

National Connected Vehicle Field Infrastructure Footprint Analysis

Final Report

www.its.dot.gov

Final Report v1 — June 27, 2014

FHWA-JPO-14-125



U.S. Department of Transportation

Produced by the American Association of State Highway and Transportation Officials
(AASHTO)

U.S. Department of Transportation

Federal Highway Administration

Intelligent Transportation Systems/Joint Program Office

And

Transport Canada



Transport
Canada

Transports
Canada

Notice

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The U.S. Government is not endorsing any manufacturers, products, or services cited herein and any trade name that may appear in the work has been included only because it is essential to the contents of the work.

Technical Report Documentation Page

1. Report No. FHWA-JPO-14-125		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle National Connected Vehicle Field Infrastructure Footprint Analysis Final Report				5. Report Date June 27, 2014	
				6. Performing Organization Code	
7. Author(s) James Wright (AASHTO); J. Kyle Garrett (Synesis Partners); Christopher J. Hill, Ph.D., PMP (Booz Allen Hamilton); Gregory D. Krueger, P.E. (Leidos); Julie H. Evans (Leidos); Scott Andrews (Cogenia Partners); Christopher K. Wilson (Cogenia Partners); Rajat Rajbhandari (Texas Transportation Institute); Brian Burkhard (Transpo Group)				8. Performing Organization Report No.	
9. Performing Organization Name And Address American Association of State Highway and Transportation Officials (AASHTO) 444 North Capitol Street NW, Suite 249 Washington, D.C. 20001				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. DTFH61-11-D-00008	
12. Sponsoring Agency Name and Address Federal Highway Administration Intelligent Transportation Systems/Joint Program Office (ITS JPO) 1200 New Jersey Avenue SE Washington, DC 20590				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplementary Notes Ben McKeever, Task Manager					
16. Abstract The fundamental premise of the connected vehicle initiative is that enabling wireless connectivity among vehicles, the infrastructure, and mobile devices will bring about transformative changes in safety, mobility, and the environmental impacts in the transportation system. Key federal policy decisions relating to connected vehicle safety needs are currently moving forward. In particular, the work of the National Highway Traffic Safety Administration (NHTSA) to consider a rulemaking for vehicle-to-vehicle (V2V) communications in light vehicles has received significant national attention. While the future actions of NHTSA and the state and local transportation agencies are independent, and the NHTSA decision will not require agencies to deploy any connected vehicle infrastructure, it is important for the state and local agencies to understand what this action will mean to them, what they need to know to prepare for an emerging connected vehicle environment, and what investments may need to be made to leverage a nationwide fleet of equipped vehicles in support of their own policy and operational objectives. The American Association of State Highway and Transportation Officials (AASHTO), with the support of United States Department of Transportation (USDOT) and Transport Canada, has undertaken a Connected Vehicle Field Infrastructure Footprint Analysis to provide supporting information to agency decision-makers. AASHTO's work in this analysis has been performed through its Connected Vehicle Deployment Coalition, a group comprising representatives from a number of state and local transportation agencies, and the findings and recommendations in this report represent the opinions of this AASHTO community. In addition, the development of connected vehicle deployment scenarios engaged a broader group of state and local agency participants. This Final Report consists of a vision for a national footprint; a description of the background for and current research on connected vehicle deployments; a set of assumptions underlying the infrastructure footprint analysis; the applications analysis; the deployment concepts, the preliminary national footprint, including the value proposition, deployment objectives, context, scenarios, and experience to date; and a preliminary deployment and operations cost estimation.					
17. Key Words intelligent transportation systems, connected vehicles, infrastructure, deployment, DSRC, cellular, cost estimation				18. Distribution Statement	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	22. Price

Acknowledgements

This report was developed by the American Association of State Highway and Transportation Officials (AASHTO) under the sponsorship of the United States (U.S.) Department of Transportation (DOT) Federal Highway Administration (FHWA) and of Transport Canada. The authors would like to thank the numerous representatives and staff members of AASHTO, the AASHTO Connected Vehicle Deployment Coalition, USDOT, state and local transportation agencies, metropolitan planning organizations, and vehicle and DSRC device manufacturers for their support in the development and review of materials in this report.

Alex Power, Texas Department of Transportation
Barry Pekilis, Transport Canada
Ben McKeever, U.S. Department of Transportation
Bill Legg, Washington State Department of Transportation
Blaine Leonard, Utah Department of Transportation
Bob Rupert, U.S. Department of Transportation
Bob Sheehan, U.S. Department of Transportation
Brian Cronin, U.S. Department of Transportation
Carl Andersen, U.S. Department of Transportation
Carol Kuester, Metropolitan Transportation Commission
Collin Castle, Michigan Department of Transportation
Danielle Deneau, Road Commission for Oakland County (Michigan)
Dawn Hardesty, Noblis, Inc.
Edward Fok, U.S. Department of Transportation
Elizabeth Birriel, Florida Department of Transportation
Faisal Saleem, Maricopa County Department of Transportation (Arizona)
Gabriel Guevara, U.S. Department of Transportation
Gary Piotrowicz, Road Commission for Oakland County (Michigan)
George Webb, Palm Beach County Engineering and Public Works Department (Florida)
Greg Davis, U.S. Department of Transportation
Greg Larson, California Department of Transportation
Gummada Murthy, AASHTO
Gwo-Wei Torng, Noblis, Inc.
James Chang, Noblis, Inc.
James Pol, U.S. Department of Transportation
Janet Banner, Metropolitan Transportation Commission
Jeff Spencer, U.S. Department of Transportation
Jim Hubbell, Mid-America Regional Council
John Corbin, Wisconsin Department of Transportation
John Harding, U.S. Department of Transportation
Karen White, U.S. Department of Transportation
Kate Hartman, U.S. Department of Transportation
Mark Kopko, Pennsylvania Department of Transportation
Matt Smith, Michigan Department of Transportation
Max Azizi, U.S. Department of Transportation
Melanie Crotty, Metropolitan Transportation Commission

Melissa Lance, Virginia Department of Transportation
Michelle Mueller, Michigan Department of Transportation
Mike McGurkin, Noblis, Inc.
Paul Pisano, U.S. Department of Transportation
Petar Duvnjak, Transport Canada
Ray Starr, Minnesota Department of Transportation
Ray Webb, Mid-America Regional Council
Reza Karimvand, Arizona Department of Transportation
Richard McDonough, New York State Department of Transportation
Robert Koeberlein, Idaho Transportation Department
Ron Achelpohl, Mid-America Regional Council
Ryan Klomp, Transport Canada
Ryan Rice, Colorado Department of Transportation
Sarah Tracy, Nebraska Department of Roads
Steve Mortensen, U.S. Department of Transportation
Suzanne Sloan, U.S. Department of Transportation
Tom Bamonte, North Texas Tollway Authority
Tom Kearny, U.S. Department of Transportation
Tom Sands, Nebraska Department of Roads
Valerie Briggs, U.S. Department of Transportation
Volker Fessmann, U.S. Department of Transportation

Table of Contents

Executive Summary.....	1
PURPOSE	1
BACKGROUND	1
VISION FOR A CONNECTED VEHICLE INFRASTRUCTURE FOOTPRINT	2
ANALYSIS OF POTENTIAL APPLICATIONS	3
DEPLOYMENT CONCEPTS	5
DEPLOYMENT SCENARIOS	5
A NATIONAL INFRASTRUCTURE FOOTPRINT	6
ANTICIPATED DEPLOYMENT COSTS	8
INFRASTRUCTURE DEPLOYMENT TIMELINES	8
OPERATIONAL AND ORGANIZATIONAL IMPACTS	9
RECOMMENDED NEXT STEPS	10
Purpose and Scope	11
Vision for a National Footprint	13
VISION STATEMENT	13
BACKGROUND	13
Background, Current Research, and Understanding.....	16
OVERVIEW.....	16
THE BENEFITS OF CONNECTED VEHICLE INFRASTRUCTURE DEPLOYMENT	18
DEPLOYING A CONNECTED VEHICLE INFRASTRUCTURE	19
CONNECTED VEHICLE INFRASTRUCTURE PLANNING AND DEPLOYMENT TODAY.....	20
Assumptions	21
Analysis of Potential Connected Vehicle Applications	24
Deployment Concepts for Connected Vehicle Field Infrastructure.....	31
The Preliminary National Footprint and Deployment Timeline	38
VALUE PROPOSITION	38
DEPLOYMENT OBJECTIVES	39
DEPLOYMENT CONTEXT.....	42
System Elements and Interactions	43
Stakeholder Roles	44
DEPLOYMENT SCENARIOS	46
Urban Deployments	47
Rural Deployments.....	51
Multi-State Corridors.....	56
DOT System Operations and Maintenance.....	59
Commercial Vehicle and Freight Systems.....	63
International Land Border Crossings	67
Fee Payment Systems	71
BUILDING UP TO THE NATIONAL FOOTPRINT	73
ITS Deployment Experience	73
Connected Vehicle Infrastructure Deployment to Date	81

National Deployment Patterns	84
Potential Infrastructure Deployment Sites	86
INFRASTRUCTURE DEPLOYMENT MILESTONES AND TIMELINES	90
Deployment Milestones	90
Timelines	93
Preliminary Infrastructure Deployment and Operations Cost Estimation	97
DEPLOYMENT COSTS	98
DSRC Field Infrastructure Deployment Costs	98
Backhaul Deployment Costs	101
Signal Controller Replacement Estimates	104
Total DSRC Site Deployment Costs	105
ADDITIONAL COSTS	106
DSRC Site Operation and Maintenance Costs	106
Backend System O&M Cost Estimates	108
Vehicle Fleet Data Collections	111
Third-Party Traffic Data	113
Operational and Organizational Impacts	115
STEPS TO DEPLOYMENT	115
FUNDING STRATEGIES AND OTHER AGENCY IMPACTS	117
Conclusions and Recommendations	119
References	122
Appendix A. Detailed Applications Analysis	126
Appendix B. Detailed Deployment Concepts	159
RURAL ROADWAY	159
Current State	159
Concept Description	159
Applicability	161
URBAN HIGHWAY	163
Current State	163
Concept Description	164
Applicability	165
URBAN INTERSECTION	167
Current State	167
Concept Description	167
Applicability	168
URBAN CORRIDOR	170
Current State	170
Concept Description	170
Applicability	171
INTERNATIONAL LAND BORDER CROSSING	173
Current State	173
Concept Description	173
Applicability	175
FREIGHT INTERMODAL FACILITY	178

Current State	178
Concept Description	178
Applicability.....	180
SMART ROADSIDE FREIGHT CORRIDOR.....	182
Current State	182
Concept Description	182
Applicability.....	183
DOT OPERATIONS AND MAINTENANCE.....	186
Current State	186
Concept Description	186
Applicability.....	188
FEE PAYMENT	190
Current State	190
Concept Description	190
Applicability.....	191
Appendix C. Considerations Common to All Deployment Concepts .	193
CONNECTED VEHICLE SYSTEM ARCHITECTURES	193
CONNECTED VEHICLE DATA NEEDS AND STANDARDS	195
MOBILE ELEMENT COMPONENTS	197
Embedded Vehicle Terminals.....	197
Aftermarket Vehicle Terminals.....	198
Portable Consumer Electronic Terminals.....	199
V2I COMMUNICATIONS.....	200
DSRC WAVE Communications.....	200
Cellular Communications	202
COMMUNICATIONS SECURITY.....	202
Privacy	203
Authenticity	203
Certification.....	204
Other Security Elements	204
BACKHAUL.....	205
MAPPING SUPPORT	213
Consistency	214
SITING AND INSTALLATION	214
Siting Dependencies for DSRC.....	214
Installation.....	215
POWER CONSIDERATIONS	216
Power Consumption	216
Power Type Considerations	216
Appendix D. List of Acronyms	218

List of Tables

Table ES-1 – Application Groups and Bundles (<i>Source: USDOT/AASHTO 2014</i>)	4
Table ES-2 - Percentages of Signalized Intersections Equipped with Connected Vehicle Infrastructure (<i>Source: USDOT/AASHTO 2014</i>)	7
Table ES-3 - Total Number of Deployment Locations (<i>Source: USDOT/AASHTO 2014</i>)	7
Table 1 - Applications, Bundles and Groups (<i>Source: USDOT/AASHTO 2014</i>)	24
Table 2 - Potential Deployment Objectives, Scenarios, and Applications (<i>Source: USDOT/AASHTO 2014</i>)	41
Table 3 - Summary of ITS Assets (<i>Source: USDOT 2010</i>)	48
Table 4 - 2011 Road Lengths and Traffic Densities (<i>Source: USDOT/AASHTO 2014</i>)	51
Table 5 - Applications for 511 Program Assistance Funds (<i>Source: USDOT FHWA 2014</i>)	74
Table 6 - Launch Dates of 511 Services in the US (<i>Source: USDOT FHWA 2013</i>)	77
Table 7 - Signalized Intersection Deployment Objectives (<i>Source: USDOT/AASHTO 2014</i>)	88
Table 8 - Number of Additional Deployment Locations (<i>Source: USDOT/AASHTO 2014</i>)	89
Table 9 - Total Number of Connected Vehicle Deployment Locations (<i>Source: USDOT/AASHTO 2014</i>)	90
Table 10 - Average Equipment Costs per DSRC Site (<i>Source: USDOT/AASHTO 2014</i>)	99
Table 11 - Average Installation Costs per DSRC Site (<i>Source: USDOT/AASHTO 2014</i>)	99
Table 12 - Planning and Design Costs per DSRC Site (<i>Source: USDOT/AASHTO 2014</i>)	100
Table 13 - Average Total Direct Costs per DSRC Site (<i>Source: USDOT/AASHTO 2014</i>)	101
Table 14 - Costs Associated with Backhaul Installation (<i>Source: USDOT/AASHTO 2014</i>)	101
Table 15 - Estimated Backhaul Upgrade Costs (<i>Source: USDOT/AASHTO 2014</i>)	103
Table 16 - Estimated Total Cost of Backhaul Upgrade (<i>Source: USDOT/AASHTO 2014</i>)	104
Table 17 - Estimated Number of Controller Replacements (<i>Source: USDOT/AASHTO 2011</i>)	105
Table 18 - Total Cost Estimate to Upgrade Signal Controllers (<i>Source: USDOT/AASHTO 2014</i>)	105

Table 19 - Total Potential DSRC Site Costs of Connected Vehicle Infrastructure Deployment (<i>Source: USDOT/AASHTO 2014</i>).....	106
Table 20 - Estimated Annual DSRC Site Operations, Maintenance and Replacement Costs (<i>Source: USDOT/AASHTO 2014</i>).....	108
Table 21 - Unit Costs for DSRC-based Data Collection Equipment (<i>Source: USDOT/AASHTO 2014</i>).....	112
Table 22 - Example Cellular Data Plan Rates (<i>Source: USDOT/AASHTO 2014</i>).....	113
Table 23 - Traditional and Third-Party Data Service Cost Comparison (<i>Source: USDOT 2010</i>).....	114
Table 24 - Application Assessment (<i>Source: USDOT/AASHTO 2014</i>).....	127
Table 25 - Representative SAE J2735 Messages and Communication Modes (<i>Source: USDOT/AASHTO 2014</i>).....	196
Table 26 - Backhaul Technology Overview (<i>Source: USDOT/AASHTO 2014</i>).....	206

List of Figures

Figure ES-1 - Connected Vehicle Infrastructure Deployment Milestones (Source: USDOT/AASHTO 2014)	8
Figure ES-2 - Deployment Timelines by Application Type (Source: USDOT/AASHTO 2014)	9
Figure 1 - Connected Vehicle Concept (Source: USDOT 2013)	19
Figure 2 - Number of 511 Service Launches by Year (Source: USDOT FHWA 2014)	76
Figure 3 - Status of 511 Deployments in the US (Source: USDOT FHWA 2013)	78
Figure 4 - Deployment of Commercial Vehicle Pre-Clearance Systems in the United States (Source: Federal Motor Carrier Safety Administration 2008)	79
Figure 5 - Growth of ETC in the United States as of 2010 (Source: USDOT ITS JPO 2010)	80
Figure 6 - 2013 Connected Vehicle Test Beds (Source: USDOT/AASHTO 2014)	82
Figure 7 - Connected Vehicle Agencies and Test Beds (Source: USDOT/Transport Canada/AASHTO 2014)	85
Figure 8 - Potential Corridors for Deployment Expansion (Source: USDOT/AASHTO 2014)	86
Figure 9 - Connected Vehicle Infrastructure Deployment Milestones (Source: USDOT/AASHTO 2014)	91
Figure 10 - Equipped Vehicle Population over Time (Source: USDOT/AASHTO 2014)	93
Figure 11 - Deployment Timelines (Source: USDOT/AASHTO 2014)	96
Figure 12 - Rural Roadway Deployment Concept (Source: USDOT/AASHTO 2014)	162
Figure 13 - Urban Highway Deployment Concept (Source: USDOT/AASHTO 2014)	166
Figure 14 - Urban Intersection Deployment Concept (Source: USDOT/AASHTO 2014)	169
Figure 15 - Urban Corridor Deployment Concept (Source: USDOT/AASHTO 2014)	172
Figure 16 - International (Land) Border Crossing Concept (Source: USDOT/AASHTO 2014)	177
Figure 17 - Freight Intermodal Facility Deployment Concept (Source: USDOT/AASHTO 2014)	181
Figure 18 - Smart Roadside Freight Corridor Deployment Concept - Weigh Station (Source: USDOT/AASHTO 2014)	184
Figure 19 - Smart Roadside Freight Corridor Deployment Concept – Parking (Source: USDOT/AASHTO 2014)	185

Figure 20 - DOT Operations and Maintenance Deployment Concept (<i>Source: USDOT/AASHTO 2014</i>).....	189
Figure 21 - Fee Payment Deployment Concept (<i>Source: USDOT/AASHTO 2014</i>).....	192
Figure 22 - Top Level View of Connected Vehicle System (<i>Source: USDOT/AASHTO 2014</i>).....	193
Figure 23 - Connected Vehicle System Diagram (<i>Source: USDOT/AASHTO 2014</i>).....	194
Figure 24 - Embedded Connected Vehicle Terminal Example (<i>Source: USDOT/AASHTO 2014</i>).....	198
Figure 25 - Aftermarket Connected Vehicle Terminal Example (<i>Source: USDOT/AASHTO 2014</i>).....	199
Figure 26 - Consumer Electronic Connected Vehicle Terminal Example (<i>Source: USDOT/AASHTO 2014</i>).....	200

Executive Summary

Purpose

The fundamental premise of the connected vehicle initiative is that enabling wireless connectivity among vehicles, the infrastructure, and mobile devices will bring about transformative changes in safety, mobility, and the environmental impacts in the transportation system. Key federal policy decisions relating to connected vehicle safety needs are currently moving forward. In particular, the work of the National Highway Traffic Safety Administration (NHTSA) to consider a rulemaking for Dedicated Short Range Communications (DSRC) devices in light vehicles has received significant national attention. While the future actions of NHTSA and the state and local transportation agencies are independent, and the NHTSA decision will not require agencies to deploy any connected vehicle infrastructure, it is important for the state and local agencies to understand what this action will mean to them, what they need to know to prepare for an emerging connected vehicle environment, and what investments may need to be made to leverage a nationwide fleet of equipped vehicles in support of their own policy and operational objectives.

