includes discussion of how existing funding programs might be used, as well as how other relevant public and private partnerships might contribute. Potential challenges and limitations in deployment are identified, and activities and timelines for deployment are outlined. Particular points in the scenario descriptions may be illustrated by inset examples of agency circumstances drawn from interviews.
Urban Deployments

Urban areas represent the largest concentrations of both traffic and transportation infrastructure. As such, the potential impact of connected vehicle technologies on urban transportation conditions is similarly high relative to other scenarios. Just as intelligent transportation system (ITS) deployments are more numerous in large metropolitan areas, connected vehicle infrastructure is likely to be concentrated in those regions. Urban settings are also likely to see the broadest variety of connected vehicle applications. These factors together suggest that urban settings will host the early highest-impact connected vehicle deployments.

Deployment Context

According to the Census Bureau, there are 486 urbanized areas in the U.S. with a total population of almost 220 million people, which is more than 71% of the total U.S. population. There are 16 urbanized areas with populations of 2.5 million or more; and 41 with populations of 1 million or more. There are almost 1.1 million miles of roadways in these areas (of a total of almost 4.1M miles of public roads in the U.S.). Of the urban roadways, 115,000 miles fall under the jurisdiction of state agencies and almost 950,000 miles are under the jurisdiction of other non-federal agencies (principally units of local government).

In 2011, almost 2 billion vehicle miles of travel (VMT) occurred on urban roads (of a total U.S. VMT of 2.9 trillion). According to the TTI Urban Mobility Study published in December 2012, urban congestion caused 5.5 billion hours of delay in 2011 and 2.9 billion gallons of wasted fuel at total cost of $121 billion. FHWA has identified principal causes of urban congestion as:

- Bottlenecks (responsible for 40 percent of urban congestion);
- Traffic incidents (responsible for 25 percent);
- Bad weather (responsible for 15 percent);
- Work zones (responsible for 10 percent);
- Poor signal timing (responsible for 5 percent); and
- Special events and other factors (responsible for 5 percent).

State and local agencies have and continue to implement a variety of countermeasures to urban congestion, including improved traffic signal operations and various ITS solutions. According to the ITS deployment tracking survey conducted in 2010 by the ITS JPO, the 108 largest metropolitan areas include 266 agencies with TMCs, plus the additional deployed ITS assets shown in Table 1.

Transportation improvements will follow the metropolitan planning process in urban areas with populations greater than 50,000 where an MPO exists. Most MPOs do not lead the implementation of transportation projects, but provide overall coordination in planning and programming funds for projects and operations. The MPO works with local transportation providers in the planning process, including transit agencies, state and local highway departments, and others. Core functions include developing and updating a long-range transportation plan for the metropolitan area and developing a short-range Transportation Improvement Plan (TIP).
Table 1 - Summary of 2010 ITS Assets

<table>
<thead>
<tr>
<th>Category</th>
<th>Reported</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freeway Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miles under electronic surveillance</td>
<td>11607</td>
<td>21679</td>
<td>54%</td>
</tr>
<tr>
<td>Ramps controlled by ramp meter</td>
<td>2901</td>
<td>32630</td>
<td>9%</td>
</tr>
<tr>
<td>Miles under lane control</td>
<td>2026</td>
<td>21679</td>
<td>9%</td>
</tr>
<tr>
<td>Number of Dynamic Message Signs (DMS)</td>
<td>4038</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Miles covered by Highway Advisory Radio (HAR)</td>
<td>4550</td>
<td>21679</td>
<td>21%</td>
</tr>
<tr>
<td><strong>Freeway Incident Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway miles under incident detection algorithms</td>
<td>2411</td>
<td>21679</td>
<td>11%</td>
</tr>
<tr>
<td>Freeway miles covered by surveillance cameras (CCTV)</td>
<td>8704</td>
<td>21679</td>
<td>40%</td>
</tr>
<tr>
<td>Freeway miles covered by service patrols</td>
<td>8914</td>
<td>21679</td>
<td>41%</td>
</tr>
<tr>
<td><strong>Arterial Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signalized intersections covered by electronic surveillance</td>
<td>58188</td>
<td>115850</td>
<td>50%</td>
</tr>
<tr>
<td>Signalized intersections under closed loop with field masters only</td>
<td>7752</td>
<td>115850</td>
<td>7%</td>
</tr>
<tr>
<td>Signalized intersections under closed loop with field masters and central management system</td>
<td>14970</td>
<td>115850</td>
<td>13%</td>
</tr>
<tr>
<td>Number of Dynamic Message Signs (DMS)</td>
<td>886</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Arterial miles covered by Highway Advisory Radio (HAR)</td>
<td>2125</td>
<td>52956</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Arterial Incident Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial miles under incident detection algorithms</td>
<td>965</td>
<td>52956</td>
<td>2%</td>
</tr>
<tr>
<td>Arterial miles covered by surveillance cameras (CCTV)</td>
<td>5468</td>
<td>52956</td>
<td>10%</td>
</tr>
<tr>
<td>Arterial miles covered by service patrols</td>
<td>9022</td>
<td>52956</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Transit Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed route buses equipped with Automatic Vehicle Location (AVL)</td>
<td>26989</td>
<td>40812</td>
<td>66%</td>
</tr>
<tr>
<td>Fixed route buses with electronic real-time monitoring of system components</td>
<td>14543</td>
<td>40812</td>
<td>36%</td>
</tr>
<tr>
<td>Demand responsive vehicles that operate under Computer Aided Dispatch (CAD)</td>
<td>1439</td>
<td>1649</td>
<td>87%</td>
</tr>
<tr>
<td>Bus stops with electronic display of dynamic traveler information to the public</td>
<td>13554</td>
<td>387489</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Electronic Fare Payment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed route buses equipped with Magnetic Stripe Readers</td>
<td>25045</td>
<td>40812</td>
<td>61%</td>
</tr>
<tr>
<td>Fixed route buses equipped with Smart Card Readers</td>
<td>16167</td>
<td>40812</td>
<td>40%</td>
</tr>
<tr>
<td><strong>Emergency Management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vehicles under Computer Aided Dispatch (CAD)</td>
<td>61596</td>
<td>77316</td>
<td>80%</td>
</tr>
<tr>
<td>Vehicles equipped with on-board navigation capabilities</td>
<td>34160</td>
<td>77316</td>
<td>44%</td>
</tr>
<tr>
<td><strong>Electronic Toll Collection</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toll collection plazas with Electronic Toll Collection capabilities</td>
<td>845</td>
<td>850</td>
<td>99%</td>
</tr>
<tr>
<td>Toll collection lanes with Electronic Toll Collection capabilities</td>
<td>4669</td>
<td>4971</td>
<td>94%</td>
</tr>
</tbody>
</table>
Value Proposition

Primary motivations for connected vehicle deployments in urban areas will be safety improvements (particularly intersection safety and incident/emergency response) and congestion mitigation. Eco-driving applications enabled by connected vehicle technologies will be important along signalized routes for reducing the environmental impact of travel and reducing the consumer’s cost of fuel. Corridor-wide information from connected vehicles will support broader deployment of ICM strategies and enable agencies to communicate with drivers through in-vehicle messaging. Information gathered from connected vehicles will help identify congestion at bottlenecks and that caused by incidents across the urban network. All of this information will support traffic management and traveler information applications of public agencies.

Public agencies will assess and trade-off the opportunities to use connected vehicle probe data aggregation and processing versus the continued deployment, operations and maintenance of traditional ITS vehicle detection versus purchasing commercial traffic information services. Connected vehicle-based transit and pedestrian applications will be important in urban areas. Connected vehicle technologies may also be viewed as a means to more broadly enable pricing solutions (e.g., HOT lanes).

Opportunities to enhance current capabilities or to reduce ongoing costs of operating and maintaining existing ITS systems and services may create opportunities to replace or enhance those systems with connected vehicle technologies. Connected vehicle deployment decisions can be expected to be driven by perceived benefits and costs versus deployment of other solutions.

Deployment Description

Deployments could incorporate elements of the Urban Highway, Urban Intersection, and Urban Corridor Deployment Concepts, including the following applications:

- Red Light Violation Warning and Stop Sign Violation
- Driver Gap Assist at Signalized Intersections and Stop Signs
- Motorist Advisories and Warnings (emergencies, weather, variable speeds, queue, speed zone, work zone, oversize vehicle)
- Active Traffic Management (lane control, dynamic speed harmonization, cooperative adaptive cruise control)
- Advanced Traveler Information System (dynamic route guidance, travel time)
- Multimodal Intelligent Traffic Signal Systems (freight signal priority, intelligent traffic signal system, transit signal priority, pedestrian mobility, emergency vehicle pre-emption)
- Integrated Dynamic Transit Operations (Connection Protection, Dynamic Transit Operations, Dynamic Ridesharing)
- Integrated Dynamic Multimodal Operations
- Origin-Destination (with opt-in permissions or anonymization), Traffic Model Baselining & Predictive Traffic Studies
- Eco-Signal Operations (approach and departure, traffic signal timing, transit signal priority, freight signal priority, connected eco-driving)
Dynamic Eco-Routing

Since larger legacy deployments of ITS are anticipated in urban areas, it can be expected therefore that greater consideration must be given to the interactions and integration with existing ITS, especially existing TMCs (potentially requiring upgrades to ATMS software) and other back-office systems.