The American Association of State Highway and Transportation Officials (AASHTO), with the support of United States Department of Transportation (USDOT) and Transport Canada, has undertaken a Connected Vehicle Field Infrastructure Footprint Analysis to provide supporting information to agency decision-makers. AASHTO's work in this analysis has been performed through its Connected Vehicle Deployment Coalition, a group comprising representatives from a number of state and local transportation agencies, and the findings and recommendations in this report represent the opinions of this AASHTO community. In addition, the development of connected vehicle deployment scenarios engaged a broader group of state and local agency participants.

Background

The development of the connected vehicle environment is envisioned to leverage several types of wireless connectivity (cellular, Wi-Fi, 5.9 Gigahertz (GHz) dedicated short range communications (DSRC)) to serve the public good:

- 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 modes and routes and when vehicles can communicate with the infrastructure to enhance fuel efficiency by avoiding unnecessary stops.

Over the last eight years, substantial progress has been made in understanding the opportunities and demonstrating that the known challenges can be met through research and technology development. In early 2014, NHTSA determined that it will be pursuing a rulemaking that would require carmakers to equip new light vehicles with technologies required to support V2V communications for safety applications. NHTSA continues to consider whether a similar rulemaking should be pursued for heavy vehicles.

The NHTSA decision greatly increases the likelihood of a connected vehicle environment. With the emergence of a nationwide base of suitably-equipped vehicles, vehicle-to-infrastructure (V2I) applications become a practical reality but will require the deployment of a suitable field infrastructure. The infrastructure *footprint* describes the types and extent of infrastructure to be deployed over time in the connected vehicle environment. A connected vehicle infrastructure deployment will generally include:

- Roadside communications equipment (for DSRC or other wireless services) together with enclosures, mountings, power, and network backhaul.
- Traffic signal controller interfaces for applications that require signal phase and timing (SPaT) data.
- Systems and processes required to support management of security credentials and ensure a trusted network.
- Mapping services that provide highly detailed roadway geometries, signage, and asset locations for the various connected vehicle applications.
- Positioning services for resolving vehicle locations to high accuracy and precision.
- Data servers for collecting and processing data provided by vehicles and for distributing information, advisories, and alerts to users.

Some elements, such as traffic signal interfaces or roadside equipment to send infrastructure information or to receive DSRC messages broadcast from vehicles, are unique to state and local DOT interests. Other elements of the overall connected vehicle system, particularly those necessary for vehicle-based safety applications, may be provided by the automotive industry, and the elements associated with security management could be provided by a third-party entity. These specifics are still evolving.

Vision for a Connected Vehicle Infrastructure Footprint

The AASHTO Connected Vehicle Deployment Coalition has established a vision for the infrastructure footprint that anticipates a mature connected vehicle environment by 2040, by which time a large majority of vehicles on the roadway will be connected. From an infrastructure perspective:

- Up to 80% (250,000) of traffic signal locations will be V2I-enabled.
- Up to 25,000 other roadside locations will be V2I-enabled.
- Accurate, real-time, localized traveler information will be available on 90% or more of roadways.
- Next-generation, multimodal, information-driven, active traffic management (ATM) will be deployed system-wide.

Achieving this vision will require cooperation among all stakeholders. Applications depend on complementary sets of information flowing through the system in multiple directions and through multiple channels. Data describing the traffic and road conditions will originate on vehicles, from travelers, or from an agency's own sensors; will pass through a communications infrastructure (whether deployed and operated by agencies or by commercial service providers); will be processed by information service providers (that may include either agencies or commercial entities); and will be integrated with other agency data to make system operational decisions. On the other hand, data describing the operation of the system will originate with an operating agency or its service provider partners and contractors; will be published by the agency; may be used by third-parties, perhaps in coordination, in value-added services (traffic information and routing, for example); will be accessed by travelers and vehicles through the communications infrastructure; and will be consumed by travelers and vehicles in making local real-time travel decisions.

Since the applications will likely involve so many transactions and stakeholders, building the connected vehicle environment will benefit from and may, in fact, require cooperation among the many stakeholders. At a minimum, system interfaces and protocols will need to be agreed upon among the originators and users of the data, primarily the agencies providing and operating infrastructure and the vehicle manufacturers providing the mobile data and user interfaces. Other stakeholders can facilitate (or impede) deployment, but agencies will have an incentive to deploy infrastructure only when applications are deployed in vehicles and smart personal devices. To that end, the AASHTO Connected Vehicle Deployment Coalition has recommended that a National Deployment Plan should be developed to guide deployment through an ongoing, proactive program of collaboration between the stakeholders to address these key issues. The plan should be developed cooperatively between the state and local infrastructure owner/operators and vehicle providers under the direction of USDOT, with further cooperation from communications equipment manufacturers, service providers, and other third parties that may provide information to or use information from the connected vehicle environment.

Analysis of Potential Applications

The connected vehicle infrastructure needs of state and local agencies will be determined in part by the specific applications that an agency wants to deploy. For the purposes of this analysis, applications are assembled first into *groups* and then into *bundles* within each group. Application *groups* generally reflect transportation system objectives—improving safety, enhancing mobility, improving operational performance, and reducing environmental impacts. Application *bundles* logically segment those objectives by function, mode, or a combination thereof. The groups and bundles of applications used in this analysis are shown in Table ES-1. More detailed descriptions of the applications are provided later in the full report and its appendices.

Table ES-1 – Application Groups and Bundles (Source: USDOT/AASHTO 2014)

Application Group	Application Bundle
Vehicle to Infrastructure Safety	Intersection Applications
	Speed Applications
	Vulnerable Road Users
	Transit Safety
Mobility	Enable ATIS (Advanced Traveler Information Systems)
	Integrated Network Flow Optimization (INFLO)
	Freight Advanced Traveler Information Systems (FRATIS)
	Multimodal Intelligent Traffic Signal Systems (M-ISIG)
	Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)
	Integrated Dynamic Transit Operations (IDTO)
	Next Generation Integrated Corridor Management (ICM)
	Information for Maintenance and Fleet Management Systems
	Information and Routing Support for Emergency Responders
	Smart Roadside
Applications for the Environment: Real-Time Information Synthesis (AERIS)	Eco-Signal Operations
	Dynamic Eco-Lanes
	Dynamic Low Emissions Zones
	Support for Alternative Fuel Vehicle Operations
	Eco-Traveler Information
	Eco-Integrated Corridor Management Decision Support System
Road Weather	Road Weather
International Border Crossings	International Border Crossings
Fee Payments	Fee Payments
Agency Data Applications	Performance Measures
	Connected Vehicle-enabled Traffic Studies
	Probe Data Applications

Developing a connected vehicle infrastructure deployment footprint requires an understanding beyond individual applications. Field deployments will be more viable and effective when they support multiple applications. This is accomplished in the analysis by identifying common aspects of the potential applications; such as leveraging the physical infrastructure (for example, a roadside unit) or the information components (for example, the basic safety message broadcast by vehicles) that can support a group of applications with common requirements. This approach affects key design and implementation considerations and may affect the cost and complexity of deployment.

Finally, many of the identified applications could be deployed with either DSRC or cellular communications between the vehicle and infrastructure. Although future research and development may conclusively identify the preferred means of communications for each application, this analysis presumes that most of the applications are viable with DSRC, cellular, or some other form of wireless communication, effectively treating each version as a different application. For the purposes of this analysis, it is assumed that active safety applications will require the use of DSRC.

Deployment Concepts

Deployment concepts have been developed to describe the potential infrastructure and application deployments in terms of the existing setting, connected vehicle field equipment, interfaces to related transportation equipment (e.g., traffic signal controllers), communications resources, security, and basic operations. The concepts have been developed around the identified connected vehicle applications as they might be deployed in a variety of geographical and operational settings on the transportation system. The deployment concepts illustrate how applications, new and existing field equipment, power sources, and new and existing communications networks (such as fiber, cellular, microwave) come together to create integrated connected vehicle deployments. For state and local decision makers, these concepts are intended to provide sufficient detail to understand the implications of deployment—the required technologies, decision process, personnel requirements, and skill sets needed for deployment, operations, and maintenance. Deployment concepts are provided for:

- Rural freeways and arterials
- Urban highways
- Urban intersections
- Urban corridor
- Freight facilities
- Smart Roadside freight corridors
- International border crossings
- DOT system operations and maintenance
- User fee collection.

Deployment Scenarios

Deployment of a connected vehicle infrastructure by state and local agencies will be undertaken to meet a set of transportation system management and operations objectives. Objectives could include:

- Improving safety – reducing crashes, injuries and fatalities;
- Improving personal mobility and reducing environmental impacts – improving travel times and travel time reliability for drivers, riders, and pedestrians, and improving fuel efficiency and reducing idle time;
- Improving freight efficiency – improving freight mobility and compliance/enforcement;
- Improving border crossing operations – for passengers and freight; and
- Improving internal agency operations – reducing response times and costs.

In turn, each objective or group of objectives can be realized through one or more deployment scenarios. Each scenario can be described in terms of the application or bundle of applications that are enabled; applications that can be deployed may then imply a focus on a particular implementing technology.

Current and earlier connected vehicle research has led to the identification of a large number of potential applications which are synthesized in this analysis. For the purpose of describing the deployment scenarios, however, it is helpful to postulate a subset of applications 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 applications needing low communications latency; leveraging of available cellular communications infrastructure; and around enhancements to an agency's existing intelligent transportation system (ITS) deployments. These "launch" applications could include:

- V2I safety applications
 - Red Light Violation Warning Curve Speed Warning
 - Stop Sign Gap Assist
 - 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
 - Advanced Traveler Information System
 - Freight Operator Real-time Information with Performance Monitoring
 - Transit Signal Prioritization
 - Emergency Vehicle Prioritization
- Agency Operations and Maintenance
 - Enhanced Maintenance Decision Support
 - Information for Maintenance and Fleet Management Systems

A National Infrastructure Footprint

The deployment of ITS can provide insight into the deployment path and the approach of the agencies that will be responsible for deploying the field infrastructure components of the connected vehicle environment. In particular, the 511 traveler information program has many similarities to the connected vehicle program, including the relationship between USDOT and the state and local agencies in deployment, and the need for collaboration with external, commercial parties (i.e., communications carriers in the case of 511 and carmakers in the connected vehicle program). As such, the 511 program offers experiences and lessons that can inform deployment decisions for a connected vehicle environment.

For the purpose of estimating the scale of a national deployment, the analysis estimates the total number of locations at which connected vehicle field infrastructure may be deployed over the next twenty to twenty-five years. The estimates are based on an assessment of how many signalized intersections might be equipped with connected vehicle systems to support V2I safety and other applications, plus the number of additional locations on the transportation network that might be equipped to provide the desired national coverage and to support the specific connected vehicle applications that will be of interest to state and local agencies. The process of estimating the number of additional locations is based on national data on the deployment of ITS infrastructure. The potential

numbers of signalized intersection deployment sites are determined from national data on the total number of traffic signals and the application of criteria identified in Table ES-2.

Table ES-2 - Percentages of Signalized Intersections Equipped with Connected Vehicle Infrastructure (Source: USDOT/AASHTO 2014)

Deployment Fraction	Objective	Number of Deployment Sites
20%	Deploy only at highest-volume intersections, corresponding to up to 50% of intersection crashes	62,200
50%	Deploy at half of all intersections with greatest benefits, corresponding to up to 80% of intersection crashes	155,500
80%	Deploy at all intersections where warranted	248,800

Combining the potential deployment sites at signalized intersections and other locations on the transportation network provides a total estimate of the nationwide connected vehicle infrastructure footprint at maturity that is presented in Table ES-3.

Table ES-3 - Total Number of Deployment Locations (Source: USDOT/AASHTO 2014)

Level of Deployment	20% Signalized + Unsignalized/ITS-Equipped Sites	50% Signalized + Unsignalized/ITS-Equipped Sites	80% Signalized + Unsignalized/ITS-Equipped Sites
Signalized Locations	62,200	155,500	248,800
Unsignalized/ITS-Equipped Locations	25,000	25,000	25,000
Total	87,200	180,500	273,800

This nationwide connected vehicle infrastructure footprint is expected to grow from the early deployment work conducted by a small number of state and local agencies that have been on the cutting edge of connected vehicle development; federally and locally-funded test beds; other connected vehicle model deployments (such as the Ann Arbor Safety Pilot); and the upcoming federally-supported Connected Vehicle Pilots program. From these initial activities, it is envisioned that a path toward a full national deployment will occur through incremental but strategic deployments by agencies to address their particular safety, mobility, and operational objectives.

Based on analysis of the expansion of similar ITS initiatives and interviews with selected agency personnel, it is anticipated that these early deployment locations will become seed sites from which agencies deploy geographic and functional (i.e., support of additional connected vehicle applications) expansions. Through increased awareness, peer exchange, and appropriate federal guidance and support, the early seed sites will also be cloned in other locations with similar needs and settings; creating new seed sites across the country. Those areas that are likely to experience the highest initial benefits of a connected vehicle infrastructure and associated applications—notably urban areas with high traffic volumes—are anticipated to see the earliest geographic expansions. Further growth would then likely come along major interurban corridors and the national freight network.

Anticipated Deployment Costs

Potential benefits of connected vehicle infrastructure deployment to both transportation system users and operators are expected to be substantial and have been described in public media and other technical studies. Costs of deployment are estimated in this analysis based on similar ITS and connected vehicle infrastructure deployments to date.

Based on preliminary designs and the limited experience with four pilot deployments ranging in size from 1 to 2680 DSRC roadside units (RSUs), with all estimates in constant 2013 dollars:

- The average direct DSRC RSU equipment and installation cost per site is estimated to be \$17,600.
- The cost to upgrade backhaul to a DSRC RSU site is estimated to vary between \$3,000 and \$40,000 depending on an agency's existing investments, at an estimated national average of \$30,800.
- The typical cost of signal controller upgrades for interfacing with a DSRC RSU is estimated to be \$3,200.
- The annual operations and maintenance cost for a DSRC RSU site is estimated to be \$3,050.

Infrastructure Deployment Timelines

Deployment of a connected vehicle field infrastructure is anticipated to be driven by a series of key milestones. These milestones relate to national policy and regulation development and the development actions of the carmakers, as well as the decision-making processes and implementation activities of the state and local agencies responsible for infrastructure deployment. The anticipated key milestones are illustrated in Figure ES-1.

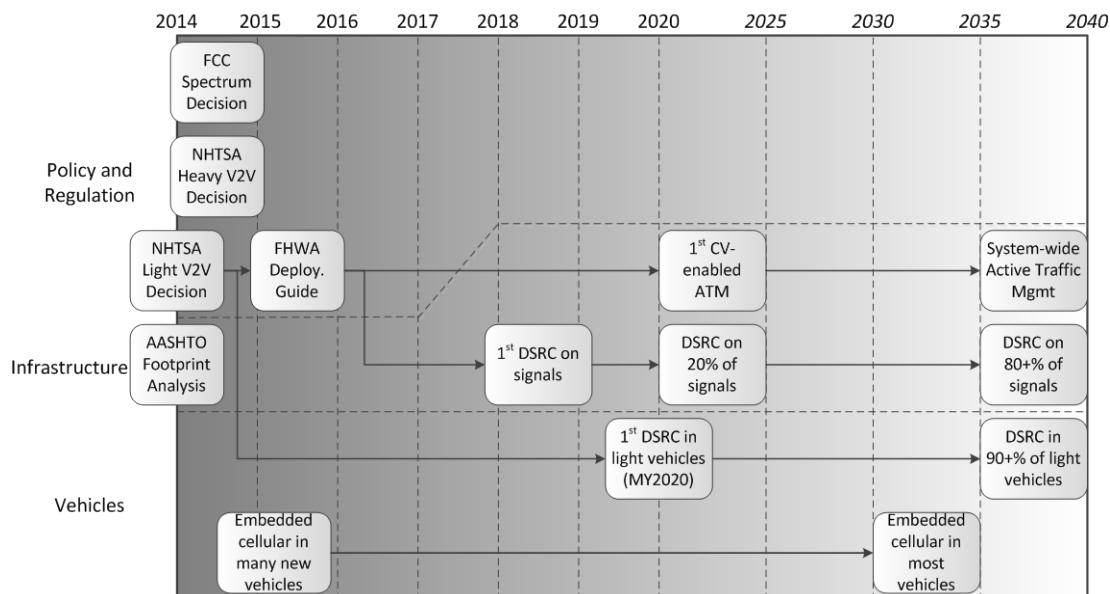


Figure ES-1 – Estimated Connected Vehicle Infrastructure Deployment Milestones (Source: USDOT/AASHTO 2014)

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

The deployment milestones provide the starting point and general timeframe for the connected vehicle infrastructure deployment in terms of current activities and projections for growth of connected vehicle capabilities in vehicles and infrastructure. However, the path and timelines by which individual agencies might move from the current state into actual deployment are anticipated to vary depending on the type of application to be deployed and the development needs of those applications. Figure ES-2 illustrates potential timelines for the deployment of infrastructure associated with various applications.

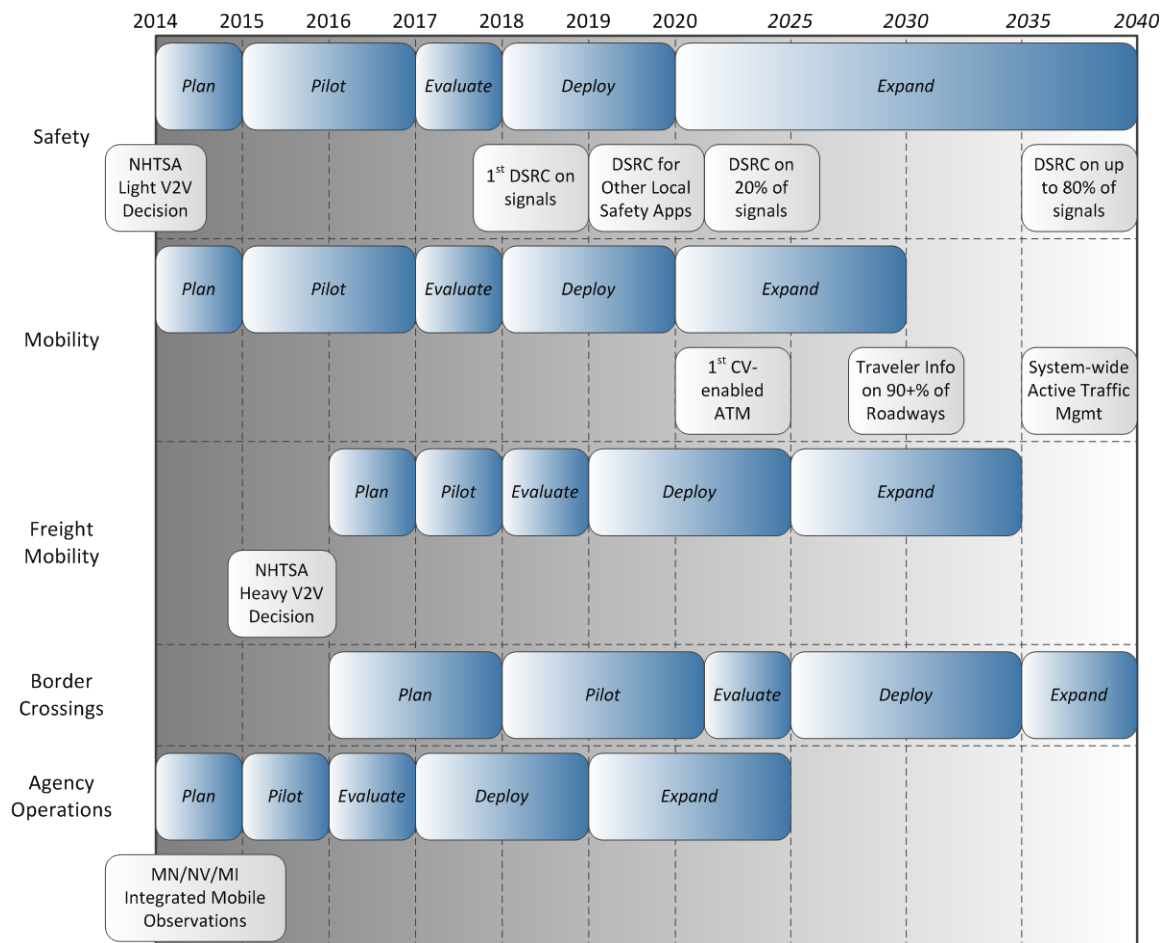


Figure ES-2 - Deployment Timelines by Application Type (Source: USDOT/AASHTO 2014)

Operational and Organizational Impacts

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 viewed as an extension of existing ITS practices. The primary distinction is that a successful connected vehicle system requires a cooperative deployment of the mobile infrastructure—vehicles that also participate in and support the applications. These vehicles, with the exception of agency maintenance and operations fleets, are generally outside the control of the agency deploying the

infrastructure. The cooperative nature of connected vehicle deployments will also require more attention to and management of connected vehicle systems security and user privacy than may have been needed for traditional ITS deployments.

For the state and local agencies, it is anticipated that the steps to deployment will comprise the identification of needs and appropriate deployment opportunities; the development of institutional awareness and local or regional support; potentially conducting pilot projects to demonstrate viability and to determine benefits; the development of specific projects and inclusion of those projects in an agency's transportation planning process; and the 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 the Federal Highway Administration (FHWA) in 2015, as well as the deploying agency's existing procedures and provisions for ITS.

For the purposes of this analysis, it is assumed 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. 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. It is anticipated that the same processes for identifying funding sources and allocating funding that involve metropolitan planning organizations (MPOs), state and local agencies will be adopted. Deploying agencies may also look to public-private partnerships (P3), including relationships with data service providers and commercial application developers, to support infrastructure deployment and ongoing operations and maintenance.

Recommended Next Steps

AASHTO recommends that the next steps in preparing for deployment of connected vehicle infrastructure would include the development of a National Deployment Plan that would actively coordinate the remaining development tasks by the federal government, state and local agencies, carmakers, and application and equipment providers. Further preparations would include the development of Deployment Strategies by each state and local agency considering deployment; consideration by USDOT of a Connected Vehicle Deployment Incentive Grants program, similar to the approach used during the development of the 511 program. Resolution of a number of technical issues remain for successful implementation of a connected vehicle environment, including further analysis of the use of cellular communications for connected vehicle applications, the exploration of cloud data storage and integration, and integration of connected vehicle technologies with existing traditional and ITS infrastructure.

Purpose and Scope

The fundamental premise of the connected vehicle initiative is that enabling wireless connectivity among vehicles, the infrastructure, and mobile devices will bring about transformative changes in safety, mobility, and the environmental impacts in the transportation system. Key federal policy decisions relating to connected vehicle safety needs are currently moving forward. In particular, the work of NHTSA to consider a rulemaking for Dedicated Short Range Communications (DSRC) devices in light vehicles has received significant national attention. While the future actions of NHTSA and the state and local transportation agencies are independent, and the NHTSA decision will not require agencies to deploy any connected vehicle infrastructure, it is important for the state and local agencies to understand what this action will mean to them, what they need to know to prepare for an emerging connected vehicle environment, and what investments may need to be made to leverage a nationwide fleet of equipped vehicles in support of their own policy and operational objectives. The infrastructure *footprint* describes the types and extent of infrastructure to be deployed in development over time of the connected vehicle environment. This document provides the results of the footprint analysis and includes:

- 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.

Elements of the footprint have been previously published in a series of deliverables that are brought together in this Final Report. These component documents include the introductory technical memo entitled *Preparing to Implement a Connected Vehicle Future*, the *Applications Analysis*, the *Deployment Concepts*, the *Deployment Scenarios* and the *Footprint, Timelines and Cost Estimation*.

Following this Introduction, this document consists of a vision for a national footprint; a description of the background for and current research on connected vehicle deployments; a set of assumptions underlying the infrastructure footprint analysis; the applications analysis; the deployment concepts, the preliminary national footprint, including the value proposition, deployment objectives, context, scenarios, and experience to date; and a preliminary deployment and operations cost estimation.

Vision for a National Footprint

Vision Statement

The AASHTO Connected Vehicle Deployment Coalition has established a vision for the infrastructure footprint that anticipates a mature connected vehicle environment by 2040, by which time a large majority of vehicles on the roadway will be connected. From an infrastructure perspective:

- Up to 80% (250,000) of traffic signal locations will be V2I-enabled.
- Up to 25,000 other roadside locations will be V2I-enabled.
- Accurate, real-time, localized, traveler information will be available on 90% or more of roadways.
- Next-generation, multimodal, information-driven, active traffic management will be deployed system-wide.

Background

A connected vehicle environment will consist of vehicles, infrastructure, information services, and travelers sharing information to operate more safely and efficiently with reduced environmental impact and costs for all participants. Transportation agencies, vehicle and device manufacturers, and information service providers will develop and deploy the infrastructure, devices, services and applications enabling those operations. A fully-deployed connected vehicle environment will enable all travelers and their vehicles to exchange information with the transportation infrastructure, providing information on their location and key operational parameters, and receiving current relevant information. Transportation managers will receive traffic conditions from connected vehicles and will provide information across the transportation network. From an infrastructure perspective, the information exchange could include traffic control and traveler information interfaces at the roadside or offered through other information services on a wireless wide-area network.

The connected vehicle environment will emerge from a mix of applications deployed in pursuit of specific operational objectives. The operational objectives are broadly described in the *Deployment Scenarios* analysis. Relative to infrastructure deployment, the objectives will be quantified in terms of an expanded set of performance measures similar to those already established by the deploying agencies for their current systems and ITS applications. Deployed connected vehicle applications of interest, described in the *Applications Analysis*, will ultimately address all operational objectives and consider all vehicle types, travelers and modes. At full deployment, it is envisioned that the connected vehicle field infrastructure will provide appropriate coverage of rural freeways and arterials; urban highways, intersections, and corridors; freight facilities, freight corridors, and commercial vehicle monitoring sites; and the international land border crossings between the US and Mexico and Canada; as well as supporting agency system operations and management needs and transportation system user fee collection.

Deployment of the vehicle systems, infrastructure and communications to support these applications and operational objectives will take time. Based on typical vehicle and infrastructure replacement intervals of 12 to 15 years, a connected vehicle environment could be fully deployed over 25 years, by about 2040.¹ The environment would show increasing safety, mobility and environmental benefits over the build-out period. The degree to which any particular operational objectives would be met at any point in that period would depend on which applications were being deployed. At full deployment in 2040, infrastructure for a connected vehicle environment would be deployed nationwide at intersections and selected other roadside locations, and would be providing system-wide active traffic management and traveler information.

Intersections represent significant opportunities for vehicle-infrastructure interaction. In particular, deployment of infrastructure at signalized intersections will provide an immediate benefit for all connected vehicles through a variety of applications: red light violation warnings based on signal phase and timing data; signal prioritization for emergency vehicles, transit and freight; and vehicle-signal interactions for improved fuel economy. A goal of equipping eighty percent of intersections is intended to capture an upper bound on the fraction of locations where deployment would be warranted by the potential benefits. The benefit-cost balance will be tested over time as increasing numbers of intersections are V2I-enabled.

Non-signalized locations with significant vehicle-infrastructure interactions are also candidates for deployment. These sites will generally fall into two categories: those where a low-latency data exchange may be needed to provide a safety benefit and those where significant information exchange is already taking place. In the first category, for example, curves represent potential speed hazards because driving conditions may change quickly due to weather, and work zones are subject to dynamic operational changes. In the second category, existing ITS sites—vehicle detection stations, variable message signs, environmental sensor stations—already demonstrate a need for information gathering or broadcast that could be further enhanced by real-time connected vehicle interaction. Surveys of ITS deployment, described later in this report, indicate that there are currently about fifty thousand such sites across the U.S.² Similar to the signalized intersections, it is a reasonable goal to assume that fifty percent or twenty-five thousand such sites might demonstrate net benefits of deployment, subject to verification as these sites are V2I-enabled over time.

The connected vehicle environment will create tremendous opportunities for the enhancement of travel information. The ability to gather traffic information directly from vehicles will provide a much finer spatial data resolution than is currently available with infrastructure-based solutions like loops and roadside radar units. Traffic detection will be far more broadly enabled on arterials, where fixed station detection is too limited to provide a true dynamic picture. V2I communications will also enable information to get back to drivers quickly enough that routing decisions can be made dynamically rather than just at the outset of a trip. These benefits are already becoming available through some commercial fleet data-gathering and traveler information services, and will increase over time. Since virtually all vehicles in the national vehicle fleet will eventually be V2I-enabled, it is not unreasonable to forecast that actionable traveler information would be available on the vast majority of roadways—say ninety percent—by 2040.

¹ The basis for this assertion is described in the later section on *Deployment Milestones*.

² The basis for this assertion is described in the later section on *ITS Field Infrastructure (Non-Intersection) Sites*.

The availability of ubiquitous real-time traffic data will create the potential for system-wide active integrated traffic management by agencies. The current generation of traffic management systems is constrained by the availability of traffic data, particularly on arterials, and by the controls and countermeasures that can be implemented. The increasingly detailed view of traffic conditions from a V2I-enabled fleet, coupled with the ability to broadcast advisories or warnings over large areas and at specific control points, will provide completely new capabilities to monitor conditions and respond to events. In addition, the ability for an agency to monitor its own operations through connected vehicle technologies further expands the opportunities. Winter maintenance operators, for example, could monitor traffic conditions throughout a region to provide real-time local advisories, actively adjust speed limits, and dispatch road treatment and plowing operations based on actual conditions rather than forecasts and pre-set routes. The potential traffic management benefits would be limited only by the operational investments.

Achieving this vision will require cooperation among all stakeholders. Applications depend on complementary sets of information flowing through the system in multiple directions and through multiple channels. Data describing the traffic and road conditions will originate on vehicles, from travelers, or from an agency's own sensors; will pass through a communications infrastructure (whether deployed and operated by agencies or by commercial service providers); will be processed by information service providers (that may include either agencies or commercial entities); and will be integrated with other agency data to make system operational decisions. On the other hand, data describing the operation of the system will originate with an operating agency or its service provider partners and contractors; will be published by the agency; may be used by third-parties, perhaps in coordination, in value-added services (traffic information and routing, for example); will be accessed by travelers and vehicles through the communications infrastructure; and will be consumed by travelers and vehicles in making local real-time travel decisions.

Since the applications will likely involve so many transactions and stakeholders, building the connected vehicle environment will benefit from and may, in fact, require cooperation among the many stakeholders. At a minimum, system interfaces and protocols will need to be agreed upon among the originators and users of the data, primarily the agencies providing and operating infrastructure and the vehicle manufacturers providing the mobile data and user interfaces. Other stakeholders can facilitate (or impede) deployment, but agencies will have an incentive to deploy infrastructure only when applications are deployed in vehicles. To that end, the AASHTO Connected Vehicle Deployment Coalition has recommended that a National Deployment Plan should be developed to guide deployment through an ongoing, proactive program of collaboration between the stakeholders to address these key issues. The plan should be developed cooperatively between the state and local infrastructure owner/operators and vehicle providers under the direction of USDOT, with further cooperation from communications equipment manufacturers, service providers, and other third parties that may provide information to or use information from the connected vehicle environment.

Background, Current Research, and Understanding

Overview

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 their lives. Instant access to information and the proliferation of “apps” through which users are able to perform almost limitless functions have dramatically recast the ways in which they work, play, and socialize. The transportation system has not been immune to these changes.

The development of the connected vehicle environment is envisioned to leverage several types of wireless connectivity to serve the public good in a number of ways:

- 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 modes and routes and when vehicles can communicate with the infrastructure to enhance fuel efficiency by avoiding unnecessary stops.

AASHTO has been a partner in the Connected Vehicle initiative since 2004, working collaboratively with USDOT and the automobile industry.

The Connected Vehicle initiative was originally based on exclusive use of DSRC. DSRC is a fast, dedicated network that is particularly well suited to safety applications and was designed specifically for automotive applications. The DSRC standards and protocols are based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards for wireless local area networks like Wi-Fi. In the U.S., DSRC operates over 75 megahertz (MHz) of spectrum in the 5.9 GHz band. This spectrum was allocated by the Federal Communications Commission (FCC) in 1999 with service rules adopted in 2003 to be used for the purpose of protecting the safety of the traveling public. DSRC can communicate directly between vehicles and infrastructure and has low latency, but it also has limited range.

Today, the connected vehicle initiative's strategy is to leverage any appropriate and cost-effective wireless network. Vehicles are increasingly connected wirelessly through cellular technology. Fourth-generation (4G) and older third-generation (3G) mobile communications provide high-bandwidth data communications for mobile data terminals including smart phones, tablets, and laptop computers. Commercial networks are deployed across most of the U.S. The 4G networks may be based on Long-term Evolution (LTE) or Worldwide Interoperability for Microwave Access (WiMAX) standards and operate in various frequency bands. ABI Research predicts that 80 percent of the cars operating on North American roads will be wirelessly connected by 2015. General Motors announced at the Mobile World Congress that it plans to install high-speed wireless connections on all of its vehicles beginning with the 2015 model year. Existing vehicle telematics systems use these networks to exchange data between vehicles and their remote information services. There is great potential in this type of wirelessly connected vehicle for mobility and environmental applications. However, connected vehicle active safety applications that prevent crashes present more challenges. They require fast and secure communications—faster than are currently available with traditional cellular. DSRC is uniquely suited to this type of safety application.

Three key federal policy milestones lay on the immediate horizon that may advance the connected vehicle program from research to implementation: the 2014 NHTSA agency decision to consider DSRC rulemaking for light vehicles; the 2014 NHTSA agency decision to consider DSRC rulemaking for heavy vehicles; and the 2015 FHWA development of infrastructure deployment guidance.

Due to the potential to positively transform highway safety, NHTSA has been considering requiring DSRC technology on new cars in the future. NHTSA's decision in early 2014 to pursue a rulemaking means light vehicles equipped with DSRC could begin rolling off the production line in late 2019. These vehicles would broadcast information such as their location, speeds, and direction of travel through the high-speed communication of DSRC.

Under this NHTSA decision, only information needed for safety applications would be broadcast. However, vehicles contain a wealth of information and in the future it may be possible to share additional information with appropriate consumer privacy protections, such as crash notifications and location, pavement condition, or slippery road surfaces. This type of information could be shared across any available wireless network. At its most robust, connected vehicle information such as travel times, border crossing wait times, work zone speed limits, curve speed warnings, intersection signal phases, and in-vehicle signing could also be transmitted from the roadside to vehicles.

As the key federal policy decisions move forward, 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 USDOT and Transport Canada, has undertaken this Connected Vehicle Field Infrastructure Footprint Analysis. The goal of this analysis is to describe the applications and infrastructure needed to realize the significant transportation benefits of connected vehicle systems no matter the type of wireless technology used.

The Benefits of Connected Vehicle Infrastructure Deployment

The vision of a national, multimodal transportation system in which there is connectivity among all types of vehicles, the infrastructure, and other mobile devices requires the participation of a broad community of stakeholders. Federal, state, and local transportation agencies; car, truck, and bus manufacturers; telecommunications providers and consumer electronics manufacturers; and researchers must come together to design, develop, build, and deploy the technologies, applications, systems, and policy frameworks that will foster the connected vehicle environment. This presents a unique approach and challenge in the history of the nation's transportation system. However, significant potential benefits are expected to accrue through this effort:

Highway Safety—According to NHTSA, motor vehicle crashes accounted for 32,310 deaths in 2011. Crashes are the leading cause of death for Americans between the ages of five and 44 years, according to the Centers for Disease Control. The application of connected vehicle technologies is expected to offer some of the most promising opportunities for crash reductions. Research conducted by the Volpe National Transportation Systems Center for NHTSA found that deployment of connected vehicle systems and the combined use of V2V and V2I applications have the potential to affect up to 81 percent of unimpaired crash types involving cars or heavy vehicles.

Evaluating the potential benefits of the connected vehicle system and driver acceptance of vehicle-based safety systems has been central to the research undertaken. This type of analysis provides the factual evidence needed to support NHTSA's decisions on the deployment of core technologies for light and heavy vehicles. The Connected Vehicle Safety Pilot was a real-world implementation of the safety technologies, applications, and systems using everyday drivers. A Model Deployment conducted in Ann Arbor, Michigan from fall 2012 to fall 2013 collected data from approximately 3,000 equipped vehicles. Using a mix of cars, trucks, and transit vehicles, the Safety Pilot was used to test performance, evaluate human factors and usability, observe policies and processes, and collect the empirical data needed to present a more accurate, detailed understanding of the potential safety benefits.

Traffic Congestion—The *Urban Mobility Report* prepared by the Texas A&M Transportation Institute indicates that congestion in 498 urban areas during 2011 accounts for 5.5 billion hours of extra time and 2.9 billion gallons of wasted fuel at a cost of \$121 billion annually. The cost to the average commuter was \$818 in 2011. While there is no comprehensive analysis of the potential impacts of connected vehicle systems on urban congestion, the focus of certain applications on reducing travel delays should ensure that benefits will accrue in this area. Much is happening today through wireless apps in the vehicle and through personal devices.

Vehicle Emissions—Vehicle internal combustion engines produce emissions that include pollutants and greenhouse gases (GHGs). GHGs are not as directly harmful as pollutants but could contribute significantly to climate change. Reduction of pollutants and GHGs produced by surface transportation through reductions in fuel consumption, idling, and vehicle miles of travel is a major goal of some connected vehicle applications.

Deploying a Connected Vehicle Infrastructure

Overall, the connected vehicle environment has the potential to exchange data among all types of vehicles and the infrastructure supporting all surface transportation modes, as illustrated in Figure 1. Data communications will occur among vehicles, personal wireless devices, and transportation infrastructure components, as well as to local and back-office services running applications and other systems responsible for a variety of services, such as connected vehicle security.