Deployment will likely begin by identifying the most important segments of urban freeway networks (especially those with complex access points to/from the arterial network); key freeway, arterial, and transit corridors; and/or significant signalized intersections (e.g., based on number of crashes or other criteria). Identification of candidate deployment locations will be followed by prioritization of those locations. This will most likely occur through a multi-agency, multi-jurisdictional process involving MPO leadership. The need for prioritization is based on an assumption that desirable deployment locations will exceed the resources and early deployment capabilities of the various public agencies in the urban area.

New connected vehicle solutions will be integrated into regional ITS architectures, and connected vehicle projects will be included in the metropolitan planning process as described below. These projects will generally be considered to be ITS projects and need to follow a systems engineering process in development.

Once projects that will be funded have been identified, agencies will move to the development of designs and specifications, followed by procurement and deployment, and then ongoing operations and maintenance.

Funding Strategies and Other Agency Impacts

Connected vehicle deployment projects will receive prioritization and programming of funds in accordance with local metropolitan planning processes, and will be included in the MTP and TIP. In some states, development of alternative funding strategies (such as public-private partnerships (P3s) or commercial arrangements) will likely led by a state agency in collaboration with the region’s MPO. Such arrangements may require legislative action. Depending on the approach taken, new operational policies and procedures may be required, and new or retrained personnel may be required if public agencies will be responsible for operations and maintenance of connected vehicle infrastructure.

Challenges and Limitations

- The multi-agency/multi-jurisdictional nature of transportation infrastructure deployment in urban areas may present challenges.
- Inclusion in metropolitan planning process will place connected vehicle infrastructure deployment decisions against competing priorities. This may be especially challenging given the role of local units of government in the planning process given their lower exposure to connected vehicle solutions and technologies.
- The impacts of necessary changes to existing ITS systems (especially TMCs and back-office systems) where recent, significant investments may have been made may be seen as an impediment to investment in connected vehicle infrastructure.
• The density of connected vehicle infrastructure deployment may need to be large (and therefore costly) for investment to be impactful. This may be a further impediment to investment decisions.
Rural Deployments

Deployment of connected vehicle technologies has to consider the full range of facilities, modes, and traffic conditions throughout the deploying agency’s jurisdiction. Although traffic and transportation facilities are concentrated in urban areas, safety and mobility challenges are equally present outside major metropolitan areas. This scenario focuses on rural and small urbanized areas, including those that lie along corridors between the major metropolitan areas that were described in the previous scenario. While rural and urbanized settings may share interest in a common core set of applications, differences in the cost and benefits of deployment and operations in those settings, as described below, may drive agencies to different deployment approaches.

Deployment Context

Although geography and land use patterns vary widely across the continent, all states have both urban and rural areas to be considered in the context of connected vehicle deployments. Most states have at least one urbanized area fitting the prior scenario of an urban area, most of which have some existing ITS deployment. All states similarly have rural areas typically with a few high-volume highways between urbanized areas and numerous lower-volume roadways. As shown in Table 2, the U.S. has more roadway miles in rural areas than in urban areas, and the majority of those roadways are owned and maintained by the states, counties and municipalities without Federal Aid.

Table 2 - 2011 Road Lengths and Traffic Densities

<table>
<thead>
<tr>
<th>Road Ownership</th>
<th>Public Road Length, miles (1)</th>
<th>Vehicle Miles Traveled, millions (2)</th>
<th>Category Average Daily Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Federal Aid Highway</td>
<td>Non-Federal Aid</td>
<td>Total Length</td>
</tr>
<tr>
<td>Rural</td>
<td>681,116</td>
<td>2,300,797</td>
<td>2,981,913</td>
</tr>
<tr>
<td>Small Urban</td>
<td>66,889</td>
<td>134,188</td>
<td>201,077</td>
</tr>
<tr>
<td>Urbanized</td>
<td>249,942</td>
<td>496,493</td>
<td>746,435</td>
</tr>
<tr>
<td>Total Urban</td>
<td>316,831</td>
<td>630,681</td>
<td>947,511</td>
</tr>
<tr>
<td>Total Rural and Urban</td>
<td>997,947</td>
<td>2,931,478</td>
<td>3,929,425</td>
</tr>
</tbody>
</table>


Traffic volumes, on the other hand, are on average significantly lower on rural roadways than in urban areas. High volume corridors between major urban areas may approach urban traffic densities. Commercial vehicle traffic may be even higher as a fraction of traffic volume on some rural highways than on typical urban roadways. Rural roadways may also be subject to congestion just as much as urban areas. Recurring congestion on rural roadways can occur due to daily, weekly or seasonal variations in commuter, freight, and recreational travel. Non-recurring congestion on rural roadways, as in urban areas, generally is a result of inclement weather or crashes.

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Scenarios

It should be noted that not all high-volume rural roadways will be limited access highways or interstates. Rural intersections present a range of safety concerns and solutions. Rural signalized (and four-way stop) intersections may represent larger speed reductions—from highway speeds to a full stop—than similar signalized intersections in urban areas. Intersections of minor arterials with higher-volume higher-speed highways can present issues with limited sight lines and gap perception, particularly in areas where the rural population skews to an older demographic.

Traditional ITS solutions in rural areas are most likely distributed along high-volume interurban corridors, but will be otherwise scarce relative to ITS deployments in urban areas. Typical urban deployments are integrated with advanced traffic management systems (ATMS) and controlled from a metropolitan area transportation management center (TMC). A rural ITS is more likely to be deployed as either part of a statewide system or as a standalone solution to a particular operational need. Statewide systems have been significantly expanded in response to the terms of the Real-Time System Management Information Program established in Section 1201 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). Examples of ITS deployed in rural areas include:

- 511 and associated traveler information systems
- Variable message signs (VMS)
- Highway Advisory Radio (HAR)
- Vehicle detection stations in key locations (e.g., high-volume segments, mountain passes)
- Road weather information systems (RWIS) and their associated environmental sensor stations (ESS)
- Standalone ITS systems deployed in rural areas to address local operational concerns and safety warnings such as curve speed, animal crossings, and high winds.

Road weather management is especially important in rural areas. Winter weather conditions impose significant risks on travelers, particularly those in remote areas where pavement treatment and snow plowing may be delayed and help may be further away. Some locations may have implemented automated detection of hazardous weather conditions for access control or treatment—for example, high wind warnings or bridge icing treatment—but these are exceptional. In any case, winter road weather maintenance is both logistically complex and costly for transportation agencies.

Value Proposition

Connected vehicle deployment in the rural context presents significant opportunities for safety improvement. While traffic volumes are typically lower on rural roadways than in urban areas, crash and fatality rates are somewhat higher in rural areas. In North Dakota, for example, over 90% of fatal and disabling injury crashes involving trucks in the past five years occurred on rural roads, and 1 in 5 of these were on rural local roads. Improving awareness of local traffic, roadway and weather conditions is a

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8 [http://www.ops.fhwa.dot.gov/1201/]
9 Synthesis of Western U.S. Automated Safety Warning Systems; presented by David Veneziano, Western Transportation Institute, at the National Rural ITS Conference, St. Cloud, Minnesota, on August 28, 2013; http://nritsconference.org/agenda.html

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key means of reducing the likelihood of events in rural areas, and connected vehicle applications for rural areas are focused on providing that awareness,

Localized congestion may be a concern on particular rural corridors and roadways. Although congestion would generally be considered an urban problem, its consequences for the traveling public and operating agencies may be just as significant in those rural locations. Travel time reliability is important to long-distance highway travel, particularly for commercial vehicle operations along interurban freight corridors. Connected vehicle capabilities for gathering probe data and providing traveler information could directly address these congestion-related issues in rural areas.

The ongoing costs of operating and maintaining existing ITS systems and services may create opportunities to replace or enhance those systems with CV capabilities. As noted earlier, ITS deployments in rural areas tend to be fewer and further between than in urban areas. This lower density of deployment tends to drive up the cost of those installations. Connected vehicle technologies have the potential to mitigate some of those costs by linking to or replacing infrastructure with capabilities on the vehicles. Using sensors and cellular communications on vehicles, for example, could expand probe data gathering in remote areas with minimal infrastructure deployment, at least in areas with reasonably reliable cellular service.