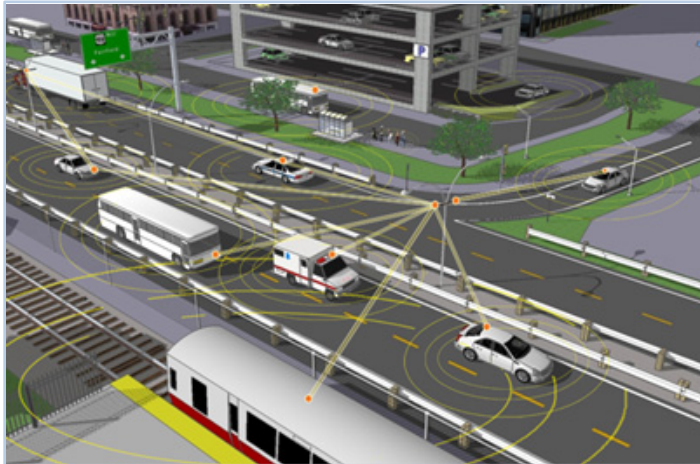


Figure 1 - Connected Vehicle Concept (Source: USDOT 2013)

A connected vehicle infrastructure deployment will generally include several elements such as:

- Roadside communications equipment (for DSRC or other wireless services) together with enclosures, mountings, power, and network backhaul.
- Traffic signal controller interfaces for applications that require signal phase and timing (SPaT) data.
- Systems and processes required to support management of security credentials and ensure a trusted network.
- Mapping services that provide highly detailed roadway geometries, signage, and asset locations for the various connected vehicle applications.
- Positioning services for resolving vehicle locations to high accuracy and precision.
- Data servers for collecting and processing data provided by vehicles and for distributing information, advisories, and alerts to users.

Some elements are specific and unique to state and local DOT interests. These elements may include traffic signal interfaces, or the roadside equipment needed to send infrastructure information or to receive DSRC messages broadcast from vehicles. Agencies may choose to deploy these elements themselves or may consider a variety partnership or outsourcing approaches for deployment. Some elements of the overall connected vehicle system, particularly those necessary for vehicle-based safety applications, may be provided by the automotive industry if regulated by NHTSA, and the elements associated with security management could be provided by a third-party entity. These specifics are still evolving.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Connected Vehicle Infrastructure Planning and Deployment Today

As illustrated in Figure 2, several state and local DOTs are already engaged in the deployment of a connected vehicle infrastructure in support of research, development, and testing activities; many more are active participants in the AASHTO Connected Vehicle Deployment Coalition that is providing oversight to the current *Footprint Analysis*. The more connected vehicle infrastructure is deployed nationwide using common standards, the more likely applications will be developed to take advantage of new safety, mobility, and environmental opportunities. Particularly for connected vehicle infrastructure, deploying on a broad scale improves the benefits for all.

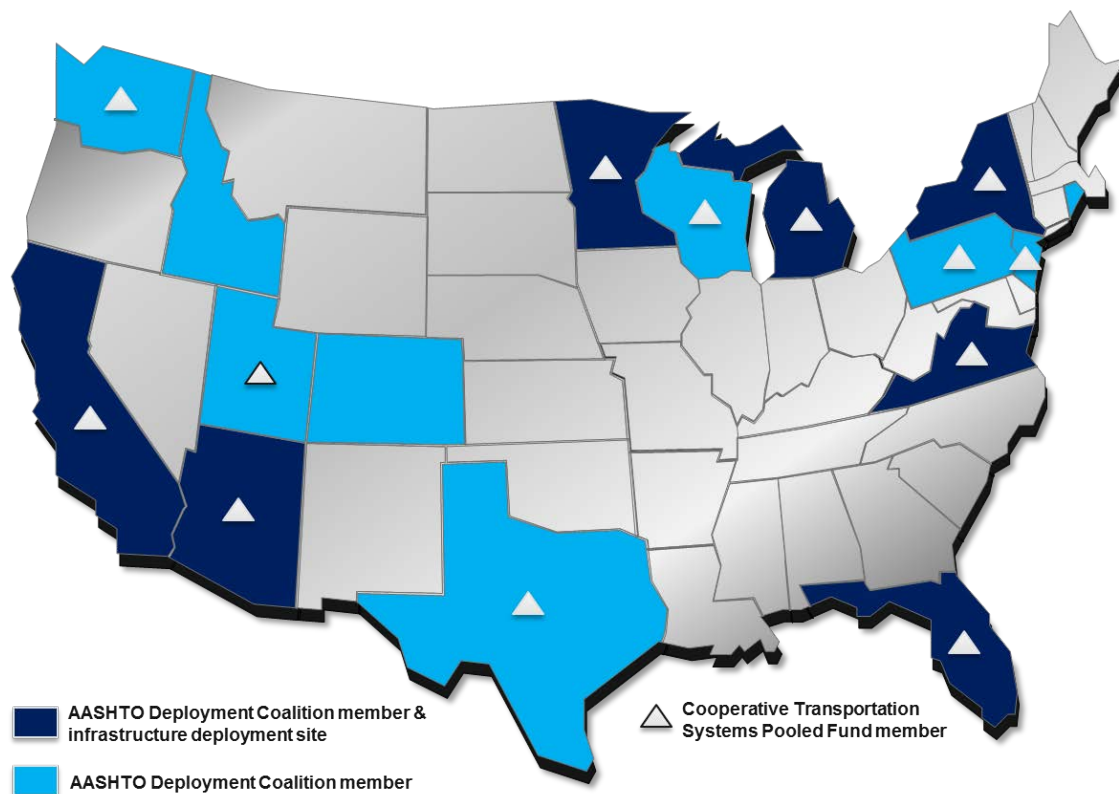


Figure 2 - State Participants in Connected Vehicle Infrastructure Planning and Deployment
(Source: AASHTO 2014)

Assumptions

The eventual 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 as appropriate elsewhere in the report.

1. **Having made a decision in early 2014 to begin taking steps to enable V2V communication technology for light vehicles, NHTSA will develop a regulatory proposal requiring V2V devices in new vehicles in a future year in support of safety applications.** This assumption sets a base expectation that these capabilities will eventually be deployed across the U.S. light vehicle fleet and available to interact with roadside equipment.
2. **NHTSA makes the decision in 2014 to pursue rulemaking for deployment of V2V communications technology 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.
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 RSU form/fit/function and on-board unit (OBU) 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.³ 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.

³ A description of the potential connected vehicle applications relevant to this assumption is provided in the *Applications Analysis* section.

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 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 RSUs 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. Agencies should expect to improve monitoring of their infrastructure systems to preserve overall network security and availability.
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 cellular communications services continue to expand so as to meet or exceed the prior-generation 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 in a cooperative way 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.

A Note on Terminology as Used in this Report

Connected vehicles communicate with each other and the infrastructure over any of several means of wireless communication. *Autonomous vehicles* are those that operate independently by means of on-board sensors and controls. *Automated vehicles* use autonomous sensors and controls, and communicate with other vehicles and infrastructure.

Analysis of Potential Connected Vehicle Applications

The purpose of this section is to provide a summary analysis of connected vehicle applications and their deployment needs to be considered in the Footprint Analysis. These applications and needs have been previously described in an extensive collection of other documents focused on particular functional, modal and programmatic approaches. This analysis surveys those references from the perspective of connected vehicle system deployments to identify what operational needs might be addressed by connected vehicle applications, what aspects of deployment are shared by the applications, and how those common attributes might be leveraged to reduce costs and increase deployment benefits.

The survey of connected vehicle applications took a very broad view of potential application deployments. Applications were identified from:

- The *AASHTO Connected Vehicle Infrastructure Deployment Analysis*,
- USDOT connected vehicle programs for safety, mobility, and environment across all modes,
- State and local programs addressing agency planning, operations and maintenance, and
- Special case for international land border crossings, combining some aspects of other USDOT and State programs

Table 1 lists connected vehicle applications that have been identified from the survey of current research efforts. The listing assembles the applications into application groups and bundles within each group. Application *groups* correspond roughly with application objectives and programs—improving safety, enhancing mobility, improving operational performance, and reducing environmental impacts. Application *bundles* represent segments within those objectives, distinguished by function, mode, or combination thereof.

Table 1 - Applications, Bundles and Groups (Source: USDOT/AASHTO 2014)

Application Group	Application Bundle	Applications
Vehicle to Infrastructure Safety	Intersection Applications	Red Light Violation Warning
		Stop Sign Violation
		Driver Gap Assist at Signalized Intersections
		Stop Sign Gap Assist
	Speed Applications	Curve Speed Warning
		Reduced Speed Work Zone Warning
		Spot Weather Impact Warning
		Speed Zone Warning
	Vulnerable Road Users	Work Zone Alerts
		Infrastructure Pedestrian Detection

		Railroad Crossing Violation Warning
		Pedestrian Warning for Transit Vehicles
		Disabled Vehicles
	Transit Safety	Pedestrian in Signalized Crosswalk Warning
	Other Applications	Oversize Vehicle Warning
Mobility	Enable Advanced Traveler Information Systems (ATIS)	ATIS
		Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles (WX-INFO)
		Motorist Advisories and Warnings
	Integrated Network Flow Optimization (INFLO)	Cooperative Adaptive Cruise Control (CACC)
		Queue Warning (Q-WARN)
		Dynamic Speed Harmonization (SPD-HARM)
		Next Generation Ramp Metering System (RAMP)
	Freight Advanced Traveler Information Systems (FRATIS)	Real-Time Reliable Information (F-ATIS)
		Dynamic Route Guidance (F-DRG)
		Information for Freight Carriers
	Multimodal Intelligent Traffic Signal Systems (M-ISIG)	Freight Signal Priority (FSP)
		Intelligent Traffic Signal System (I-SIG)
		Transit Signal Priority (TSP)
		Pedestrian Mobility (PED-SIG)
		Emergency Vehicle Priority
	Response, Emergency Staging and Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.)	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
		Advanced Automatic Crash Notification Relay (AACN-RELAY)
		Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
		Emergency Communications and Evacuation (EVAC)
	Integrated Dynamic Transit Operations (IDTO)	Connection Protection (T-CONNECT)
		Dynamic Transit Operations (T-DISP)
		Dynamic Ridesharing (D-RIDE)
	Next Generation Integrated Corridor Management (ICM)	Enhanced Maintenance Decision Support System
	Information for Maintenance and Fleet Management Systems	Information for Maintenance and Fleet Management Systems
	Information and Routing Support for Emergency Responders	Information and Routing Support for Emergency Responders
	Smart Roadside	E-Screening / Virtual Weigh Station
		Wireless Roadside Inspection
		Smart Truck Parking
AERIS	Eco-Signal Operations	Eco-Approach and Departure at a Signalized Intersection
		Eco-Traffic Signal Timing
		Eco-Transit Signal Priority

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

		Eco-Freight Signal Priority
		Connected Eco-Driving
	Dynamic Eco-Lanes	Eco-Speed Harmonization
		Eco-Cooperative Adaptive Cruise Control
	Dynamic Low Emissions Zones	Dynamic Emissions Pricing
	Support for Alternative Fuel Vehicle Operations	Engine Performance Optimization
	Eco-Traveler Information	Dynamic Eco-Routing
Road Weather	Road Weather	Eco-Integrated Corridor Management Decision Support System
		Enhanced Maintenance Decision Support System
		Information for Maintenance and Fleet Management Systems
		Variable Speed Limits for Weather-Responsive Traffic Management
		Motorist Advisories and Warnings
		Information for Freight Carriers
		Information and Routing Support for Emergency Responders
International Border Crossings	International Border Crossings	Pre-Clearance, Expedited Screening of Cars and Trucks
		Truck Safety Condition Monitoring and Reporting
		Wait Time and Other Traveler Information
		Automated Toll/User Fee Collection and Administration
		Approach Lane Use Management
		Hazardous Material (HAZMAT) Monitoring and Response
		Shipment (Trailer) Tamper Monitoring [Cargo Security]
		Excess Emission Reduction from Trucks and Cars [Emissions Analysis]
		Border Crossing Performance Monitoring
Fee Payments	Fee Payments	Tolling
		High-occupancy Toll Lanes
		Congestion Pricing
Agency Data Applications	Performance Measures	CV-enabled Performance Measures
	CV-enabled Traffic Studies	Vehicle classification-based Traffic Studies
		CV-enabled Origin-Destination Studies
		CV-enabled Turning Movement Analysis
		CV-enabled Traffic Model Baselineing
		CV-enabled Predictive Traffic Studies
	Probe Data Applications	Probe-based Pavement Maintenance
		Probe-enabled Traffic Monitoring [e.g., exceptional braking]

Identifying the potential applications is a necessary but incomplete step toward determining application needs. Developing a national deployment footprint requires understanding the deployment

of not just individual applications, but of connected vehicle capabilities as they might support multiple applications. Deployment of field infrastructure becomes more effective when it can be demonstrated to support multiple applications, leveraging both the physical (for example, an RSU) and informational (for example, the basic safety message) resources.

To that end, having identified a set of applications that might be enabled by deployment of connected vehicle technologies, the next step in the application analysis is to identify common aspects of the potential applications. These aspects represent key design and implementation considerations that may affect the cost and complexity of deployment. The aspects are not necessarily independent of one another, and may combine so as to geometrically increase the cost and complexity of deployment relative to other applications.

The key infrastructural features and aspects of deployment may also be fundamentally different for the same application using different communications technology. Many of the applications identified in Table 1 could be deployed with either DSRC or cellular communications between the vehicle and infrastructure. Although future application research and development may conclusively identify the preferred means of communications for each application, this analysis presumes that most of the applications are viable with either DSRC or cellular, effectively treating the cellular and DSRC versions as different applications.

Aspects of deployment other than the fundamental choice of communications technology for which applications were evaluated are described below and detailed for each application in Appendix A. Some elements that would be purely infrastructural or common to all applications and are not described here. For example, the DSRC security system for the infrastructure is assumed to be present for all applications and is not a differentiator among them.

Physical RSU Installation: Describes the options for deploying a DSRC RSU, which are:

- None: no DSRC RSU is deployed
- Fixed: the DSRC RSU is deployed to a particular location and fixed to a permanent structure
- Portable: the DSRC RSU is temporarily deployed to a particular location

Roadside Interface to Local: Indicates whether one or more connections to local infrastructure systems are present. Local infrastructure systems could include traffic signal controllers, environmental sensor stations, or other ITS components; connections could be from a DSRC RSU or a back office system. Options are:

- No: no connections are needed.
- Yes: connections are required.
- Optional: connections would depend on the particular implementation of the subject application.

Backhaul Communications: Indicates whether backhaul communications from the RSU or local infrastructure systems are needed to deploy the application. The medium and format of the backhaul are not specified. Options are:

- None: no backhaul communications are needed.
- Required: backhaul communications are required.

- Optional: backhaul communications may be used, but are not required for all particular deployments.

Backhaul Restrictions: Describes restrictions on backhaul communications access for the subject application. Options are:

- N/A: backhaul restrictions are not applicable since there are no backhaul communications needed for the subject application.
- Exclusive: the backhaul connection for the subject application is restricted to a finite number of agency-controlled connections, most likely to a transportation management center.
- Limited Domains: the subject application connections are restricted to a particular set of domains; the list might represent, for example, a set of third-party information services to which data is pushed from the roadside.
- Unrestricted: the subject application needs unrestricted access to Internet domains.

Mapping Support: Describes the level of mapping support needed for the subject application. Options are:

- None: the subject application does not need mapping support; this may be because the application depends on proximity to a DSRC RSU rather than location coordinates.
- Road Network: the subject application needs to be able to place the mobile unit within the context of a particular road.
- Lane Level: the subject application needs to be able to place the mobile unit within the context of a lane of travel on a particular road.
- Localized Geometric: the subject application needs to be able to place the mobile unit within the context of the roadway and intersection geometry, for example, at the stop line in a particular lane.

Siting Dependency: The effectiveness of an application may depend on the reliability and consistency of communications between the roadside and mobile units across the area of the application's deployment. This field indicates whether or not siting of the roadside to mobile unit communications is critical. Options are:

- Not critical: variability in communications is acceptable.
- Critical: consistency and reliability of roadside to mobile unit communications is critical to application effectiveness.

Management of Collected Data: Indicates whether ongoing management of data collected from mobile units is needed to deploy the application. Options are:

- No: no data management services are needed.
- Yes: a data management infrastructure and operations services are needed to deploy and support the application.

Back Office Services/Applications: Indicates whether back office (management center) applications/services are needed to deploy the application. Options are:

- No: no back office applications/services are needed.

- Yes: center computing infrastructure and operations services are needed to deploy and support the application.

Latency: Indicates the relative response time in communications between the originating and the responding application components (OBU and/or RSU and/or back office services) needed for the application to be effective. Options are:

- Low: prompt information exchange is essential to the effectiveness of the application; response times on the order of one second or less are needed.
- Medium: response times between one and five seconds are acceptable.
- High: variability and delay in communications is acceptable; response times may exceed five seconds.

Vehicle Data Connection: Indicates whether the mobile unit requires a connection to the vehicle's data bus. Options are:

- Required: the subject application requires data from the vehicle.
- Not required: the subject application does not require data from the vehicle.

Benefits versus Deployment Level: Indicates at what level of application deployment, generally based on mobile units, benefits from the subject application would be seen by users. Mobile units in this context could be units built into vehicles, aftermarket devices, or smart personal devices. Options are:

- Benefits Realizable Day One: users could begin to see benefits from the subject application as soon as it is deployed.
- Benefits Require Threshold Deployment: users would not see benefits from the subject application until a threshold number of mobile units are deployed with the infrastructure.

Other Dependency: Some applications have will be dependent on resolution of non-technical issues before they could be deployed. Factors identified in this analysis include:

- Privacy: the subject application may have consequences for user privacy that need to be addressed before it can be deployed.
- Policy: the subject application may need review or changes in agency policy or jurisdictional legislation before it can be deployed.

Data Needs from OBU: Indicates what kinds of data the subject application needs from the OBU for transmission to the infrastructure. Data groups identified in this analysis include:

- None: no data are needed from the OBU.
- Position: only positional data are needed.
- BSM1: data included in the Basic Safety Message Part 1 are needed.
- BSM1+2: data included in the Basic Safety Message Parts 1 and 2 are needed.
- BSM1+2+other: data included in the Basic Safety Message Parts 1 and 2, and other data are needed.
- BSM1+other: data included in the Basic Safety Message Part 1 and other data are needed.

- Other: data of types *not* included in the Basic Safety Message Parts 1 and 2 are needed. Data of this type would be application-specific, such as fee payment information or routing requests.

Data Needs from Infrastructure: Indicates what kinds of data the subject application needs from the infrastructure for transmission to the OBU. Data groups identified in this analysis include:

- None: no data are needed from the infrastructure.
- TI: traveler information of some kind is needed. This is a broad class of data that could include road and weather conditions; incidents and work zones; and routing guidance.
- SPaT: traffic signal phase and timing are needed.
- GIDs/Maps: geometric intersection descriptions and maps.
- SPaT/GIDs: combinations of the signal phase and timing and geometric intersection descriptions.
- App-specific: information specific to the subject application beyond the other data groups.

The evaluation of these aspects of deployment for each application is detailed in Appendix A.

Deployment Concepts for Connected Vehicle Field Infrastructure

The purpose of this section is to describe a set of high-level, generic connected vehicle infrastructure deployment concepts. The descriptions address potential infrastructure and application deployments in terms of the existing setting, connected vehicle field equipment, interfaces to related transportation equipment (e.g., traffic signal controllers), communications resources, security, and basic operations. The concepts have been developed around the applications described in the prior section of the report as they might be deployed in a variety of geographical and operational settings.

The deployment concepts are expected to form a basis for further analysis by both the USDOT and by State and local agencies. As such, they illustrate how applications, new and existing infrastructure equipment, power sources, and new and existing communications networks and equipment (i.e., fiber, cellular, microwave, modems, etc.) come together into snapshots of integrated connected vehicle deployments. For State and local decision makers, these deployment concepts are intended to provide enough detail to understand the implications of deployment—the required technologies, decisions, steps, personnel, knowledge and skill sets needed for deployment, operations, and maintenance. For the USDOT, the deployment concepts are intended to support further assessment of connected vehicle policy, planning, communications technology, deployment, operations, security, risk management, certifications and training.

In this context, the deployment concepts are informative rather than normative. The concepts are descriptions of potential connected vehicle infrastructure deployments, but do not constitute designs for such deployments. The state of connected vehicle technologies continues to evolve and could see extensive changes during the design, development and deployment of applications. Additionally, any eventual connected vehicle infrastructure deployments may be considered ITS projects and would then be subject to the relevant system engineering requirements in Title 23 of the Code of Federal Regulations (23 CFR) Section 940.11⁴ and any similar regulatory requirement from Federal Transit Administration (FTA) and Federal Motor Carrier Safety Administration (FMCSA). The concept descriptions and illustrations herein should not be interpreted as design templates; they are intended solely to provide a basis for further discussion and analysis of potential deployments.

The concepts have been selected to illustrate connected vehicle infrastructure deployment in broad terms rather than for specific applications. Each concept illustrates geographical and application considerations that would influence the configuration of a connected vehicle deployment in a particular setting.

The deployment concepts were selected based on a thorough review of anticipated connected vehicle applications. An initial list of nearly 100 dynamic mobility, safety, environmental, and agency-focused

⁴ Title 23 of the Code of Federal Regulations (CFR) Part 940, Intelligent Transportation Systems Architecture and Standards, Section 11, Project Implementation

connected vehicle applications was created. These applications were drawn from the Federal connected vehicle program, as well as work conducted through the Cooperative Transportation Systems Pooled Fund Study and by individual state and local agencies. In some cases, similar applications with different names were combined into one commonly-titled application.

Since the scope of this effort is focused on infrastructure, only the applications that require a connected vehicle field infrastructure were considered. V2V applications were not included in the analysis. Similarly, infrastructural support for V2V applications is presumed, but not explicitly addressed. In that context, the systems that address the security needs of V2V and V2I applications are discussed in the Appendix C Common Considerations as part of explaining the architectural interfaces. The application infrastructure will be required to work with the security infrastructure, but they may or may not share physical deployments. A more complete definition of the relationship between these infrastructural needs will necessitate further policy and technical research.

The final grouping of applications focused on possible geographical and operational settings. These settings were chosen to illustrate a diversity of potential application deployments using connected vehicle field infrastructure, recognizing that some attributes and considerations would be common to all or most of the anticipated settings. These settings are:

- Rural Freeways and Arterials
- Urban Highway
- Urban Intersection
- Urban Corridor
- Freight Facility
- Smart Roadside Freight Corridor
- International Border Crossings (IBC)
- DOT Operations and Maintenance (O&M)
- User Fee Collection

Illustrations of the deployment concepts have been created to help practitioners visualize what a typical infrastructure deployment might look like. Each concept presents a likely setting for equipment requirements, locations of equipment, interconnects to existing facilities, and anticipated communications interfaces. Rather than creating detailed plans or an architecture, these drawings are intended to abstract the full set of application deployment requirements into a “real world” view for interested implementation stakeholders.

In addition to each drawing, the text further describes each setting, field infrastructure, communications, field management centers or information services, and a list of anticipated applications that could be supported in each setting. These descriptions focus on differences among the deployment settings.

As a guiding principle, it is generally assumed that applications requiring direct data communications between connected vehicles (mobile elements) and roadside infrastructure-based field elements will be carried out using DSRC technology. Where applications are supported by direct communications between connected vehicles and central elements (e.g. transportation management centers (TMCs),

other control centers, or other back-office facilities) then data communications will be carried out using cellular/LTE.

In some settings—including the Rural Roadway and Urban Highway settings—it is recognized that DSRC, cellular, or both DSRC *and* cellular could be used as the communication links with vehicles. Therefore, in these settings, each of the options is shown in the drawings and the alternative communications approaches described in the text. A further consideration used in the development of the concepts acknowledges the focus of this study on the infrastructural aspects of deployment. Therefore, while a cellular communication link may supplement or take the place of DSRC for an application in a given setting, DSRC is the more demanding case from the standpoint of infrastructure deployment by an agency and so is represented in the majority of the setting descriptions. Ultimately, the deploying agency will select the most appropriate communications architecture and technology based on their local needs and the requirements of the application(s) being deployed.

Each of the deployment concepts is briefly described below in terms of its setting and current state, design considerations, and potential applications. The more detailed descriptions of the deployment concepts, with illustrations, are found in Appendix B.

Rural Roadways

Rural roadways include freeways, arterials and minor roadways with typically lower traffic volumes, higher speeds and fewer intersections than are normally found in urbanized areas. The most common rural roadway is a two-lane undivided highway with intermittent warnings signs for upcoming roadway conditions and potential hazards. Most intersections are unsignalized and depend on stop signs for an appropriate level of control. ITS equipment is only rarely deployed on rural roadways due to the low traffic volumes and higher cost of power and communications.

Connected vehicle infrastructure deployment in rural areas will likely be focused on support for safety applications related to roadway configurations and conditions. The most valuable applications are like to be curve speed warnings, road weather condition warnings and other applications that may benefit from information exchange describing the vehicle's operations—speed, heading, traction control—and road conditions—geometry, icing, wind speeds.

The deployment concept in a rural setting could be built around local V2I communications using DSRC or wide area communications using cellular networks. In the DSRC case, roadside units would broadcast the local roadway conditions and collect any basic safety and probe data broadcast from passing vehicles. In the cellular case, the vehicle would request updates on road conditions based on the vehicle's current location and heading from remote servers over the cellular connection.

Urban Highways

Urban highways—interstates, other freeways and other principal arterials—carry the highest traffic volumes and proportion of total urban travel within the roadway network. ITS deployments are widespread on urban highways, collecting information on traffic conditions, providing the traveling public with information on travel time and conditions, and in some cases providing dynamic traffic controls.

Connected vehicle applications have tremendous potential to improve urban highway safety, mobility and environmental impacts. Applications for urban highways could include active traffic management functions, advanced real-time local traveler information, and advisories and warnings similar to those that might be deployed in rural settings.

Connected vehicle application deployment concepts for urban highways are likely to include both V2I DSRC communications and cellular wide area communications. As in the rural concept, roadside DSRC units would collect basic safety and probe messages from passing vehicles and broadcast local advisories, alerts and traveler information. In the cellular case, the vehicle would request updates on road and traffic conditions based on the vehicle's current location and heading from remote servers. Probe data would be processed and integrated with other operations center data to provide enhanced traveler information in both the DSRC and cellular cases.

Urban Intersections

Urban intersections are junctions of two or more roadways within a city setting, typically including features such as curbing, designated lane use markings, pedestrian crossings, and traffic controls (traffic signals or stop signs). Signal controllers at signalized intersections may operate in pre-timed, actuated, semi-actuated or adaptive modes, and may be coordinated with other nearby signals. ITS infrastructure at intersections may additionally include red light cameras, closed-circuit television (CCTV), and freight, transit and emergency vehicle prioritization. Signalized and ITS-equipped intersections are likely to include backhaul for system operations and maintenance.

Connected vehicle applications at urban intersections have been the focus of much research and have significant potential for improving both intersection safety and arterial mobility. Applications could include red light and stop sign violation warnings, gap assist for left turns, Multimodal Intelligent Traffic Signal Systems with prioritization and pedestrian features, and advanced signal and arterial operations.

The deployment concept for urban intersections deploys DSRC roadside units to provide communications between the intersection infrastructure and vehicles approaching and passing through the intersection. Roadside units are interfaced with signal controllers to provide signal phase and timing to the vehicles as they approach and collect basic safety and probe messages as input to local operations applications and for transmission to operations centers.

Urban Corridors

Urban corridors typically consist of multiple signalized intersections, spaced at regular intervals. These roadways have multiple types of roadway users, including pedestrians, bicyclists, transit vehicles, personal cars, and freight deliveries. ITS infrastructure may include components deployed at individual signalized intersections and higher-level coordination and integration to provide safety, mobility and environmental benefits for the corridor as a whole. ITS-equipped urban corridors are more likely to have high-bandwidth communication networks than are stand-alone intersections or rural sites.

The combination of user modes and facilities along a corridor provide a rich environment for potential connected vehicle applications. In this deployment concept, applications could provide operators at a transportation management center with information to enhance corridor mobility, provide multimodal

traveler information, improve the performance of transit routes, and reduce the environmental impacts of travel through the corridor.

As in the urban highway setting, deployment concepts for urban corridors are likely to include both V2I DSRC communications and cellular wide area communications. As in the other concepts, roadside DSRC units would collect basic safety and probe messages from passing vehicles and broadcast local advisories, alerts and traveler information, as well as traffic signal phase and timing. Cellular communications would be used to request updates from remote servers on road and traffic conditions for the corridor or region based on the vehicle's current location. Probe data would be processed and integrated with other operations center data to provide enhanced traveler information in both the DSRC and cellular cases.

Freight Intermodal Facilities

Freight intermodal facilities assist in long haul and drayage assignments where containers are transferred between rail and trucks. Information shared between the intermodal facility and truck drivers includes credential information, goods manifest, inspection information, and the availability and location of containers for transport. At some facilities, driver credential information is communicated through radio frequency identification (RFID) technology established by the Transportation Security Administration (TSA).

Connected vehicle applications of specific interest at intermodal facilities could include real-time traveler information for freight carriers and shipment tamper monitoring.

Within the freight intermodal facility setting, the connected vehicle field equipment would be installed at truck decision points and inspection points, such as in-gate stations, inspection stations, exit gates, and major truck decision points. The onboard equipment in the trucks would transmit and receive information to automate credentialing, inspection, customs, way finding, and traffic information at the facility. Additional DSRC field equipment could also be installed on roadways leading to the intermodal facility to enable inbound trucks to report their arrival and receive notification of expected wait times.

Smart Roadside Freight Corridor

Freight movement is a pivotal part of the US economy and relies on the nation's network of roadways, railways, waterways and airspace to transport goods. The National Highway System (NHS) identifies a strategic network of highways servicing major freight routes. Along these freight routes, various facilities exist to regulate commercial vehicle safety, security, and mobility. Some of these facilities include inspection checkpoints, border crossings, weigh stations, truck parking and rest facilities. The USDOT has developed a Commercial Vehicle Information Systems and Networks (CVISN) nationwide initiative that focuses on safety information exchange, credentials administration, and electronic screening.

The Smart Roadside concept for freight transportation includes E-Permitting Verification/Wireless Roadside Inspection, E-Screening/Virtual Weigh Stations, and Smart Truck Parking. Other potential connected vehicle applications for freight would provide enhanced freight traveler information and routing.

Connected vehicle field equipment in a smart roadside concept would be installed at major freight facilities including truck fuelling stops, weigh station facilities, truck parking facilities, highway rest stops and tolling facilities. These facilities generally have power and backhaul communications that would facilitate connected vehicle application deployment.

International Land Border Crossing

Cross-border transportation is an important element of the nation's transportation system. Laws of the US, Canada, and Mexico require that every vehicle and passenger crossing the border must be screened and verified. Customs agencies stop and screen all incoming vehicles and verify proper documentation before letting them in their respective countries. Each international border crossing (IBC) is different in terms of traffic patterns, geography, configuration, and physical characteristics, but the key functions performed by customs agencies of all three countries are similar. IBCs are probably the most complicated of any potential connected vehicle application setting, presenting interrelated policy, technical, physical, and operational challenges.

Applications that might be deployed at IBCs could include any of the traveler information and freight applications described for other concept settings, as well as applications specific to the needs of the border crossing itself. A next-generation wait time and approach management system, for example, could automatically and accurately estimate wait and crossing times, providing that information to motorists and drivers in the queues.

The concept would presumably be deployed on roadway approaches leading to primary inspection points operated by customs agencies on both sides of the international border. As in other deployment concepts, V2I communications using DSRC and cellular communications could both have roles in the border crossing concept. For example, the application could use DSRC to gather vehicle information, identify lanes in which vehicles are traveling, and exchange trusted shipper and traveler program registrations and permissions.

DOT Operations and Maintenance

A Department of Transportation's maintenance and operations divisions oversee the day-to-day needs of maintaining and operating the roadway network—its pavement, drainage, roadside and vegetation, bridges and tunnels. These maintenance operations require effective traffic control to preserve the safety of both the agency workers and the traveling public. These divisions also respond to the occasional and exceptional traffic and weather events, removing debris and working to maintain safe, passable roadways in winter storms or high water events.

These maintenance activities and operations need timely and accurate data to monitor and assess roadway conditions. Connected vehicle applications can supplement the existing data sources by using the DOT's own vehicles as probes. Sensors on the vehicles can monitor traffic movement in work zones through vehicle position, speed and heading; roadway weather conditions through air temperature, ambient pressure, windshield wiper state, and traction control actuations; and even pavement conditions through accelerometry.

The agency operations and maintenance concept would collect and transmit probe data from vehicles to roadside and back office services for aggregation and processing into actionable decision support information. The data exchange with the back office could use V2I DSRC or cellular communications

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

for near real time applications like work zones and winter maintenance operations. More data-intensive but less latency-dependent applications like pavement condition monitoring could use Wi-Fi connections at maintenance facilities to download data from vehicles to servers.

Fee Payment

User fees are used in some transportation systems to collect revenue to fund transportation projects, recuperate funds from a past project, and sustain maintenance and operations for roadway infrastructure. Fees may be assessed on the use of a roadway, bridge, tunnel, or on a particular (e.g., high-occupancy toll) lane within a roadway. User fees were traditionally collected through means such as toll booths and have been evolving towards electronic tolling collection (ETC) systems for improved operational efficiencies. Vehicles in an ETC system are assessed a fee through tag readers and RFID technology and typically do not have to stop for the collection transaction.

Connected vehicle applications could be used to replace or supplement many of the fee payment transactions. Since the vehicle in these applications is “aware of” and can communicate its location anywhere on the transportation network, the fee payment concept could be used for traditional roadway tolling, congestion pricing, or even approach lane management at facilities for which fees are to be paid.

The Preliminary National Footprint and Deployment Timeline

The purpose of this section is to describe the progress of connected vehicle infrastructure deployment through various deployment scenarios from the initial demonstration prototypes into a national footprint. In order to provide the proper context, the value proposition and objectives are restated with a description of the system elements and stakeholders that would be essential to deployment. The scenarios build on the applications and deployment concepts described in previous sections of this report and describe the processes by which agencies might approach the deployment of connected vehicle infrastructure for applications. The broader national view of deployment is described in terms of its similarities to previous ITS deployment, connected vehicle infrastructure deployment to date, national deployment patterns, and estimation of the number of infrastructure deployment sites. Forecasts of milestones and timelines for deployment conclude the footprint description.

Value Proposition

The development of a connected vehicle environment is envisioned to leverage several types of wireless connectivity—cellular, Wi-Fi, and 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*.⁵ 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.

⁵ USDOT Research and Innovative Technology Administration; *Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications*; Publication Number FHWA-HRT-11-040; November 2012.

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.
- 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 Objectives

The most frequent question asked by state and local agency personnel preparing for the connected vehicle environment is "where do I start?" Research and development of connected vehicle systems and applications have thus far focused more on their technical viability and potential benefits, and less on the strategic and tactical aspects of a connected vehicle deployment program. The situation in many ways resembles that of ITS in its early phases.

One approach, based on effective systems engineering practices, is to start with an analysis of the objectives to be met in deploying connected vehicle capabilities. At a high level, the potential objectives are the same as those that come into play in any other ITS deployment or, more generally, in transportation system management and operations:

- Improving safety – reducing crashes, injuries and fatalities;

- Improving personal mobility and environmental impacts – improving travel times and travel time reliability for drivers, riders, and pedestrians, and improving fuel efficiency and reducing idle time
- Improving freight efficiency – improving freight mobility and compliance/enforcement
- Improving border crossing operations – for passengers and freight; and
- Improving internal agency operations – reducing response times and costs.

Each of these objectives can be played out in a particular scenario or scenarios. As described in detail in the *Deployment Scenarios* section, each scenario focuses on one or more sets of applications, which in turn may imply a focus on a particular implementing technology.

For example, an interest in improving safety in urban areas would suggest deployment of Red Light Violation Warning capabilities at high crash rate, high volume intersections. Improving mobility along urban corridors would suggest deployment of Intelligent Traffic Signal Systems within those corridors. Deployment of connected vehicle capabilities at intersections along a high volume urban corridor could then facilitate both safety and mobility applications.

Improving safety in rural areas could be addressed by deploying speed zone and other safety Warnings and Advisories at roadway curves with known high crash rates, or at sites known to be subject to dangerous weather conditions—bridge icing, high winds, or fog. Improving freight mobility could be facilitated by providing Next-generation Traveler Information—routing and parking information— across the Primary Freight Network (PFN). Connected vehicles technologies deployed throughout the PFN could then support multiple applications for freight mobility and safety applications.

Table 2 - Potential Deployment Objectives, Scenarios, and Applications (Source: USDOT/AASHTO 2014)

Objective	Scenarios	Applications Focus	Example Applications	Tech Focus	Priority Deployments
Improve Safety	Urban	V2I safety	Red Light Violation Warning Speed Zone and other safety warnings	DSRC	High crash rate intersections High volume intersections
	Rural				High crash rate curves High consequence weather sites: bridges, fog areas
Improve Mobility and Environmental Impact	Urban, Corridor	Arterial Management	Intelligent Traffic Signal Systems with Prioritization Eco-Drive	DSRC	High volume corridors
		Freeway Management	Next-generation Active Traffic Management Next-generation Traveler Information	Cellular	High-volume corridors High consequence weather sites: bridges, fog areas
	Rural	Traveler Information	Next-generation Traveler Information including local weather alerts	Cellular	High volume corridors High consequence weather sites: bridges, fog areas
Improve Freight Mobility	Urban, Rural, Freight, Corridor	Traveler Information	Next-generation Traveler Information	Cellular	Primary Freight Network
		Enforcement	Smart Roadside	DSRC or Cellular	Primary Freight Network
Improve Border Crossing Operations	International Border Crossings	Traveler Information	Next-generation Traveler Information	Cellular	Border Crossings
		Enforcement	Similar to Smart Roadside	DSRC or Cellular	Border Crossings
Improve Agency Operations	DOT Ops and Maintenance	Maintenance Management	Enhanced Maintenance Decision Support Maintenance and Fleet Management Systems	Cellular or other wide area wireless	

Identification of the objectives, whether as part of a research plan or a formal planning process, sets the initial direction and goals of the deployment process. In the current early phase of technology development, this is naturally followed by deployment of test beds and pilot demonstrations as described earlier. The technological iterations generated by these tests and demonstrations then become the basis for another round of decision-making: what applications are ready for deployment? Where would initial deployments be most effective? At what level of deployment are the costs commensurate with the measured and perceived benefits? The projected answers to these and similar questions, asked and answered by each and all of the agencies considering deployment, are the drivers for the national infrastructure footprint.