In any of these cases, the CV deployment decision is expected to be driven by the perceived benefit and cost versus deployment of other solutions. An agency objective to obtain real-time system management information in rural areas of a state, for example, could be obtained by an agency through its own traditional ITS vehicle detection such as magnetic loops or radar; from commercial traffic information services; or through new connected vehicle systems. Similarly, improvement in spot safety systems for curve speed warnings, animal crossings, and local weather conditions could be achieved through infrastructure-only ITS deployment or through connected vehicle applications. The benefits and costs of these alternatives will depend on the particulars of the applications, geography, and existing infrastructure.

**Deployment Description**

**System Elements and Interactions**

Connected vehicle infrastructure deployments in rural areas are expected to initially focus on features and applications included in the rural roadway concept described in the *Deployment Concepts* document. Those applications include:

- Motorist Advisories and Warnings (emergencies, weather, variable speeds, curve speed, oversize vehicle)
- Stop Sign Assist
- Intersection Violation Warnings
- Reduced Speed / Work Zone Warnings
- Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles (WX-INFO)
Small urbanized areas within a larger rural context might also benefit from deployment of particular applications previously described in the Urban Deployments scenario. Applications relevant to small urban settings, similar to those described above for purely rural settings, would include:

- Red Light Violation Warning and Stop Sign Violation
- Driver Gap Assist at Signalized Intersections and Stop Signs

Interurban corridors with high traffic densities through rural areas might also benefit from certain mobility-related applications including:

- Active Traffic Management (lane control, dynamic speed harmonization, cooperative adaptive cruise control)
- Advanced Traveler Information System (dynamic route guidance, travel time)

As described in the Deployment Concepts document, some of these applications can conceivably be deployed with either DSRC or cellular communications from the vehicle. The DSRC form of the applications will typically require power and communications backhaul connections at the deployment site, but will minimize any potential application latency. The cellular deployment would preclude the need for any roadside deployment (and therefore any site power and communications), but may introduce latencies between the vehicle and back office components of the application. The deploying agency will need to further assess the deployment areas for cellular coverage as part of the deployment design.

Deployment of applications may also require or benefit from integration with other ITS and asset management systems. Connected vehicle traveler information applications should be consistent or integrate directly with 511 systems and HAR, particularly in presentation of weather, road condition, and work zone information. Intersection/red light violation applications will interface directly with the associated traffic signal controller, but may also benefit from any regional traffic signal management systems.

**Steps to Deployment**

The deployment process begins with identification of the specific connected vehicle application needs, in terms of both the operational objectives to be achieved and the locations over which they are to be deployed. In a rural context, these will be driven primarily by spot safety problem areas, including those driven by road weather conditions, and traveler information needs.

An assessment of the selected sites relative to the application needs will need to be performed. The Deployment Concepts document provides a general summary of the deployment considerations for a rural setting; the Application Assessment report provides additional detail on deployment features for particular applications. Many applications may be deployable using DSRC between the vehicle and the roadside with backhaul to supporting network information services, or using cellular communications directly between the vehicle and the network information services. In those cases, the site assessments will need to address the availability of power and backhaul communications and the availability of reliable cellular services in order to make a decision as to which communications mode to use for those applications at that site.

Recognizing that resources are limited, prioritizing the application and site deployments will be important to integrating connected vehicle deployment into the agency planning process.
As described in the Deployment Assumptions and Base Case section, this prioritization will be similar to those performed for ITS projects. Every state transportation agency has a Strategic Highway Safety Plan (SHSP) that describes the basis for meeting its safety goals and may suggest strategies for prioritizing applications and sites. Local agencies within a state may have similar plans. Deployments under consideration should also be integrated with the statewide and regional ITS architectures to identify any potential synergies or conflicts with existing systems. First-of-a-kind deployments may be developed as research projects outside the formal planning process.

Engineering and development of connected vehicle infrastructure projects in rural settings is not fundamentally different from traditional ITS projects, and is described in the Deployment Assumptions and Base Case section of this report.

**Funding Strategies and Other Agency Impacts**

As deployment of connected vehicle applications moves from research and demonstration to the mainstream of transportation projects, prioritization and programming of funds will proceed in accordance with state and local planning processes. The general outline for that strategy is described in the Base Case section.

Programming might be more strongly linked to economic development for projects in rural areas than for urban projects. Development of new infrastructure and enabling technology in rural areas in many cases provides completely new opportunities rather than incremental improvement. Such economic links could also open up new funding mechanisms.

Connected vehicle application deployment in rural areas could be institutionally complicated. Whereas transportation technology deployment in developed urban areas will tend to fall under established patterns of local, metropolitan and state jurisdictions, corresponding relationships in rural areas may not be as clear. In the rural west, for example, deployment could conceivably require coordination among multiple federal, state, local and Native American tribal authorities, with multiple agencies—transportation, commerce and communications, and military/security services—at each level.

Depending on the applications and communications technologies involved, new operational policies and procedures may be required to support deployment. While this will be true of all scenarios and settings, it may be a greater challenge in rural deployments than in urban areas. The technologies involved in a connected vehicle deployment will require new training for installation, operation and maintenance that may need a critical density of deployment to be justified.

**Challenges and Limitations**

Although the suite of connected vehicle applications available and suitable for deployment in rural areas is similar to those in urban areas, rural deployments have their own potential challenges and limitations. Most of these relate to the fixed cost of a roadside infrastructure deployment relative to the number of vehicles using that infrastructure, and to the limited existing deployment of supporting communications and utilities.

If deployment decisions are affected by the desirability of providing benefits for the largest population of users, it is likely that deployment of connected vehicle applications in rural areas will be less of a priority than in urban metro areas. Lower population densities and rates of technology deployment—
wireless data communications, fiber, and even vehicles—in rural areas could limit and delay the net effectiveness of connected vehicle applications.

Improvement of safety on rural roadways is challenged by crash events being driven more by individual driver behavior and road weather conditions than by traffic congestion or system operations. Connected vehicle applications can address some of these factors, particularly in providing warnings of road and weather conditions to inform driver decisions, but there are very few controls outside signalized rural intersections. The benefits of connected vehicle systems in a rural environment are likely to be less direct than in comparable urban deployments.

Scaling of DSRC RSE deployment in rural areas relative to traffic volume is less cost effective (higher cost per vehicle-infrastructure interaction) than deployment in urban areas. As noted earlier, traffic densities on rural roadways are on average less than one-fifth of those on urban roadways. While the cost of an infrastructure deployment is comparable or higher than that in an urban area, the number of infrastructure-vehicle interactions and the potential benefit is much lower.

The limited range and cost of DSRC deployments would seem to favor cellular communications for use in rural connected vehicle applications. Cellular coverage in rural areas may however be less reliable and have lower bandwidth than in urban areas. Particularly remote rural areas may have no cellular coverage at all, leaving geographical gaps in areas that might still have significant safety needs.

Backhaul communications for ITS and connected vehicle systems are problematic in rural areas. Agencies frequently have to resort to creative (non-fiber) solutions for providing rural backhaul for ITS deployments, and the challenges could be even greater with connected vehicle backhaul requirements. Delivery of security certificates and revocation lists for DSRC deployments would be very challenging in rural areas without fiber connections.
Multi-State Corridors

Although the planning and deployment of transportation infrastructure and ITS ultimately rests with the states, MPOs and local agencies, coalitions of agencies can significantly accelerate operational and technological changes. Multi-state corridor organizations like the I-95 Corridor Coalition\(^1\) and the NorthWest Passage Corridor\(^2\) have been successful in the research, procurement and deployment of many new ITS technologies and strategies. Prior experience suggests that multi-state corridor organizations and deployments could offer similar opportunities to identify and accelerate implementation of connected vehicle applications.

Deployment Context

Formally designated multi-state corridors tend to be those where high passenger or commercial vehicle travel demand exists; particularly when travel impacts affect the regional economy, or where other regional impacts (such as severe weather) affect regional travel. Regions containing these multi-state corridors are likely to be those experiencing significant transportation impacts that include:

- Substantial increases in VMT;
- Substantial increases in urban interstate delay and in increasing delay across all federal-aid systems;
- Increased congestion without offsetting capacity additions;
- Increasing highway fuel consumption and greenhouse gas (GHG) emissions, even in light of improving vehicle fuel economy;
- Truck volumes increasing to levels that may not be physically or environmentally sustainable in the region;
- Increasing highway bottlenecks that constrain interstate commerce and economic productivity;
- Lack of consistent and adequate traveler information; and
- Challenges in responding to severe weather events in a coordinated manner.

Value Proposition

Primary concerns for connected vehicle system deployment along multi-state corridors will be safety improvements (particularly response to major incidents and events, such as natural disasters) and congestion mitigation. Environmental applications enabled by connected vehicle technologies will be important along corridors to reduce vehicle emissions from passenger cars and commercial vehicles.