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 ITS are summarized in the *Deployment of ITS: A Summary of the 2010 National Survey Results*.⁶ 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, 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*,⁷ the precursor to this current study. That document provided a history of connected vehicle research; a review of the relevant USDOT, state and local programs and Vehicle Infrastructure Integration Consortium (VIIC) initiatives at that

⁶ USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Deployment of ITS: A Summary of the 2010 National Survey Results*; Publication Number FHWA-JPO-11-132; August 2011; download available at <http://www.itsdeployment.its.dot.gov/documents/nationalreport.pdf>.

⁷ USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *AASHTO Connected Vehicle Infrastructure Deployment Analysis*; Publication Number FHWA-JPO-11-090; June 17, 2011; available for download at http://ntl.bts.gov/lib/43000/43500/43514/FHWA-JPO-11-090_AASHTO_CV_Deploy_Analysis_final_report.pdf

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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. These public sector pilot demonstration test beds and their significance as starting points for the national footprint are described in more detail in the section on *Connected Vehicle Infrastructure Deployment to Date*.

System Elements and Interactions

Although this document has already described potential connected vehicle applications and infrastructure deployment concepts, it is important before jumping into the deployment scenarios and footprint development to provide some working assumptions as to 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 Wireless Access in Vehicular Environments (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 RSU 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 earlier section on *Analysis of Potential Connected Vehicle Applications* 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:

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

- V2I safety applications
 - Red Light Violation Warning (similar to the earlier Cooperative Intersection Collision Avoidance System (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)
 - 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

Just as it was important to describe the system components and applications addressed by the scenarios, developing a national footprint will depend on contributions from a large stakeholder community. 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 RSUs)
- 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)
- Secure and reliable 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

- 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 OBU 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:

- Embedded communications units (for example, DSRC OBUs 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 RSUs, 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

Deployment Scenarios

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 a common template. 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 described earlier in this report) 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.

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 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 4.1 million 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 Texas Transportation Institute (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 Joint Program Office (JPO), the 108 largest metropolitan areas include 266 agencies with TMCs, plus the additional deployed ITS assets shown in Table 3.

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 3 - Summary of ITS Assets (Source: USDOT⁸ 2010)

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

⁸ *Deployment of ITS: A Summary of the 2010 National Survey Results*; Publication Number FHWA-JPO-11-132; August 2011.

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., high-occupancy toll (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 Baselineing & 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 advanced traffic management systems (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 metropolitan transportation plan (MTP) and transportation improvement plan (TIP). In some states, development of alternative funding strategies (such as public-private partnerships or commercial arrangements) will likely be 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 4, 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 4 - 2011 Road Lengths and Traffic Densities (Source: USDOT/AASHTO 2014)

Road Ownership	Public Road Length, miles (1)			Vehicle Miles Traveled, millions (2)	Category Average Daily Traffic
	Federal Aid Highway	Non-Federal Aid	Total Length		
Rural	681,116	2,300,797	2,981,913	974,038	895
Small Urban	66,889	134,188	201,077		
Urbanized	249,942	496,493	746,435		
Total Urban	316,831	630,681	947,511	1,972,094	5702
Total Rural and Urban	997,947	2,931,478	3,929,425	2,946,131	2054

(1) <http://www.fhwa.dot.gov/policyinformation/statistics/2011/hm16.cfm>

(2) <http://www.fhwa.dot.gov/policyinformation/statistics/2011/vm1.cfm>

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

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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.

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 ATMS and controlled from a metropolitan area 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).⁹ 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.¹⁰

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,

⁹ [<http://www.ops.fhwa.dot.gov/1201/>]

¹⁰ *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>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

and one in five of these were on rural local roads.¹¹ Improving awareness of local traffic, roadway and weather conditions is a 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 connected vehicle 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 connected vehicle 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* section. 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

¹¹ Upper Great Plains Transportation Institute; *Truck Crash Facts – ND Crash Summary*; http://www.ugpti.org/rtssc/briefs/downloads/2013_TruckCrashFacts.pdf

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

- 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* section, 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* section 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.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Recognizing that resources are limited, prioritizing the application and site deployments will be important to integrating connected vehicle deployment into the agency planning process. 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, or from the process used for any of the other scenarios.

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. 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—

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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 RSU 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 Coalition¹² and the North/West Passage Corridor¹³ 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;

¹² <http://www.i95coalition.org/i95/Home/I95CorridorFacts/tabid/173/Default.aspx>

¹³ <http://www.nwpassage.info/about/history.php>

- 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 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.

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., New York/New Jersey and the District of Columbia/Virginia/Maryland 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 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.,

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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 2011¹⁴, a total that does not

¹⁴ <http://www.fhwa.dot.gov/policyinformation/statistics/2011/pdf/sf12.pdf>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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 collect information from environmental sensor stations 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, the Moving Ahead for Progress in the 21st Century Act (MAP-21)¹⁵ defined a process for establishing performance management goals that 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.¹⁶ 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:

¹⁵ Moving Ahead for Progress in the 21st Century Act (PL 112-141), July 6, 2012

¹⁶ <http://www.fhwa.dot.gov/policyinformation/statistics/2011/pdf/mv1.pdf>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

- The performance of the 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 O&M applications and setting are generally described in the *Deployment Concepts* section.

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 RSU.

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' controller area network (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 RSUs supporting other applications—for example, intersection safety applications—could be used for agency applications at the same time. Latency and RSU location requirements, especially for those supporting winter maintenance applications, could also require RSUs in locations that are not otherwise optimal for safety and mobility applications.

Commercial Vehicle and Freight Systems

With 11 million¹⁷ 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

¹⁷ http://www.ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/11factsfigures/table3_2.htm

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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 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 Protection (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

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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[®], North American Preclearance and Safety System (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 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 North American Free Trade Agreement (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 USDOT FHWA 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)¹⁸. 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

¹⁸ <http://www.iteris.com/itsarch/bifa/>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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)¹⁹.

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. 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 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 U.S.-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 RFID 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

¹⁹ U.S. Department of Transportation Federal Highway Administration and Transport Canada; *Border Information Flow Architecture Final Report*; January 2006.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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 new systems are added and existing system gradually phased out as the equipment depreciates and becomes obsolete.

On the U.S.-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.

IBCcs 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. IBCcs 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 IBCcs 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 IBCcs.

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 IBCcs. 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 IBCcs, 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 IBCcs. 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 Program²⁰ for trusted cross-border personal travel across the U.S.-Canada border and the FAST Program²¹ for commercial vehicle operations across both the U.S.-Canada and U.S.-Mexico borders. It is not clear, however, that U.S. CBP, the 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.

²⁰ http://www.cbp.gov/xp/cgov/travel/trusted_traveler/nexus_prog/

²¹ <http://usa.immigrationvisaforms.com/travel/fast-card-us-canada> and <http://usa.immigrationvisaforms.com/travel/fast-card-us-mexico>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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)²², 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 FHWA²³, 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. High occupancy toll (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 based largely on the business case. A transition from existing technologies to 5.9 GHz DSRC would be especially valuable if the change is demonstrated to reduce operating or

²² The US Tolling Industry: Facts in Brief 2012, IBTTA, Reprinted 2013.

²³ http://ops.fhwa.dot.gov/publications/managelanes_primer/

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

maintenance costs—particularly cost per dollar of revenue collected—or if the use of the technology creates new revenue-generating services that could not be easily or cost-effectively implemented using the existing technologies. Replacement with DSRC is however unlikely to be cost-effective unless most potential users already have DSRC capabilities in their vehicles.

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. Operating authorities acknowledge 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 need to consider the value of existing transponders in passenger cars operating in the region, and on the proportion of vehicles already equipped with DSRC capabilities at that time

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 would likely be different again. 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 U.S., could see a strong value proposition created.

Deployment Description

Deployment of connected vehicle technologies on existing toll and managed lane facilities may 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 is likely that connected vehicle technologies will be considered for the revenue collection component. In the longer term, as connected vehicle technologies become widely available in light and heavy vehicles for applications beyond revenue collection, it will likely become very 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

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

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, a rapid transition to 5.9 GHz DSRC may be challenging 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 may wish to leverage an existing installed base of electronic toll collection transponders used by other authorities in the region.

Building up to the National Footprint

Building up to a national connected vehicle infrastructure footprint will require cooperation among stakeholders, planning, technological and financial resources, and time. Describing the means of getting there will look back at previous ITS deployment experience; the current state of infrastructure deployment; potential deployment objectives, as a way of eliciting priorities; potential patterns for the growth of the infrastructure deployment; and at an analysis of the potential number of infrastructure sites.

ITS Deployment Experience

The deployment of Intelligent Transportation Systems (ITS) may provide some insight into the deployment path and the approach of the agencies that will be responsible for deploying the field infrastructure components of the connected vehicle environment. The Federal ITS research program was formalized in 1991 with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA), although several of the core technologies and some of the formative program initiatives had been around for years or even decades before that date. However, this milestone anchors a period that approaches the anticipated timeframe of connected vehicle deployments that described in this study.

Several components of the ITS program can provide a model for the deployment approaches that may be adopted by state and local agencies for connected vehicle systems. Unfortunately, there does not appear to be any aggregate source of data relating to the development of traffic management centers by agencies or the deployment of their related field infrastructure components such as DMS.²⁴ The deployment approach and decision-making process adopted by agencies in this area was identified as a strong proxy for connected vehicle system deployments. In spite of the lack of data on the deployment of particular infrastructure components, there have been similar ITS application and system deployments. Although these prior ITS applications generally lack the safety emphasis of connected vehicle applications, the national infrastructure deployment patterns may be similar.

²⁴ It will be important for USDOT to collect and maintain information on the field deployment path of the connected vehicle environment to inform future analyses of this type.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

511 Travel Information Telephone Number

In March 1999, USDOT petitioned the FCC to designate a nationwide three-digit telephone number for traveler information. This petition was formally supported by 17 state DOTs, 32 transit operators, and 23 MPOs and local agencies. In July 2000, the FCC designated “511” as the traffic information telephone number to be made available to states and local jurisdictions across the country. The FCC ruling left nearly all implementation issues and schedules to state and local agencies and telecommunications carriers. There are no federal implementation requirements and no nationally-designated funding source for 511 implementation. Despite this, USDOT and the FCC anticipated some level of nationwide deployment.

While the flexibility provided in the FCC ruling was viewed as desirable, it also presented a challenge. To address this challenge, two principal efforts were undertaken. AASHTO, in conjunction with the American Public Transportation Association (APTA) and the Intelligent Transportation Society of America (ITS America), and with support from USDOT, established a 511 Deployment Coalition.

The goal of the 511 Deployment Coalition was “the timely establishment of a national 511 traveler information service that is sustainable and provides value to users.” The intent of the Coalition was to implement 511 nationally using a bottom-up approach facilitated by information sharing and a cooperative dialogue through the national associations. As such, this is almost identical to AASHTO’s approach to begin discussion and information sharing on connected vehicle field infrastructure deployment by state and local transportation agencies through its Connected Vehicle Deployment Coalition.

The second principal effort to encourage 511 deployment was a 511 Program Support Assistance Program established by USDOT in 2001 that provided grants of up to \$100,000 to public agencies in developing plans for implementing 511 systems. If an implementation plan had already been developed by an agency, the assistance grant could be used to convert existing traveler information telephone numbers to 511. USDOT received applications and providing grants to 46 states and the District of Columbia as shown in Table 5.

Table 5 - Applications for 511 Program Assistance Funds (Source: USDOT FHWA 2014)

State	Application Received	Grant Sent
Kentucky	09/06/00	08/07/01
Washington	04/22/01	08/07/01
Utah	08/14/01	08/22/01
Arizona	10/22/01	10/25/01
California	10/18/01	10/25/01
North Carolina	11/14/01	11/21/01
Virginia	11/28/01	12/07/01
Alaska	12/19/01	01/14/02
Florida	01/03/02	01/14/02
Illinois	12/21/01	01/14/02

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Indiana	12/21/01	01/14/02
Iowa	12/19/01	01/14/02
Maine	12/19/01	01/14/02
Minnesota	12/19/01	01/14/02
New Hampshire	12/19/01	01/14/02
New Mexico	12/19/01	01/14/02
Vermont	12/19/01	01/14/02
Wisconsin	12/21/01	01/14/02
Michigan	01/15/02	01/29/02
Nevada	03/06/02	03/11/02
Massachusetts	01/15/02	04/05/02
Rhode Island	04/05/02	04/10/02
Nebraska	01/16/02	04/22/02
Montana	04/15/02	04/29/02
Idaho	05/15/02	05/17/02
Delaware	05/22/02	06/03/02
Oregon	05/20/02	06/03/02
Connecticut	05/23/02	06/10/02
Kansas	05/29/02	06/10/02
Mississippi	05/29/02	06/10/02
Missouri	05/29/02	06/10/02
New York	05/29/02	06/10/02
North Dakota	05/30/02	06/10/02
District of Columbia	06/02/02	06/12/02
New Jersey	05/31/02	06/12/02
South Dakota	05/31/02	06/12/02
Louisiana	06/10/02	06/19/02
South Carolina	07/08/02	07/10/02
Oklahoma	07/31/02	08/09/02
Texas	08/01/02	08/15/02
Tennessee	04/15/03	04/24/03
Pennsylvania	06/11/03	06/16/03
Alabama	06/13/03	06/18/03
Ohio	06/13/03	06/18/03
Colorado	12/31/03	01/23/04
Maryland	07/16/04	07/20/04
Wyoming	05/18/05	05/24/05

The national 511 program reveals a number of factors that influenced deployment by public agencies. Among the earliest deployers were agencies that had an existing telephone-based traveler information service infrastructure (notably a group of states nested in the upper Midwest that used the #SAFE system). Subsequent deployments appear to be strongly influenced by the availability of the USDOT assistance grants—with a peak in deployments occurring during 2002 and 2003 (see Figure 2). Deployment also appears to be influenced by the peer exchange effects of participation in the Deployment Coalition and information sharing between neighboring states. Table 6 provides data on the launch dates of 511 services across the US, and Figure 3 illustrates the extent of 511 deployments as of January 2013.

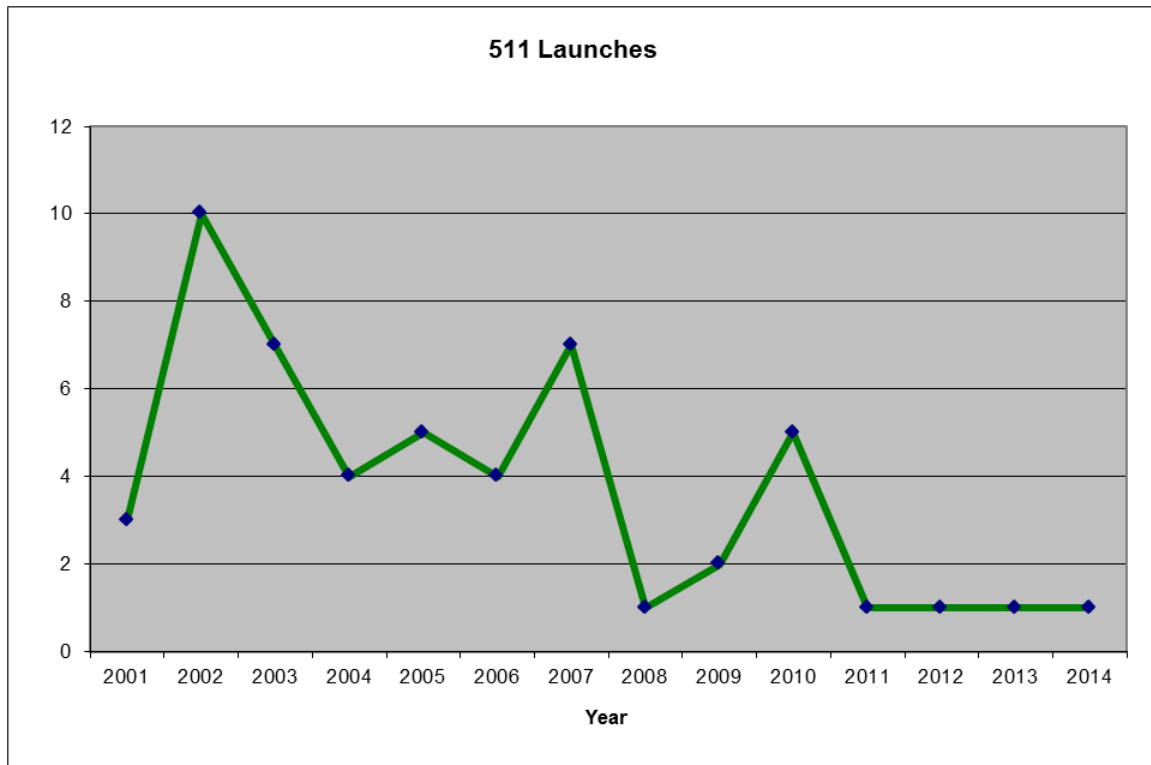


Figure 2 - Number of 511 Service Launches by Year (Source: USDOT FHWA 2014)

Table 6 - Launch Dates of 511 Services in the US (Source: USDOT FHWA 2013)

No.	Location	Launch Date	Days After Launch of Previous System
1	Cincinnati	6/11/2001	- - -
2	Nebraska	10/1/2001	112
3	Utah	12/18/2001	78
4*	I-81 Corridor	2/15/2002	59
5	Arizona	3/20/2002	33
6	Minnesota	7/1/2002	103
7	South Florida	7/16/2002	15
8	Orlando / I-4	7/16/2002	0
9	South Dakota	11/18/2002	125
10	Iowa	11/22/2002	4
11	Kentucky	11/26/2002	4
12	San Francisco	12/6/2002	10
13	Montana	12/12/2002	6
14	North Dakota	2/10/2003	60
15	Alaska	4/25/2003	74
16	Maine	5/15/2003	20
17	New Hampshire	5/15/2003	0
18	Washington	7/10/2003	56
19	Vermont	10/7/2003	89
20	Oregon	12/10/2003	64
21	Kansas	1/15/2004	36
22	North Carolina	8/25/2004	223
23	Sacramento / Northern California	9/1/2004	7
24	Tampa	9/2/2004	1
4*	Virginia (*expansion)	2/15/2005	166
25	Rhode Island	3/9/2005	22
26	Colorado	4/1/2005	23
27	Florida (statewide)	11/17/2005	230
28	Idaho	11/21/2005	4
29	Wyoming	7/1/2006	222
30	Tennessee	8/14/2006	44
31	Nevada	11/16/2006	94
32	Louisiana	12/27/2006	41
33	San Diego	2/21/2007	56
34	St. Louis	5/11/2007	79
35	Eastern Sierra, California	5/29/2007	18
36	Georgia	8/15/2007	78
37	New Jersey	8/29/2007	14
38	Boston	10/1/2007	33
39	New Mexico	12/5/2007	65
40	Wisconsin	12/18/2008	379
41	New York	2/5/2009	49

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

42	Pennsylvania	7/20/2009	165
43	Massachusetts	5/11/2010	295
44	Inland Empire, California	6/30/2010	50
45	Los Angeles / Orange County	7/4/2010	4
46	San Luis Obispo	8/20/2010	47
47	South Carolina	12/9/2010	111
48	Maryland	8/11/2011	245
49	West Virginia	12/12/2012	489
50	Honolulu	11/5/2013	328
51	Mississippi	2/18/2014	105

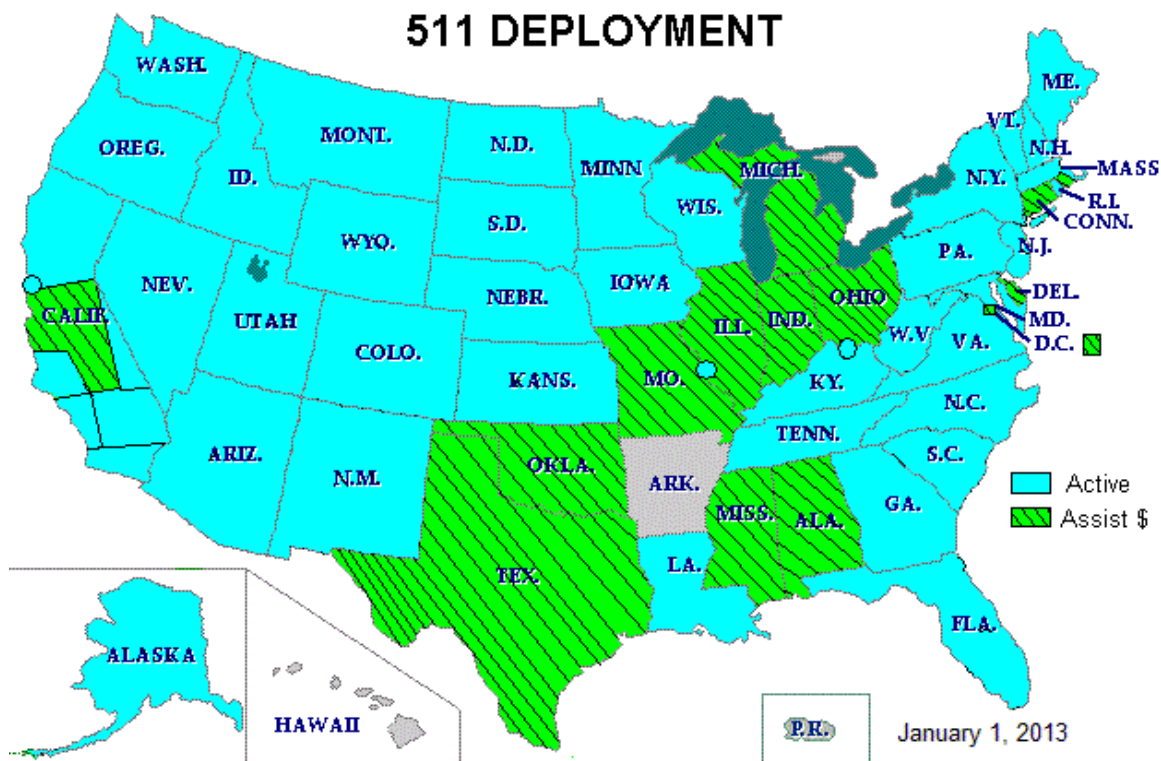


Figure 3 - Status of 511 Deployments in the US (Source: USDOT FHWA 2013)

Commercial Vehicle Electronic Pre-Clearance

A similar model can be seen in the area of commercial vehicle preclearance. Early development and deployment of the field infrastructure and systems was undertaken by state transportation agencies. A transition to a public-private partnership with contracting of subsequent equipment deployment and operations by the private sector occurred much later in the implementation timeline. In the case of electronic preclearance, two state DOTs—Arizona and Oregon—established a consortium with other states to develop a Heavy Vehicle Electronic License Plate (HELP) program beginning in 1983. The group of states was responsible for collaboratively undertaking the necessary technology and policy

research in cooperation with the motor carrier industry. Recognizing the importance of a regional pilot implementation to demonstrate the system benefits, the HELP consortium deployed a Crescent Demonstration covering six western and southwestern states along three principal interstate corridors. USDOT funding was provided to support the large-scale demonstration.

As a broad understanding of the costs and benefits of deployment emerged, a non-profit, public-private partnership, HELP, Inc. was created in 1991 through which member agencies could contract with a private sector provider of the Pre-Pass system. Many of the original HELP consortium members became early deployers and other agencies have subsequently joined Pre-Pass or other similar commercial vehicle preclearance systems, as shown in Figure 4.

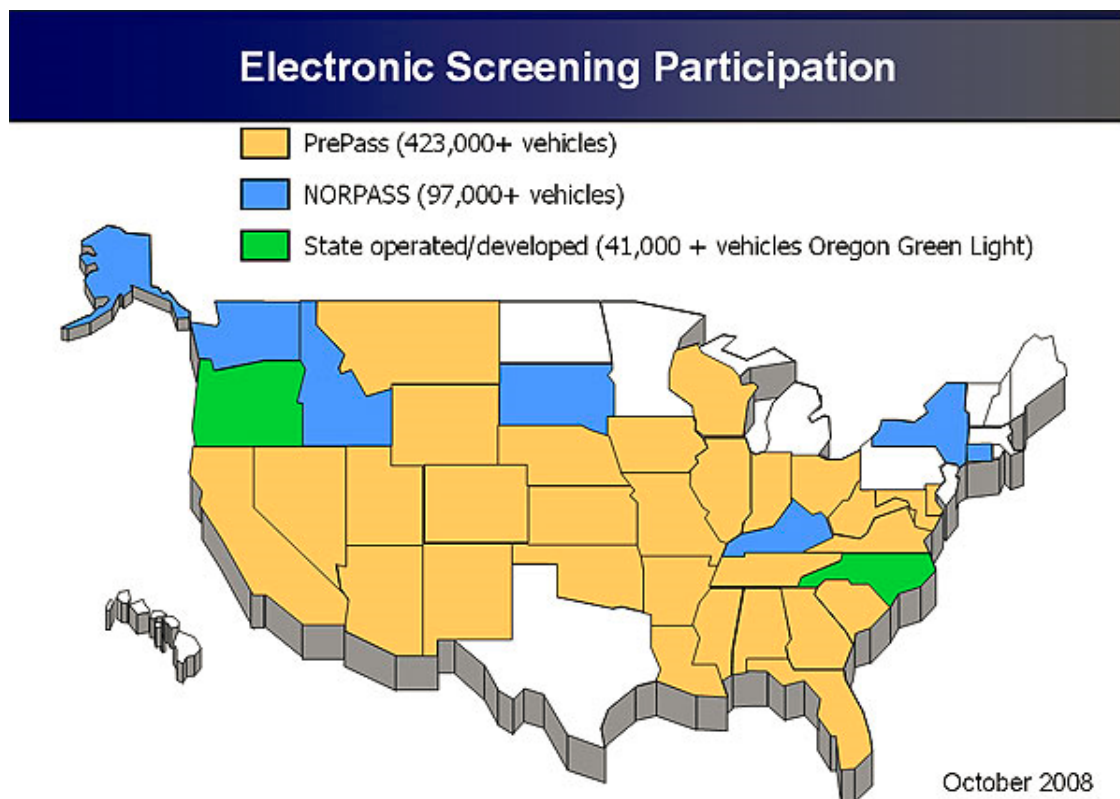


Figure 4 - Deployment of Commercial Vehicle Pre-Clearance Systems in the United States
(Source: Federal Motor Carrier Safety Administration 2008)

Electronic Toll Collection

Deployment of Electronic Toll Collection (ETC) may be viewed as distinctly different from a connected vehicle system deployment. However, the differences are not as stark as they may appear. The early transition from conventional cash collection to ETC was motivated in large part by desires to improve mobility (particularly increasing throughput and reducing bottlenecks at toll plazas), to bring efficiencies to the cash collection and processing processes by toll agencies, and to improve security surrounding the cash handling and banking components. Early analyses of ETC identified only limited opportunities for direct revenue increases as a result of system deployment, and instead required

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

justification of the deployment and operations cost in relation to the benefits that would accrue through improvements in other areas.

ETC saw its first deployments on two facilities in the late 1980s, in part through the efforts of a vendor that had been developing the core technology for other applications since the early 1980s. The potential of ETC to improve traffic flow through toll plazas and to reduce the costs of cash collection was quickly recognized in the toll industry and several other toll operators began planning for deployment. In the northeast, where there are many adjacent toll operators, an E-Z Pass Interagency Group (IAG) was established to promote the need for ETC interoperability in system deployments. The first large scale deployment by the IAG was completed in 1993, and the initial group of three IAG members has grown to eleven.

In many instances, ETC deployments subsequently grew as neighboring states adopted the technologies implemented by the early adopters, as shown in Figure 5²⁵. According to a report by USDOT, part of the spread can be attributed to location factors and suggests that state agencies learn from their neighbors or are more comfortable adopting a technology that their neighbors use. Regional travel patterns also create increasing value to both individual travelers and the operating agencies when a common technology can be used in multiple locations.

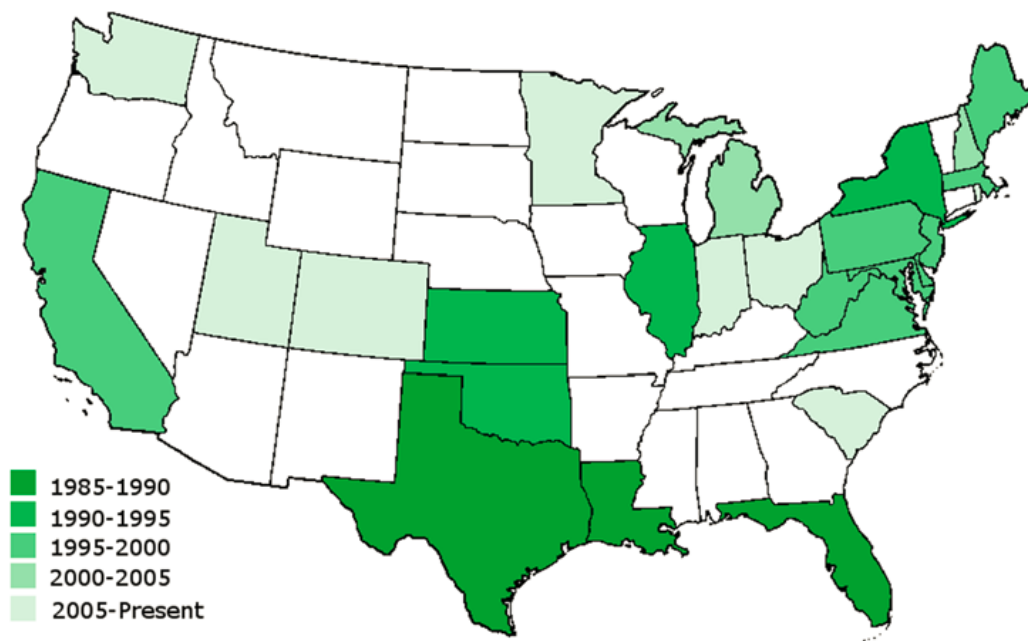


Figure 5 - Growth of ETC in the United States as of 2010 (Source: USDOT ITS JPO 2010)

²⁵ US Department of Transportation, Research and Innovative Technology Administration, "ITS Technology Adoption and Observed Market Trends from ITS Deployment Tracking," Report no. FHWA-JPO-10-066, Final Report, October 2010.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Connected Vehicle Infrastructure Deployment to Date

Deployment of connected vehicle infrastructure to date has been in test beds supporting technology and application demonstrations. These test beds can be considered prototypes of the broader deployments that would be needed to achieve operational objectives and a true national footprint. As such, a brief review of test bed experience provides reference points for larger-scale infrastructure deployments and some bases for the cost estimations described later in this report.

Each test bed represents an implementation of a set of connected vehicle technologies configured to particular test objectives and applications. Since the technologies and standards have been and are still under development, these test beds come from similar technological roots but may represent distinct evolutions of standards, component designs, and applications. Some of the test beds have already seen upgrades to their original configurations, and all are candidates for continued adaptation.

The following synopses provide an overview of the active connected vehicle test beds shown in Figure 6. The USDOT's ITS JPO maintains a *Connected Vehicles Test Beds* web site with more detailed reference materials and links.²⁶

USDOT Southeast Michigan Test Bed²⁷

Southeast Michigan contains the largest concentration of connected vehicle infrastructure in the U.S. Although developed in several distinct phases over the last ten years, these deployments are collectively referred to as the Southeast Michigan Test Bed. The various segments of the test bed were built to provide research and testing support for private developers of DSRC-enabled applications. The test bed includes 50 DSRC roadside units deployed along several arterial and freeway corridors in Oakland County. The test bed has been used in development and testing of the SCMS for the connected vehicle environment, the broadcast of traffic signal phase and timing, and to demonstrate the underlying DSRC technologies. As of this writing, the test bed is being further upgraded and extended in support of the 2014 ITS World Congress in Detroit.

New York State DOT Long Island Expressway Demonstration Test Bed

The New York Long Island Expressway (LIE) test bed was initially built to demonstrate various connected vehicle technologies and applications in support of the 2008 ITS World Congress in Manhattan. The test bed was subsequently used as the infrastructure side of the Commercial Vehicle to Infrastructure Integration (CVII) demonstration²⁸. From an infrastructure perspective, the test bed includes DSRC RSUs at 31 interstate freeway locations and at eight arterial traffic signal locations. CVII applications demonstrated on the test bed included enhanced e-screening; commercial vehicle driver identification and verification; wireless vehicle safety inspection; grade crossing driver warnings with in-vehicle signage and crossing signal activation; and V2V applications between commercial, maintenance and light vehicles. The test bed will be upgrading some RSUs in 2014.

²⁶ <http://www.its.dot.gov/testbed.htm>, accessed February 2014.

²⁷ http://www.its.dot.gov/testbed/testbed_SEmichigan.htm

²⁸ Volvo Technology for New York State Department of Transportation; *CVII Concept of Operations*; Document Number 6980-02941-01-03, December 17, 2009.

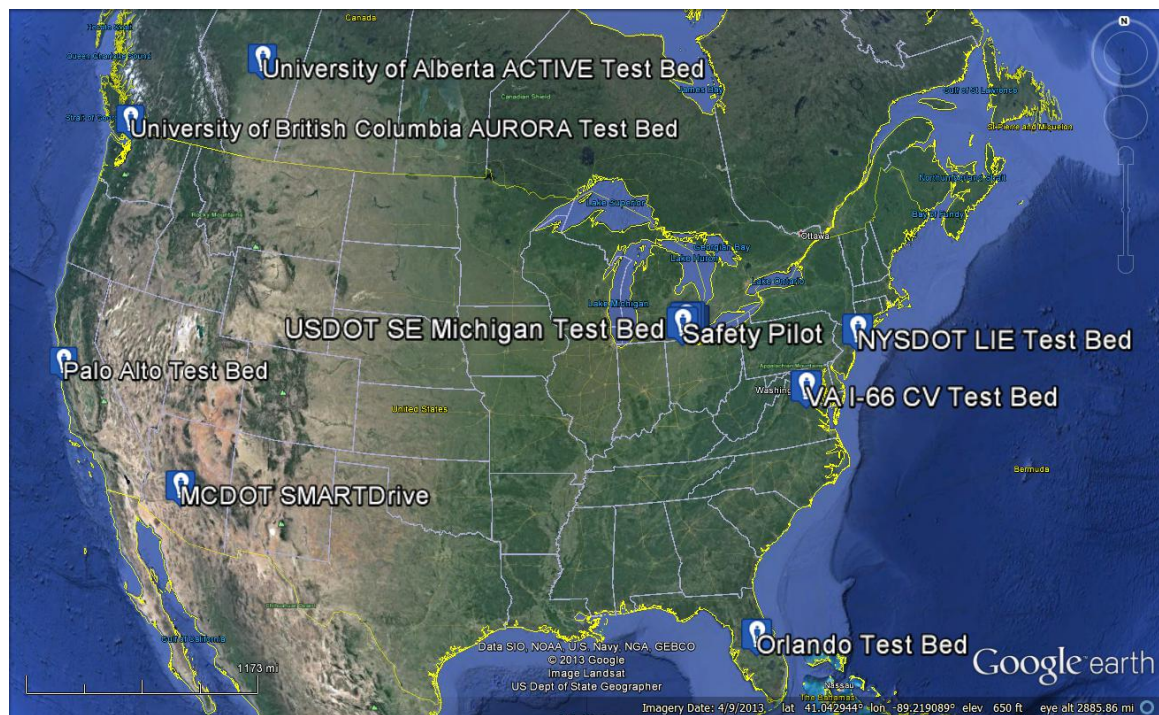


Figure 6 - 2013 Connected Vehicle Test Beds (Source: USDOT/AASHTO 2014)

Palo Alto Test Bed

The Palo Alto (California) test bed was developed by the California Department of Transportation (Caltrans) with the cooperation of several vehicle manufacturers and USDOT to assess real-world prototypes of vehicle-infrastructure integration. The test bed itself consisted of several DSRC RSUs deployed along the El Camino Real (CA-82) in Palo Alto, integrated with signal controllers and the 511 traveler information center in Oakland. The test bed has been and will be used for multiple application demonstrations including traveler information, electronic payments, CICAS, transit information, and the Multi-modal Intelligent Traffic Signal System (MMITSS).

Maricopa County SMARTDrive Test Bed

The Maricopa County SMARTDrive test bed in Anthem, Arizona was initially developed to advance multiple vehicle signal priority technologies in a real-world traffic environment. The infrastructure deployment consists of six pole-mounted DSRC RSUs integrated with traffic signal controllers along arterials with fiber communications, closed-circuit television and loop detectors. The test bed has been used for demonstration of emergency vehicle and transit signal prioritization and is being used for MMITSS application development and demonstration.²⁹

²⁹ University of Arizona; *MMITSS Final Concept of Operations*; Version 3.0; October 21, 2012.

Orlando Test Bed

The Orlando (Florida) test bed was developed by Florida DOT as a demonstration site for the 18th ITS World Congress in 2011.³⁰ The test bed infrastructure consists of 24 DSRC RSUs along freeway and arterial roadways connected to Florida DOT SunGuide servers and data management systems over their fiber network. The system was used in demonstrations of capturing Basic Safety Messages from vehicles operating on the test bed to calculate travel times.

Northern Virginia Test Bed

The Northern Virginia test bed is located in Fairfax County, Virginia, and was deployed in 2013 by the Connected Vehicle/Infrastructure University Transportation Center (CVI-UTC) (which itself includes the University of Virginia, Virginia Tech, and Morgan State University and the Virginia DOT).³¹ The test bed consists of 45 DSRC RSUs deployed along I-66 and the parallel Routes 29 and 50. The RSUs are on the Virginia DOT network and transfer data to off-site servers and the Virginia Tech Scientific Data Warehouse. The test bed is anticipated to be used for a wide variety of safety, mobility, and environmental applications on both freeways and arterial roadways.

Safety Pilot

The Safety Pilot Model Deployment³² in Ann Arbor, Michigan, represents the largest operational demonstration to date in the U.S. of connected vehicle capabilities. The test bed infrastructure includes 29 DSRC RSUs deployed along 73 lane-miles of freeway and arterial roadways, twelve of which are integrated with traffic signal controllers to provide signal phase and timing data to passing connected vehicles. The infrastructure was used in 2012-13 to gather data from approximately 2800 vehicles equipped with a variety of types of on-board equipment. Both V2V and V2I safety applications were demonstrated during Safety Pilot operations.