Information gathered from connected vehicles will identify congestion caused by bottlenecks and incidents along the corridor and will support traffic management and traveler information applications. Multi-state corridor deployments will trade-off connected vehicle probe data aggregation and processing versus deployment of traditional ITS vehicle detection solutions or the use of commercial traffic information services.

\(^1\) [http://www.i95coalition.org/i95/](http://www.i95coalition.org/i95/)
\(^2\) [http://www.nwpassage.info/about/history.php](http://www.nwpassage.info/about/history.php)
Connected vehicle technologies will be important to support efficient freight movement and provide information to commercial vehicle operators. Connected vehicle-based transit applications will be important in some regions with large multi-jurisdictional public transportation systems (e.g., NY/NJ and the DC/VA/MD region).

Connected vehicle technologies will be important in response to regional weather events (e.g., major winter storms, flooding, etc.). An effective evacuation response to regional weather events requires coordination amongst all agencies in the region, with consistent information sent directly to travelers beyond the reach of any single agency.

Connected vehicle technologies may also be viewed as a means to more broadly implement pricing solutions (e.g., interstate tolling). While electronic tolling solutions have already become standardized in some regions, V2I tolling applications could offer standardization based on embedded connected vehicle capabilities rather than aftermarket toll tags. Tolling applications are addressed separately in the Fee Payment scenario.

Opportunities to enhance current capabilities or to reduce ongoing costs of operating and maintaining existing ITS systems and services may create opportunities to replace or enhance those systems with connected vehicle capabilities. Connected vehicle deployment decisions are expected to be driven by perceived benefit and cost versus deployment of other solutions.

**Deployment Description**

Connected vehicle multi-state corridors can be expected to exhibit similarities to aspects of the Urban Highways, Rural Roadway, Freight Corridors, and DOT O&M Deployment Concepts described in earlier reports for this study. In particular, multi-state corridors will enable applications that include:

- Motorist Advisories and Warnings (including those for emergencies, weather, variable speeds, curve speed, and oversize vehicle alerts);
- Reduced Speed / Work Zone Warnings;
- Dynamic Eco-routing based on roadway conditions or congestion issues;
- Active Traffic Management (including lane control, dynamic speed harmonization, and cooperative adaptive cruise control solutions);
- Advanced Traveler Information Systems (including dynamic route guidance and travel time systems)
- Integrated Dynamic Transit Operations (including applications that focus on connection protection and dynamic ridesharing)
- Truck Wireless Roadside Inspection;
- Truck E-Screening and Virtual Weigh Stations;
- Smart Truck Parking;
- Enhanced Maintenance Decision Support Systems for winter maintenance; and
- Work Zone Traveler Information.

Multi-state corridor connected vehicle solutions will require integration with existing regional transportation information systems and operations—for example, Regional Integrated Transportation System.
Information System (RITIS) in the Maryland-Delaware-Pennsylvania region and TRANSCOM in the New York-New Jersey-Connecticut metropolitan region—and legacy ITS deployments—for example, 511 systems.

Deployment of connected vehicle systems in multi-state corridors will begin by identifying the most important corridor applications while working within the multi-agency, multi-modal environment that characterizes the corridor’s planning or operating organization. This will be followed by a prioritization of potential deployment locations within the corridor. A key planning aspect will include the development of solutions for the integration of the new connected vehicle solutions into existing regional systems, which may be outside the direct purview of the corridor organization.

Deployment will then require the identification and allocation of funding, and the development of designs/specifications, followed by procurement and implementation activities. Ongoing operations and maintenance, and issues of agency responsibility will need to be resolved.

**Funding Strategies and Other Agency Impacts**

In most instances, multi-state corridors will have no formally-chartered organization with authority over the participating agencies, and so prioritization and programming of funds in accordance with the group’s potentially informal operating principles may be required. Funds for connected vehicle infrastructure deployment are likely to be drawn from the same sources as current projects coordinated within corridor coalitions. However, development of alternative funding strategies (e.g., public-private partnerships or commercial arrangements) will likely be led by the corridor organization rather than one or more of the participating agencies (e.g., in a manner similar to the I-95 Corridor Coalition’s probe project).

In a manner similar to the existing ITS multi-state corridors, it is anticipated that there will be designation of an agency that takes on contracting responsibility for the multi-state group. Depending on the approach, new operational policies and procedures may be required. Some operating policies may have been developed for multi-state purposes (e.g., the I-95 Corridor Coalition’s Quick Clear policies) and may have to be revised in the light of connected vehicle system needs and requirements.

**Challenges and Limitations**

- The multi-agency/multi-jurisdictional nature of corridor-based deployment may create impediments in terms of planning and the time taken to realize deployment. In particular, connected vehicle system deployments will require commitment of funding from multiple states if federal sources of funding are unavailable.
- Impacts of necessary changes to existing ITS systems within individual states and in regional systems will require significant coordination.
- Depending on the application, the scale of deployment may need to be large (and therefore costly) in order for investment by the group to be impactful.
DOT System Operations and Maintenance

There is a tendency when considering the potential of connected vehicle applications to focus on large-scale deployment across privately-owned light vehicles and commercial heavy vehicles that are the majority users of the public roadways. This approach makes sense if the objectives of deployment are explicitly safety and mobility improvements. A large-scale deployment also creates significant challenges in its initial scale and complexity: it spreads responsibility for deploying essential components both across the public infrastructure and within privately-owned and manufactured vehicles; it depends on complex cooperative applications; and its success hinges on a critical level of deployment across the vehicle fleet.

An alternative approach is to concentrate initial deployment on a smaller scale within a tighter sphere of control: to deploy connected vehicle applications focused on the agency’s own internal operations and maintenance. This approach has the key advantages of reducing both the scale and complexity of deployment and providing directly measurable outcomes while still building infrastructure and experience that can be extended into other applications as connectivity and applications spread across the light vehicle and commercial fleets.

Deployment Context

Transportation agencies expend tremendous resources in the maintenance of their roadways. State DOTs in 2011 spent $13.86 billion dollars on roadway maintenance in 2011, a total that does not include similar outlays of county and municipal agencies. The majority of these expenses, especially in areas with cold wet winters, go to road treatments for snow and ice control. The total also includes non-winter maintenance including mowing along the highway, repair of potholes and pavement defects, clearance of debris on the roadway, guardrail repair, and paint striping.

Information on road conditions to be used in internal operations and maintenance is gathered by a variety of manual and automated systems. Maintenance personnel keep logs noting road conditions as part of their normal daily routine. Pavement and bridge conditions are formally inspected on a regular (annual or biennial) schedule through automated surveys and manual inspections. Road weather information systems (RWIS) collect information from environmental sensor stations (ESS) to monitor weather near the roadways and, in some cases, conditions on the road surface itself. These weather observations, combined with weather forecasts and road treatment models, can be used in a Maintenance Decision Support System (MDSS) to plan and monitor winter maintenance.

Gathering information for roadway asset management and long-term maintenance planning is also an important part of an agency’s operations. State systems monitor and report on the condition of key assets and operations, including pavement, bridges, traffic, congestion and delay, and safety. Reporting at the state level is rolled into the national Highway Performance Monitoring System (HPMS) as a means of monitoring the health of the highway system as a whole. Data gathered in the HPMS are used, among other applications, for apportioning Federal-aid funds back to the states. More recently, MAP-21 defined a process for establishing performance management goals that

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must be met by state agencies and MPOs across various components of the transportation system as an eligibility requirement for certain forms of Federal-aid funding.

Transportation and other public agencies are also users of their systems. State, county, and municipal agencies in the U.S. owned a total of 3.74 million motor vehicles in 2011, including automobiles, buses, trucks, truck tractors, and motorcycles.\textsuperscript{15} While this is a relatively small fraction—1.5%—of the total of 253 million vehicle registrations, it represents a significant population of vehicles under the control of government agencies.

**Value Proposition**

Transportation agencies at all levels are under ever-increasing pressure to control their internal operations and maintenance costs while improving the quality and reliability of service. Intelligent transportation systems have greatly improved highway operations, but the impact is limited to those regions in which fixed ITS infrastructure is deployed. RWIS have likewise vastly improved the collection of surface weather and roadway conditions for winter road maintenance, but are relatively expensive to deploy and gather data only at particular fixed locations.

Under MAP-21, USDOT will promulgate a rulemaking that establishes performance measures for various components of the transportation. Once established, these rules will require state DOTs, MPOs, and other stakeholders to implement systems and new processes, and to regularly report results as a requirement for eligibility to certain Federal-aid funding. Performance measures of note in this context include:

- The performance of the National Highway System (NHS), including the condition of pavement and bridges on the NHS;
- Measures to assess safety on all public roads, including numbers of injuries and fatalities;
- Measures to assess traffic congestion and on-road mobile source emissions;
- Measures for use by state DOTs to assess freight movement on the interstate system.

Connected vehicle technology deployments can facilitate operational improvements in both gathering operations data and providing data back to maintenance personnel. Data gathering is improved by using vehicles as probes across an agency’s region of operations—not just at fixed observing stations. Probe vehicles can gather data consistently across the entire road network at finer resolutions at any time the vehicles are in use. Operations and maintenance are improved by providing dynamic real-time information and plans (based on combining the probe data with other sources) to maintenance personnel. Connected vehicle technologies similarly have the potential to generate data that can support the gathering, calculation, and reporting of performance measures under MAP-21 and future USDOT rules.

The net of these opportunities is that agency internal operations and maintenance costs could be reduced through connected vehicle capabilities. More accurate data provided in a more timely fashion to agency staff would enable them to make smarter decisions about their operations, and to satisfy Federal performance management reporting requirements. Material costs of road treatment, for example, could be reduced if road conditions are more accurately known when routing and treatment

plans are being set. Better information and planning ultimately also leads to safer conditions for both agency personnel and for the traveling public.

**Deployment Description**

**System Elements and Interactions**

This scenario is distinct from the other scenarios since the objective is improving agency internal operations and maintenance, rather than on a broader deployment involving other stakeholders. The DOT Operations and Maintenance applications and setting are generally described in the *Deployment Concepts* document.

Deployment in this scenario is focused on an agency’s own fleet, which would include both light passenger and heavy vehicles. The light vehicles are typically used by maintenance supervisors, in motorist assist programs, and in vehicle pools for agency business between facilities. An agency’s heavy vehicles can be used in a variety of maintenance operations: in winter road maintenance for pre-treatment and snow plowing; in summer for pavement and right-of-way maintenance. Transit vehicle fleets could also contribute data for DOT applications; their regular schedules would provide high temporal resolution of changes in the infrastructure over highly-traveled routes.

Light vehicles would be used primarily for applications gathering probe data for use in monitoring the state of the system and its operations. Because they are agency vehicles, their use as probes would not be subject to the same privacy constraints as might be applied to privately-owned vehicles. The particular probe data types to be collected would be determined by the applications and by the availability of the data from the vehicle’s sensors and data bus. Data would be gathered by the on-board units as the vehicles were driven in the normal course of business, and could be sent to maintenance facilities or network information services over either a cellular connection or whenever in range of a DSRC RSE.

The heavy-vehicle integration opportunity could enable significant connected vehicle research and application development. Heavy vehicles are typically customized for particular uses—such as snow plows—and the need for customization has resulted in more modular vehicles with standardized module interfaces and aftermarket products including sensors. The SAE J1939 standard identifies data elements available from the vehicles’ CAN bus that are readily available to support connected vehicle application development.

Applications described in the *Applications Analysis* that might be enabled as part of a deployment for agency operations and maintenance include:

- Enhanced Maintenance Decision Support System
- Winter road treatment and snow plowing
- Non-winter maintenance such as spraying of plant growth retardant
- Information for Maintenance and Fleet Management Systems (including AVL/CAD-type applications)
- Probe-based Pavement Maintenance
- Work Zone Traveler Information
Steps to Deployment

The deployment process begins with identification of the specific connected vehicle application needs, in terms of both the operational objectives and the regions over which they are to be deployed. For the operations and maintenance applications, the focus will be on system performance measures and processes needing improvement within the agency.

Since a number of the applications in this case are internal to the agency’s operations and not specifically tied to Federal-aid funding, application and infrastructure deployment are not necessarily subject to planning processes used for roadway capital expenditures. The agency should nonetheless perform sufficient analysis of alternatives and benefit-cost studies and follow a systems engineering process to assure that the deployment meets the desired performance results. Implementation of performance management systems that will determine future eligibility for Federal-aid funds will be subject to reviews and approvals as described in MAP-21 and in accordance with future USDOT rules.

Implementation will generally follow the agency’s own practices for acquisition and deployment of operations and maintenance equipment and services.

Funding Strategies and Other Agency Impacts

As noted above in describing the steps to deployment, this scenario is operations-based, rather than being based on capital projects. As such, it provides more flexibility in an agency decision process to deploy than in some of the other scenarios. For funding strategies, it offers an opportunity to demonstrate an operational cost savings of deployment to directly offset investment.

Initial research and demonstration projects on applications for agency operations and maintenance are excellent candidates for pooled fund studies. This could allow agencies to share the funding and research results, further reducing the initial expenditures and increasing the potential range of applications.

Operations and maintenance applications are frequently outsourced to contractors, providing another avenue for funding. There could be significant opportunities for P3s where applications are developed to agency specifications but provided on a contract basis, especially if the contractor is then able to remarket the connected vehicle application to other agencies.

Challenges and Limitations

Like other applications based on probe data, the deployment of operations and maintenance applications may be limited by the data available from the vehicle data bus, especially for light vehicles. (Heavy vehicle manufacturers tend to conform more closely to the standards and to publish any exceptions or extensions.) Further interaction with the standards committees and manufacturers may be needed to identify and obtain access to data of interest.

Industry interest in these applications and this scenario may be limited by the size of the market and by a perception that these are not “connected vehicle applications” since they do not directly affect safety and mobility of the vehicles being deployed. This limitation is itself somewhat offset by the agency’s ability to build custom solutions to this and similar operational needs, but the custom solutions are unable to capture economies of scale.
Although not specifically excluded by the application designs, deployment may not be cost-effective with DSRC. The applications are specific to agency needs and vehicles, and it is unclear if RSEs supporting other applications—for example, intersection safety applications—could be used for agency applications at the same time. Latency and RSE location requirements, especially for those supporting winter maintenance applications, could also require RSEs in locations that are not otherwise optimal for safety and mobility applications.
Commercial Vehicle and Freight Systems

With 11 million\textsuperscript{16} trucks traversing the nation’s highways and local roads logging over 163,692 million vehicle miles per year and domestic freight ton-miles carried by truck expected to increase by 53% over the next 30 years, bottlenecks exist on corridors due to recurring and non-recurring congestion and at fixed locations, such as international border crossings and maritime ports due to enforcement of safety and compliance laws and regulations.

Federal and state governments enforce truck size, weight, and safety compliance at fixed weigh stations on major corridors and at mobile sites operated by law enforcement personnel. In 2010, law enforcement agencies across the country conducted approximately 198 million truck weighings, about 59 percent of which were made using weigh-in-motion systems and 41 percent used static scales. Less than 1 percent of weighings discover violations.

Movement of freight originating at seaports and airports has surpassed pre-recession levels due to increases in trade between North American partners and with other global trade partners. While more than 400 U.S. seaports, airports, and land border crossings handle some international merchandise trade, the majority of the trade passes through a relatively small number of gateways. In 2008, the nation's top five freight transportation gateways (land, sea, and airports) handled 25 percent ($865 billion) of the total value of U.S. international merchandise trade.

While truck congestion on corridors and at ports is of concern, the safety and the impact of truck movements on the traveling public is also a concern.

Deployment Context

Drivers of commercial vehicles operating throughout the transportation system face many of the same challenges as drivers of light passenger vehicles, amplified by the specifically professional and commercial aspects. Traveler information is essential to commercial vehicle operations dependent on safe and timely deliveries. Routing of large vehicles needs to take into account the weight and vertical clearance limits of roadway structures and the operating challenges of high-profile vehicles. The need for advance information on available commercial vehicle parking has consequences for both freight delay and driver safety.

Issues related to freight and commercial vehicle regulation and enforcement typically fall under the purview of state/provincial and the federal governments in North America. In general, independent authorities or municipal agencies own and operate seaports and airports. Federal government agencies maintain a presence at ports (except inland ports) to enforce federal laws regarding customs and security.

Roadside inspection stations are owned and operated by the states/provinces and enforce their laws pertaining to truck size and weight and other administrative regulations of trucks. However, these facilities operate under federal guidance and are funded partly by the federal government. Some roadside inspection facilities use 915 MHz RFID technology to identify trucks that are enrolled in pre-clearance programs while they are traveling at highway speeds upstream of the facility to ensure only

\textsuperscript{16} \url{http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/11factsfigures/table3_2.htm}

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office
those without potential violations are allowed to by-pass the facility. Trucks that are not enrolled in such programs must enter the facility where they may be subject to weighing, inspections, and enforcement actions.

Larger sea ports, such as the Port of Long Beach and Port of Houston, typically utilize 915 MHz RFID technology to monitor the movement of trucks within their facilities. Customs and Border Patrol (CBP) will sometimes use the same technology to identify trucks/carriers and to screen them for security and other administrative purposes (e.g., fee collection). Port operators fund, own, and operate the technologies within their facilities. Inland ports may also use 915 MHz RFID to monitor the movement of trucks within their facilities for administrative purposes. Port operators fund, own, and operate the technologies inside the facilities.

Value Proposition

It is not anticipated that the deployment or migration to connected vehicle technologies will eliminate issues related to truck congestion at ports or the need for safety inspections and compliance checks on trucks. However, such technologies will enable agencies to be more efficient by providing targeted information to truckers, carriers, and shippers, and will support more efficient demand management at ports.

There is potential to reduce costs associated with the deployment of older, legacy technologies, including the potential to make some systems unnecessary in the future. For example, dynamic message signs, highway advisory radio, and static signs may become unnecessary if vehicles can receive traveler information directly through in-vehicle displays.

For seaports, inland ports, and airports the focus of deployment will be on high volume facilities or those that handle high value import/export goods, and those which have a communications infrastructure already in place.

In the area of roadside commercial vehicle enforcement, the focus of deployment will be on high volume truck corridors where safety and the impact of truck crashes is a concern. Focus will also be placed on corridors leading to and from high volume inland, sea and airports. The use of connected vehicle technologies may support significant automation with very limited human interaction at fixed facilities.

Many truck weigh stations and ports-of-entry use RFID to identify approaching trucks and provide pre-clearance if carriers are enrolled in certain commercial programs (e.g., PrePass, NORPASS). These facilities would migrate to 5.9 GHz DSRC if there are cost savings relative to the replacement of existing and aging equipment. Agencies do not expect that the new technology will eliminate the need for safety screening, compliance checks, and other enforcement activities.

Deployment Description

The general deployment philosophy appears to be to start small and expand. Introduction of other new technologies in the commercial vehicle and freight systems arena has happened this way. Agencies and operators are expected to start with pilot deployments at facilities on high volume truck corridors or at seaports handling large freight volumes; especially those where ITS infrastructure is already in place to support communications needs. High volume corridors and ports also attract a lot of public attention; many of them are located near large urban areas that typically adopt technologies...
at higher rates. Most high volume truck corridors are interstates, and so relatively higher involvement of federal governments, states and provinces can be expected to support the funding of pilot programs. In the past, federal governments have provided funding support for pilot deployments on these types of corridors. At sea and airports, port authorities will be responsible for implementing the technologies; again, potentially with support from federal governments. Some inland ports are privately operated and these may not be inclined to deploy connected vehicle technology unless there is an immediate positive impact on revenue.

After observing favorable results from pilot deployments, states and provinces contributed significantly to full deployment of preclearance and automated safety enforcement systems for trucks along high volume corridors. State DOTs interviewed for this study indicated that they expect the federal government to lead pilot deployments, hire consultants and contractors, evaluate results, and involve states and provinces as key stakeholders to help them prepare for subsequent deployment.

Agencies operating sea, air, and inland ports will take a similar approach (i.e., pilot deployments followed by full deployments) to instrument their facilities with connected vehicle technology if they decide to do so.

However, there is likely to be a transition phase when both legacy technologies (e.g., 915 MHz RFID) will co-exist with new technologies (e.g., 5.9 GHz DSRC, 4G/LTE). This transition phase will last until penetration of connected vehicle technology reaches sufficient levels and the operators are confident that the new technology satisfies their needs.

Deployment in support of commercial vehicle and freight systems would draw on aspects of the Urban Highways, Rural Roadway, and Freight Corridors Deployment Concepts described in earlier reports for this study. Applications described in the Applications Analysis that might be enabled as part of a deployment for commercial vehicles and freight could include, but are not necessarily limited to:

- Freight Advanced Traveler Information Systems (FRATIS)
  - Real-Time Reliable Information (F-ATIS)
  - Dynamic Route Guidance (F-DRG)
  - Information for Freight carriers
- Freight Signal Priority
- Smart Roadside
  - E-Screening and Virtual Weigh Stations;
  - Wireless Roadside Inspection;
  - Smart Truck Parking;

Commercial vehicles would also benefit from other V2I applications—especially those focused on safety—not specifically identified as freight applications.

**Funding Strategies and Other Agency Impacts**

Agencies interviewed for this study mentioned that they expect federal programs to fund pilot deployments, especially at roadside inspection stations. Freight facilities associated specifically with seaports, inland ports, and airport facilities may request grants from public sources or use their own funding to perform pilot deployments.
For roadside inspection stations, states anticipate contributing for full deployment but with funding assistance from federal governments to support any system and operating changes associated with connected vehicle applications. Historically, they have used discretionary programs, statewide planning and research funds, and funds allocated through MPO programs as matching sources against federal program funds.

Roadside inspection facilities are operated by commercial vehicle enforcement divisions of individual states/provinces under the Commercial Vehicle Information Systems and Networks (CVISN) program, which is partly funded by FMCSA. States expect CVISN program to continue providing funds to states for deploying connected vehicle technologies for roadside inspection facilities.

**Challenges and Limitations**

- Agencies may expect assurance of maintenance funds to migrate to connected vehicle technology such as DSRC in order to mitigate the unknown sustainability of new technological implementations.
- Agencies must train staff and/or hire outside support to even get to pilot deployments.
- Many stakeholders do not care about the technology as long as core functionalities are met. If the existing legacy technologies can perform the needed functions and it would cost more to migrate to new technology, then there may not be any takers.
- Unless the cost of deploying new technology is less than the cost of maintaining old technology and can show additional benefit, agencies will hesitate to migrate to the new technology. For example, if an existing roadside inspection facility uses 915 MHz RFID technology, a move to DSRC might occur if the cost of new equipment is lower than maintaining the existing equipment, and additional functional benefits, such as reduction in manual inspection of trucks or benefits from other connected vehicle applications, can be shown.
International Land Border Crossings

International land border crossings (IBCs) represent a very complex but essential scenario for deployment of connected vehicle infrastructure. Movement of people and goods within and across the international land borders is vital to each nation’s economy, but IBCs and corridors leading to them are subject to recurring and non-recurring congestion due to enforcement of laws regarding safety and international trade. IBCs therefore have to accommodate multiple modes of vehicular traffic—cars, trucks, and motor coaches—in inspection and law enforcement while minimizing travel delays.

Movement of people and freight across the border at ports of entry including land border crossings, marine port and airports has already exceeded pre-recession levels, thanks to an increase in trade between North American partners and globally. While more than 400 U.S. seaports, airports, and land border crossings handle international merchandise trade, most of the trade passes through relatively few gateways. In 2008, the nation's top five freight transportation gateways (land, sea, and airports) handled 25 percent ($865 billion) of the total value of U.S. international merchandise trade, and the top 16 gateways handled 50 percent ($1.7 trillion) of U.S. international merchandise trade.

With respect to the land border crossings and their associated connected vehicle deployments, 5.6 million trucks entered the U.S. from Canada and 5.1 million entered from Mexico in 2012. Under NAFTA rules and normal drayage operations, most of these return to their country of origin.

Deployment Context

International border crossings are typically under federal jurisdictions. However, these border crossings often incorporate adjacent facilities that states and provinces own and operate to screen and inspect trucks for the purpose of enforcing their laws and regulations. The federal government is present to enforce federal laws associated with customs and security.

The U.S. DOT Federal Highway Administration Office of Freight Management and Operations and the Transport Canada ITS Office have also partnered with state and provincial DOTs and regional planning organizations to develop a Border Information Flow Architecture (BIFA)\textsuperscript{17}. The objective of the initiative is to develop an architecture to promote information sharing and coordination among agencies and stakeholders and increase interoperability of technologies used to support their operations. The BIFA itself is intended to be a framework modeling the flow of information between government (federal, state and local) agencies and components of the transportation system as they relate to border processes (e.g., the flow of advanced traveler information from inspection and enforcement agencies to transportation organizations)\textsuperscript{18}.

Most high-volume IBCs have wait time and other traveler information systems in place. On the U.S.-Canada border, traveler information may consist of independent information from Border Services (i.e., the Canadian Border Services Agency (CBSA) or the U.S. Customs and Border Protection (CBP)) or may be integrated with larger traveler information systems (i.e., state/provincial or regional). Hence, they have the necessary communications infrastructure to support other ITS and connected

\textsuperscript{17} http://www.iteris.com/itsarch/bifa/

vehicle system expansions. Border wait time systems currently exist in limited deployments at major crossings. There are six two-way border wait time systems installed at the Canada-U.S. land border crossings: four of these use loops at Washington State-British Columbia crossings, and two use Bluetooth detection at New York (Buffalo) / Ontario (Niagara Falls) crossings. They were deployed with funding from the federal governments of the two countries, the state and provincial governments, and with support of regional MPOs in a few states. The new Michigan (Detroit) / Ontario (Windsor) Detroit River International Crossing (DRIC) Bridge Project will undoubtedly have substantial ITS / Border wait time infrastructure.

On the US-Mexico border, all the systems to measure wait times of trucks use 915 MHz RFID technology. These systems were deployed with funding from the U.S. federal and state governments. States and the federal governments on both sides of the border can be expected to continue to deploy such systems in the future. Private participation in deploying such systems to measure truck wait times appears unlikely in the foreseeable future.

**Value Proposition**

Participating agencies do not expect that the deployment of connected vehicle technologies will eliminate issues related to vehicular congestion at IBCs, or eliminate the need for safety inspections and other compliance checks on trucks. However, such technologies will enable agencies to be more efficient by providing targeted information to truckers, carriers, and shippers, and thereby enable more efficient demand management at the crossings.

Deployment of connected vehicle systems and application has the potential to reduce costs relative to deployment of older technologies. For example, dynamic message signs, highway advisory radio, or static signs may become unnecessary if vehicles receive traveler information directly from their on-board connected vehicle devices.

The initial focus for deployment of connected vehicle technologies for IBCs is expected to be on high volume facilities—the ones that deal with high value import/exports; or those with a suitable communication infrastructure in place. However, agencies that collect tolls at IBCs may be hesitant to abandon existing 915 MHz technology unless they can increase revenue by doing so or achieve other goals, such as assuring some level of interoperability between toll concessionaires. On the U.S.-Canada border, E-ZPass is available to both Canadian and U.S. residents and is working well. Hence toll concessionaires at IBCs may not have a business incentive to replace existing 915 MHz RFID equipment with 5.9 GHz DSRC. In other regions, where such bi-national interoperability is not available, toll concessionaires may be inclined to deploy 5.9 GHz DSRC technologies to collect tolls as well as provide traveler information to motorists. In either case, 5.9 GHz DSRC can co-exist with 915 MHz while news systems added and existing system gradually phased out as the equipment depreciates and becomes obsolete.

On the US-Mexico border, tolling systems at IBCs are not interoperable. In addition, most lanes are cash-only since neither country shares vehicle registration information with the other and, as such, they cannot enforce toll violations. If 5.9 GHz deployment provides interoperability across international boundaries, there is at least a business case for lower transponder distribution cost. Enforcement across international boundaries will however remain unresolved.
Scenarios

IBCs with high volumes have technology in place to measure wait times and provide traveler information. The majority of these systems were deployed by state or provincial agencies with federal involvement, while some were deployed by private concessionaires. IBCs use Bluetooth, loops, and RFID technologies to measure wait times. It can be expected that agencies will migrate to connected vehicle technology only after there is a significant penetration of new devices, and demonstrated capabilities for advanced data collection (e.g., position data to the lane-level) resulting in more precise wait time information. Agencies will be able to relay geographically-relevant, border-related information through in-vehicle displays rather than fixed devices such as DMS.

Deployment Description

Agencies will start with pilot deployments at high-volume border crossings, where ITS infrastructure is available to support communication needs. High-volume border crossings also attract a lot of public attention. Because IBCs have a higher involvement from the federal governments, states and provinces will seek their support to fund pilot programs. In the past, federal governments have partly or fully funded pilot deployments to measure wait times at IBCs.

After observing favorable results from pilot deployments of wait time measurement systems, states and provinces then contributed significantly to full deployment. This practice is expected to be replicated in pilot deployments of connected vehicle technology at IBCs. State DOTs that were interviewed for this study mentioned that they expect the federal government to lead pilot deployments, procure consultants and contractors, evaluate results, yet, at the same time, involve states and provinces as key stakeholders.

However, there could be a transition phase when both existing technologies (e.g., inductive loops, Bluetooth, 915 MHz RFID) will co-exist with new ones (e.g., 5.9 GHz, 4G/LTE). This transition phase will last until the penetration of new devices reaches a sufficient level and the operators are confident that the new technology satisfies their needs.

Funding Strategies and Other Agency Impacts

States that were interviewed for this study said that they expect federal programs to fund pilot deployments at international border crossings. For IBCs, states anticipate contributing funds for full deployment but with assistance from federal governments to address changes in equipment and operations associated with the new technologies. States mentioned that they do not have dedicated programs to deploy technology at IBCs. Historically, they have used discretionary programs, statewide planning and research funds, and MPO funding as matching sources against federal program funds.

On the U.S.-Canada border, toll authorities and international bridge commissions collect tolls. Few of them have successfully deployed wait time measurement technologies to provide traveler information to motorists.

On the U.S.-Mexico border, localities collect tolls from both cars and trucks at international bridges. For some localities, tolls can be a significant source of revenue. So far, few localities have shown interest in deploying technology at IBCs to measure wait times, but have been willing to provide traveler information to passenger vehicles. This is because they view passenger vehicles as their primary and the most significant source of revenue.
In either case, user fees could be used to pay for land border connected vehicle infrastructure capital and operational costs, similar to “airport improvement fees” and “security fees” paid on air travel. Travelers are more likely to tolerate an increase in the existing tolls or the addition of a new fee when it is associated with a clear and corresponding traveler benefit—like expedited security clearances or provision of wait time information.

Some funding considerations will depend directly on the level of institutional and technical cooperation among transportation agencies and Border Services on both sides of the border. A common set of technology deployments could theoretically be used to support transportation and border security applications if standards and cooperative agreements were in place. Some success in these arrangements has been achieved, for example, in the NEXUS Program\(^{19}\) for trusted cross-border personal travel across the U.S.-Canada border and the FAST Program\(^{20}\) for commercial vehicle operations across both the U.S.-Canada and U.S-Mexico borders. It is not clear, however, that U.S. Customs and Border Patrol (CBP), the Canada Border Services Agency (CBSA), or Aduana México (the Mexican customs agency) would, for example, migrate to 5.9 GHz DSRC at their facilities for law enforcement. CBP and CBSA have existing 915 MHz-based systems at IBCs to identify trucks and carriers, and incoming shipments, and to perform security screening.

**Challenges and Limitations**

- States and provinces expect an assurance of maintenance funding to migrate to and sustain new technologies.
- The need for training staff and/or hiring outside contractors to get pilot deployments underway may be an impediment.
- Many stakeholders do not care specifically about the technology used, as long as core functionalities are met. If the existing technologies can perform the needed functions and it costs more to migrate to new technology, then migration will not take place. Unless the cost of deploying the new technology is less than cost of maintaining the old technology, and additional benefit can be demonstrated, agencies will hesitate to migrate to new technology.


Fee Payment Systems

Fee payment systems on the nation’s roadway network are not uncommon. Toll facilities, including roads and bridges, are familiar to most travelers, and managed lanes, including fee-based express lanes and high occupancy toll (HOT) lanes, are becoming increasingly widespread.

According to the International Bridge, Tunnel and Turnpike Association (IBTTA)\(^{21}\), there are more than 5,400 miles of toll roads in 35 U.S. states and territories. More than 5 billion trips are made each year on toll roads and crossings in the U.S. each year. Tolls are also becoming viewed as a means to supplement or replace declining highway revenues from Federal motor fuel taxes. While tolls currently represent about 5 percent of U.S. highway revenues, a privately-conducted survey in 2010 indicates that around 84 percent of Americans feel that tolls should be considered as a primary source of highway revenue.

More broadly, managed lanes—highway facilities where operational strategies are proactively implemented and managed in response to changing conditions—are emerging in response to the imbalance between transportation system supply and demand, and the serious funding shortages that are facing transportation agencies. While the total number of vehicle miles traveled in the US has increased more than 70 percent in the last 20 years, highway capacity has only grown by 0.3 percent. According to FHWA\(^{22}\), many factors, including increased construction costs, right-of-way constraints, environmental concerns, and societal impacts, contribute to the escalating challenges of adding new general-purpose lanes—especially in developed urban areas. Strategies for implementing managed lanes include vehicle eligibility, access control, and pricing, or some combination of the three. HOT lanes, for example, provide higher-occupancy vehicles such as buses, vanpools, and carpools with free or discounted passage, while all other vehicles are tolled.

Deployment Context

Most toll authorities are public agencies; although there are a number of facilities that are owned and operated by private entities that are regulated by state governments. Managed lane facilities, such as HOT lanes, are most commonly owned and operated by public agencies. However, there are a growing number of facilities that are constructed and operated through public-private partnerships, with the private partner making significant infrastructure investments and holding the rights to collect the revenue for a certain period of time.

The majority of facilities with toll or pricing programs use some form of RFID to provide electronic revenue collection capability. IBTTA’s 2009 toll interoperability survey indicates that there are almost 31 million RFID transponders in use for electronic toll collection in the US.

Value Proposition

The use of connected vehicle technologies will occur in existing toll facilities or managed lane facilities that use pricing when there is a compelling business case. A transition from existing technologies to 5.9 GHz DSRC could be justified if the change can be demonstrated to reduce operating or


\(^{22}\) http://ops.fhwa.dot.gov/publications/managelanes_primer/
maintenance costs—particularly cost per dollar of revenue collected—or if the use of the technology would create new revenue-generating services that could not be cost-effectively implemented using the existing technologies.

The situation could be different for new toll or managed lane facilities where there is no existing investment in legacy technologies. In this case, connected vehicle technologies would be evaluated on their own merits as the basis for providing effective and secure revenue collection, and for supporting other operating objectives such as monitoring vehicle eligibility on high occupancy facilities. However, operating authorities indicate the importance of leveraging regional investment in RFID transponders that are used on neighboring toll facilities when building new facilities. Therefore, the cost proposition for connected vehicle technologies would have to be especially strong to outweigh the value of existing transponders in passenger cars operating in the region.

In the event of policy changes at the federal level or within a state causing a move away from motor fuel excise taxes as a source of highway revenue and toward some form of usage-based charging, the situation might again be different. The characteristics of connected vehicle technologies, particularly with respect to secure vehicle to infrastructure transactions, and the potential scale of deployment envisioned for connected vehicle systems across the US, could see a strong value proposition created.

**Deployment Description**

Deployment of connected vehicle technologies on existing toll and managed lane facilities is likely to take place either as existing legacy systems reach the end of their useful lives, or where a more rapid change can be justified as a cost-effective business decision. As new toll or managed lane facilities are implemented, it would be logical to consider connected vehicle technologies for the revenue collection component, providing, however, that there is not a compelling reason to use other RFID technologies that already exist on other facilities in the region. In the longer term, as connected vehicle technologies become widely available in light and heavy vehicles for applications beyond revenue collection, it will become more appealing for toll authorities and the operators of managed lane facilities to take advantage of the in-vehicle systems deployed by others by converting their own field infrastructure to work with these newer systems.

Agencies that are examining the potential of usage-based fees as a supplement or replacement to state and local fuel taxes will likely assess the viability of using connected vehicle technologies as the basis of such systems. Benefits will likely accrue when infrastructure can be shared for fee collection and other safety and mobility applications. Similarly, the use of connected vehicle technologies will become increasingly appealing as the in-vehicle components of the system become widely available in the vehicle fleet.

**Funding Strategies and Other Agency Impacts**

A toll authority interviewed for this project indicated that deployment of connected vehicle technologies would be funded exclusively by the authority if the all-important business case was demonstrated. It was further stated that deployment could take place at an aggressive rate if the new technologies could be shown to significantly reduce the cost of revenue collection or open up new revenue-generating opportunities, such as additional fee-based services. This sector of the transportation system is familiar with the use of revenue bonds, federally-backed loans, and the use of public-private
partnerships to fund the construction and improvement of facilities. These lessons and approaches would likely play a role in the deployment of the fee payment systems described in this section.

**Challenges and Limitations**

- The tolling sector has been working toward cross-agency system interoperability for the past twenty years. Any decision to deploy connected vehicle technologies for toll collection will consider the impacts on the progress that has been to date on interoperability. In particular, with a very large investment made by authorities in 915 MHz RFID transponders and readers, it is difficult to envision a rapid transition to 5.9 GHz DSRC unless the costs of the in-vehicle components are borne by others. Counter-intuitively this is also the case for newly-constructed facilities, where the operator relies on a large, existing installed base of electronic toll collection transponders used by other authorities in the region.
References


U.S. DOT Research and Innovative Technology Administration; Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications; Publication Number FHWA-HRT-11-040; November 2012


National Cooperative Highway Research Program; NCHRP 03-101: Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies Deployment Plan; Version 1.0; August 30, 2013

Synthesis of Western U.S. Automated Safety Warning Systems; presented by David Veneziano, Western Transportation Institute, at the National Rural ITS Conference, St. Cloud, Minnesota, on August 28, 2013; http://nritsconference.org/agenda.html

Moving Ahead for Progress in the 21st Century Act (PL 112-141), July 6, 2012

U.S. Department of Transportation Federal Highway Administration and Transport Canada; Border Information Flow Architecture Final Report; January 2006
APPENDIX A.  List of Acronyms

AASHTO  American Association of State Highway and Transportation Officials
ATIS    Advanced Traveler Information Systems
ATMS    Advanced Traffic Management System
AVL     Automatic Vehicle Location
BSM     Basic Safety Message
CAD     Computer Aided Dispatch
CAN     Controller Area Network
CBP     Customs and Border Protection
CBSA    Canadian Border Services Agency
CCTV    Closed caption television
CICAS   Cooperative Intersection Collision Avoidance System
CV      Connected Vehicle
CVISN   Commercial Vehicle Information Systems and Networks
DC      District of Columbia
DMS     Dynamic Message Sign
DOT     Department of Transportation
DRIC    Detroit River International Crossing
DSRC    Dedicated Short Range Communications
ESS     Environmental Sensor Station
ETC     Electronic toll collection
F-ATIS  Freight Real-time Traveler Information with Performance Monitoring
FCC     Federal Communications Commission
FHWA    Federal Highway Administration
FMCSA   Federal Motor Carrier Safety Administration
GHG     Green-house gas
HAR     Highway Advisory Radio
HOT     High Occupancy Tolling
HPMS    Highway Performance Monitoring System
IBC     International Border Crossing
IBTTA   International Bridge, Tunnel and Turnpike Association
ICM     Integrated Corridor Management

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>IMO</td>
<td>Integrated Mobile Observations</td>
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<tr>
<td>ITS</td>
<td>Intelligent Transportation Systems</td>
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<td>ITS JPO</td>
<td>Intelligent Transportation Systems Joint Program Office</td>
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<tr>
<td>JPO</td>
<td>Joint Program Office</td>
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<tr>
<td>LTE</td>
<td>Long-term Evolution; a type of 4G cellular network</td>
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<td>MAP-21</td>
<td>Moving Ahead for Progress in the 21st Century Act</td>
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<td>MD</td>
<td>Maryland</td>
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<tr>
<td>MDSS</td>
<td>Maintenance Decision Support System</td>
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<tr>
<td>MHz</td>
<td>Megahertz, one million cycles per second</td>
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<td>MPO</td>
<td>Metropolitan Planning Organization</td>
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<tr>
<td>MTP</td>
<td>Metropolitan Transportation Plan</td>
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<tr>
<td>NAFTA</td>
<td>North American Free-trade Agreement</td>
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<td>NHTSA</td>
<td>National Highway Traffic Safety Administration</td>
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<td>NJ</td>
<td>New Jersey</td>
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<td>NY</td>
<td>New York</td>
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<tr>
<td>OBE</td>
<td>On-board Equipment</td>
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<td>P3</td>
<td>Public Private Partnership</td>
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<td>RF</td>
<td>Radio frequency</td>
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<tr>
<td>RFID</td>
<td>Radio frequency identification</td>
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<td>RITA</td>
<td>Research and Innovative Technology Administration</td>
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<tr>
<td>RITIS</td>
<td>Regional Integrated Transportation Information System</td>
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<td>RSE</td>
<td>Roadside Equipment</td>
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<td>RWIS</td>
<td>Road Weather Information System</td>
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<tr>
<td>SAFETEA-LU</td>
<td>Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users</td>
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<tr>
<td>SCMS</td>
<td>Security Credential Management System</td>
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<tr>
<td>SHSP</td>
<td>Strategic Highway Safety Plan</td>
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<tr>
<td>TBD</td>
<td>To Be Determined</td>
</tr>
<tr>
<td>TIP</td>
<td>Transportation Improvement Plan</td>
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<tr>
<td>TMC</td>
<td>Traffic Management Center</td>
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<tr>
<td>TTI</td>
<td>Texas A&amp;M Transportation Institute</td>
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<tr>
<td>US</td>
<td>United States</td>
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<tr>
<td>U.S. DOT</td>
<td>United States Department of Transportation</td>
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<tr>
<td>V2I</td>
<td>Vehicle-to-infrastructure</td>
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<tr>
<td>V2V</td>
<td>Vehicle-to-vehicle</td>
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U.S. Department of Transportation, Research and Innovative Technology Administration
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Appendix A. List of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>VA</td>
<td>Virginia</td>
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<tr>
<td>VIIC</td>
<td>Vehicle Infrastructure Integration Consortium</td>
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<td>VMS</td>
<td>Variable Message Sign, see DMS</td>
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<tr>
<td>VMT</td>
<td>Vehicle Miles of Travel</td>
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<tr>
<td>WAVE</td>
<td>Wireless Access in Vehicular Environments</td>
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<tr>
<td>Wi-Fi</td>
<td>Wireless Fidelity</td>
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<tr>
<td>WX-INFO</td>
<td>Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles</td>
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