ACTIVE-AURORA Test Bed Network

In Canada there are two major projects underway to build and operate a network of five connected vehicle systems test beds called the ACTIVE-AURORA project.³³

University of Alberta ACTIVE Test Bed. The Alberta Cooperative Transportation Infrastructure & Vehicular Environment (ACTIVE) project consists of two on-road test beds (arterial and freeway) and one laboratory test bed located in Edmonton, Alberta that will be owned and operated by the University of Alberta. The ACTIVE test beds will provide stakeholders with real-world environments for testing with an emphasis on data for active traffic and demand management, as well as providing real-time traffic density, flow and congestion data to support provincial/municipal traffic management.

University of British Columbia AURORA Test Bed. The University of British Columbia (UBC) Automotive Test Bed for Reconfigurable and Optimized Radio Access (AURORA) project consists of

³⁰ http://www.dot.state.fl.us/trafficoperations/its/projects_deploy/cv/connected_vehicles-wc.shtml, accessed February 2014.

³¹ <http://www.cvi-utc.org/?q=node/36>, accessed February 2014.

³² <http://www.safetypilot.us/>, accessed February 2014.

³³ University of Alberta, The Centre for Smart Transportation; *The ACTIVE-AURORA Test Bed Network*; accessed Feb. 2014 at http://www.transportation.ualberta.ca/News%20and%20Events/2013/December/~media/transportation/PDFs/CV_Overview12-04-13.pdf

one on-road test bed (around the UBC campus) and one laboratory test bed in Vancouver, British Columbia that will be owned and operated by the UBC. AURORA will provide stakeholder access to the next-generation of state-of-the-art connected vehicle systems, and wired and wireless communications technologies and resources to test and evaluate new and innovative products and services with an emphasis on commercialization and evaluation of technologies for wireless freight security and efficiency

National Deployment Patterns

As described earlier, connected vehicle test beds have been built in several states through the cooperation of federal, state and local agencies and vehicle and equipment manufacturers. Those test beds have in many cases become magnet sites for follow-on deployment of next generation technology and demonstration of new capabilities and applications. They can also serve as anchors for expanded geographical deployments. In Maricopa County, Arizona, for example, the original Anthem test bed will be expanded to provide connected vehicle capabilities across much of Maricopa County.

This distribution and growth of individual deployment sites is paralleled by increasing interest in connected vehicle deployments among state and local agencies and academia across the U.S. and Canada. This interest is being expressed at executive and working levels within the agencies and in several working groups.

Within AASHTO, the Connected Vehicle Deployment Coalition includes representatives from many U.S. state DOTs (Washington, Idaho, California, Utah, Arizona, Colorado, Texas, Minnesota, Wisconsin, Michigan, Rhode Island, New York, Pennsylvania, Virginia, and Florida), Transport Canada, and several counties (Maricopa, Arizona; Oakland, Michigan; Palm Beach, Florida). This group has been the core working group within AASHTO for advancement and sharing of connected vehicle deployment experience and planning. As shown in Figure 7, these agencies also encompass all of the existing test beds.

Many of these agencies are also members of the Cooperative Transportation Systems (CTS) Pooled Fund Study (PFS), which was established in 2009 “to provide a means to conduct the work necessary for infrastructure providers to play a leading role in advancing the Cooperative Transportation Systems.”³⁴ Eleven state DOTs (California, Florida, Michigan, New Jersey, New York, Pennsylvania, Texas, Washington, Virginia, and Wisconsin) and one county (Maricopa, Arizona), with the support of the FHWA and the University of Virginia Center for Transportation Studies, are pursuing research into the application and deployment of connected vehicle technologies.

³⁴ http://cts.virginia.edu/CTSPFS_1.html; accessed 2014.02.04

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

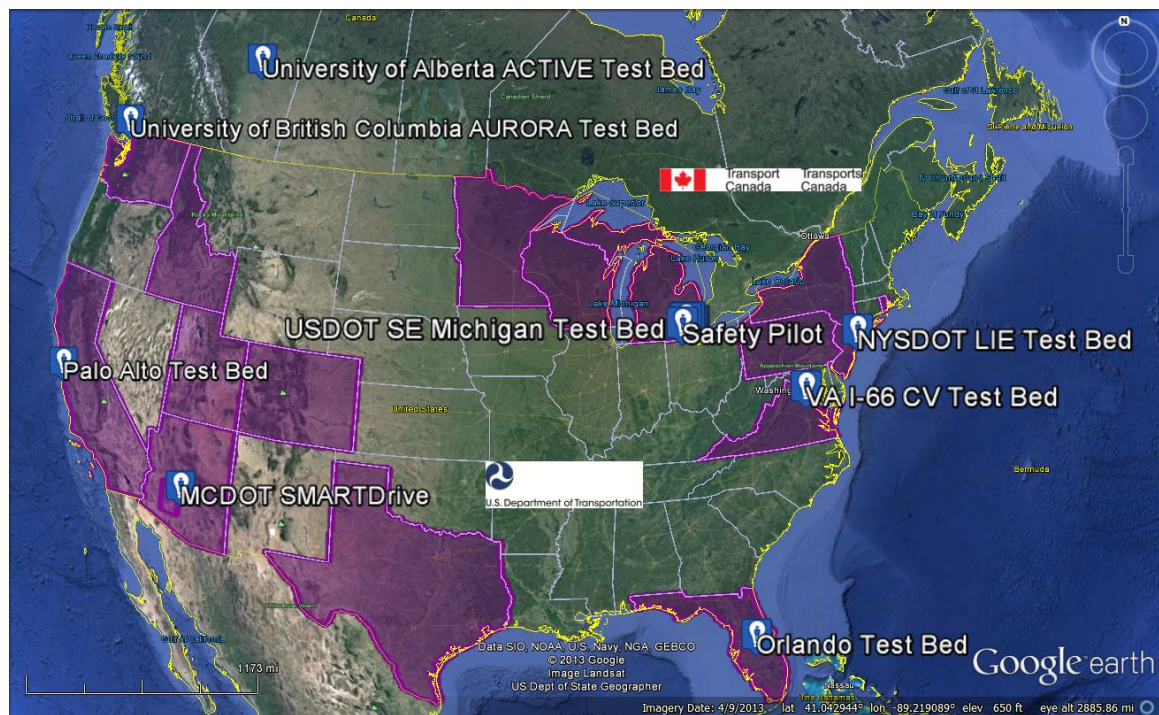


Figure 7 - Connected Vehicle Agencies and Test Beds (Source: USDOT/Transport Canada/AASHTO 2014)

These state and local agencies, working with each other, USDOT and Transport Canada, vehicle and device manufacturers, and information service providers, are likely to be among the first operational deployers of connected vehicle infrastructure and applications.

Agencies not already invested in particular operational objectives and applications would leverage the test bed experience of their partner agencies in their own parallel test bed deployments. The need for additional test beds will diminish as the technologies and applications mature; agencies waiting for the technology to mature before starting to plan could move directly to operational deployments. This pattern would closely resemble the roll-out of ITS and 511 technologies as they moved from the lead states into a national deployment.

As described in the *Deployment Scenarios*, this process of technology seeding and system growth could expand quickly once anchor deployments appear along interurban corridors of significance. This phase of the national deployment is likely to be driven by cooperation on traveler information and on freight systems. As shown in Figure 8, the distribution of test beds and agencies active in connected vehicle deployment research already favor several national corridors. All of these corridors figure prominently in the draft Primary Freight Network³⁵ and some already have formal operating coalitions and associations—the I-95 Corridor Coalition, for example. The involvement of the freight corridors would also facilitate incorporation of connected vehicle capabilities into border crossings (shown in the figure in brown text) as terminations of the transnational corridors.

³⁵ <http://www.ops.fhwa.dot.gov/freight/infrastructure/pfn/index.htm>

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

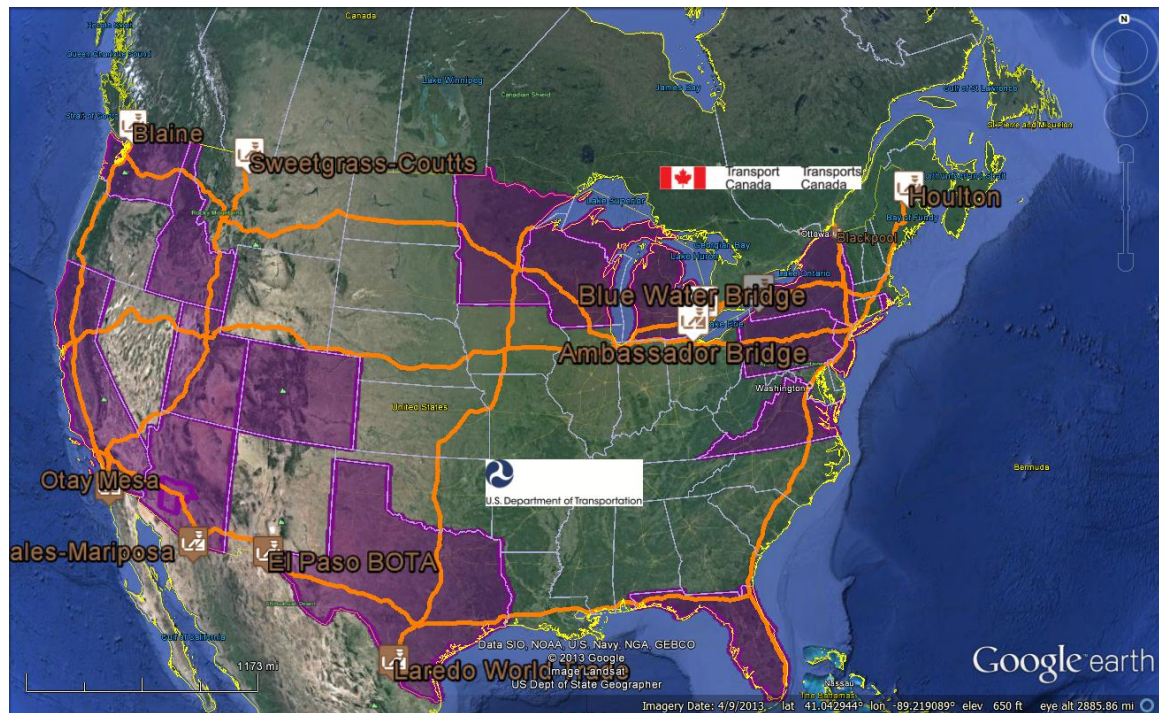


Figure 8 - Potential Corridors for Deployment Expansion (Source: USDOT/AASHTO 2014)

Potential Infrastructure Deployment Sites

As described in prior sections, the growth of ITS infrastructure over the last 25 years provides a precedent and *pattern* for an eventual national distribution of connected vehicle infrastructure. This section attempts to provide an estimate of the *number* of deployment sites within the footprint, primarily as a basis for estimating the cost of a national deployment. Deriving such an estimate at such an early phase in the technology life cycle is, of course, subject to substantial assumption and judgment. In this particular estimation, certain questions could substantially affect the final numbers: what applications will be deployed? At what levels of deployment? Using what application designs and technologies?

A first pass at the applications to be deployed was described in the earlier *Analysis of Potential Connected Vehicle Applications* section, and in particular in Table 1. In that analysis, the field infrastructure needs of the applications are seen to fall into three categories.

- Applications needing real-time V2I data exchange at intersections. These applications focus on the interaction between vehicles and the traffic signal state to reduce the likelihood of vehicles violating the intersection. They require low latency and range to be effective, and are therefore presumed to require DSRC (or other wireless local area communications).
- Applications benefiting from near real-time V2I data exchange at the roadside (other than at intersections). These applications focus on providing dynamic data—advisories and warnings—about nearby roadway conditions and may be similar to ITS application already deployed at the roadside. They require low latency to be effective, although the data provided might be applied outside the immediate range of the roadside communications unit. DSRC

- would fulfill the operational requirements, although longer latencies might be acceptable in some situations.

 - Applications for which immediacy of V2I communications is relaxed. These applications focus on gathering and providing information that is more regional—general traffic and road conditions or routing information, for example. Latency is less of an issue than the continuity of communications. Cellular (wireless wide area) communications are preferred for these applications.

It is implicitly assumed here that both DSRC and cellular V2I communications will be available. From a field infrastructure perspective, a first estimate of the number of deployment sites will then depend on the number of intersections and other roadside locations needing DSRC. Applications using cellular communications between vehicles and infrastructure would use commercial cellular networks.

Signalized Intersections

V2I research and application development to date leans heavily toward deployment at signalized intersections because of the potential benefits to safety, mobility, and environmental impacts. The earlier discussion of the *Vision for a National Footprint* suggested that 80% of traffic signal locations would be V2I-enabled in 2040. This is arguably a large percentage and it should be clear that this would be a gradual deployment over the intervening 25 years. The experience gained over that time would be used to more accurately determine at what level and at what type of signal locations the anticipated benefits would warrant the costs of deployment. For purposes of estimating the footprint, however, it is important to have an order of magnitude estimate of the potential infrastructure commitment.

Improving safety is a primary objective, and estimates of the potential for safety improvement with V2I systems could provide insight. The 2010 NHTSA report on *Frequency of Target Crashes for IntelliDrive Safety Systems* asserts that V2I systems as the primary countermeasure would “potentially address about 25% of all crashes involving all vehicle types,” including crashes at intersections.³⁶ The report does not specifically address the fraction of crashes occurring at intersections. A 2010 NHTSA report on *Crash Factors in Intersection-Related Crashes* determined that 36% of crashes in the U.S. in 2008 were intersection-related, and 52.5% of vehicles involved in those crashes were traveling on signal-controlled roadways.³⁷ A 2009 Noblis document, *Footprint Analysis for IntelliDriveSM V2V Applications, Intersection Safety Applications, and Tolled Facilities*, found in a study of intersections and collision frequency in three large metro areas that 20% of intersections account for 50% of collisions, and that 50% of intersections account for 80% of collisions.³⁸ An earlier 2005 study, *Intersection Crash Summary Statistics for Wisconsin*, found in a state-wide study that crashes at signal-controlled intersections represented 68.8% of crashes at controlled intersections, although only 48.5% of intersections studied were signalized. Crashes at intersections with greater than 25,000

³⁶ National Highway Transportation Safety Administration; *Frequency of Target Crashes for IntelliDrive Safety Systems* Report Number DOT HS 811 381; October 2010.

³⁷ National Highway Transportation Safety Administration; *Crash Factors in Intersection-Related Crashes: An On-Scene Perspective*; Report Number DOT HS 811 366; September 2010.

³⁸ Noblis, Inc.; *Footprint Analysis for IntelliDriveSM V2V Applications, Intersection Safety Applications, and Tolled Facilities*; prepared for the USDOT / RITA / ITS JPO; March 2009; Accessed February 2014 at http://www.its.dot.gov/research_docs/pdf/12Footprint.pdf.

vehicles per day entering the intersection represented 48.3% of crashes at controlled intersections, although those represented only 28.1% of controlled intersections.³⁹

Although none of these studies directly address warrants for V2I-enabling signalized intersections, it can be inferred that there are likely safety benefits, that deployment at signalized intersections would address a greater fraction of potential crashes than at non-signalized intersections, and that deployment at high-volume intersections would address the greatest likelihood of crashes. Any consideration for mobility and environmental benefits would further increase deployment incentives and would likely reinforce the safety warrants.

The 2012 *National Traffic Signal Report Card*⁴⁰ cites 311,000 signalized intersections across the country, a nominal increase over the 307,000 cited in the previous *AASHTO Connected Vehicle Infrastructure Deployment Analysis*. Based on that population, Table 7 below depicts the number of potential deployment sites and objectives for increasing levels of deployment.

Table 7 - Signalized Intersection Deployment Objectives (Source: USDOT/AASHTO 2014)

Deployment Fraction	Objective	Number of Deployment Sites
20%	Deploy only at highest-volume intersections, potentially affect 50% of intersection crashes	62,200
50%	Deploy at half of all intersections with greatest benefits; potentially affect 80% of intersection crashes	155,500
80%	Deploy at all intersections where warranted	248,800

ITS Field Infrastructure (Non-Intersection) Sites

Many of the connected vehicle applications, especially those focused on delivery of advisories and warnings, are similar to ITS applications already deployed at the roadside: curve-speed warnings, work zone speed limit advisories, or road-weather advisories, for example. Applications of this type share a need for low-latency delivery of information about roadside conditions in the immediate vicinity that may change quickly due to operations or weather. Because of the similarity to existing ITS applications, an analysis of existing ITS deployments can potentially serve as a proxy for estimating the number of non-signalized locations that should be considered for deployment of DSRC (or other wireless local area communications) roadside units. In addition, these sites already have power, RSU radio antenna mounting options (poles) and generally some form of backhaul communications. Table 8 below summarizes findings of the USDOT 2010 *Deployment Tracking Survey*⁴¹ of existing ITS equipment, as well as the number of weigh stations reported by NORPASS and PrePass.

³⁹ Traffic Operations and Safety Laboratory, University of Wisconsin-Madison; *Intersection Crash Summary Statistics for Wisconsin*; June 2005.

⁴⁰ National Transportation Operations Coalition; *2012 National Traffic Signal Report Card – Technical Report*; accessed at <http://www.ite.org/reportcard/TechnicalReport.pdf> in February 2014.

⁴¹ *Deployment of ITS: A Summary of the 2010 National Survey Results*; Publication Number FHWA-JPO-11-132; August 2011.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Table 8 - Number of Additional Deployment Locations (Source: USDOT/AASHTO 2014)

Data Collection Equipment	Reported Number of Deployments
Loop Stations	12,465
Radar Stations	7,184
Video Image Detection Stations	2,261
Toll Tag Readers (for data collection)	707
Dynamic Message Signs	4,038
Ramp Meters	933
CCTV Cameras for Freeway Monitoring	10,481
Toll Plazas	845
Toll Collection Lanes with ETC	4,669
NORPASS Weigh Station Locations (US)	41 ⁴²
PrePass	310 ⁴³
Environmental Sensor Stations (ESS)	2151 ⁴⁴
Total	48,026

The surveys from which unsignalized/ITS-equipped locations data in Table 8 was obtained counted the number of deployed elements rather than the number of sites. Many freeway ITS deployments are co-located, meaning that, for example, a CCTV camera and detector station share the same pole, cabinet and backhaul connection. Additionally, many sites are in close proximity to one another, such as a CCTV placed to verify the message on a DMS display. Of the deployments shown in Table 8, the loop, radar and video image detection locations are less likely to be used for or replaced one-for-one with connected vehicle infrastructure deployment since connected vehicle detection will be provided by the vehicles themselves. Images provided by CCTV cameras complement connected vehicle capabilities and applications. The remaining elements correspond to particular connected vehicle applications and could represent potential sites. Taken together, the number of ITS elements corresponding to connected vehicle applications and a reduction for potential co-locations suggests roughly 25,000 sites for non-intersection connected vehicle infrastructure deployment locations.

Total Infrastructure Deployment Sites

Taken together, the signalized intersection and ITS application deployment sites represent a reasonable estimate of the total number of locations (Table 9) at which connected vehicle field infrastructure might be deployed. As noted earlier, deployment would be paced out over the next twenty to twenty-five years as appropriately equipped vehicles are entering the fleet as well. The final population and distribution of field infrastructure would be determined by the deployment experience itself. A less aggressive deployment of infrastructure at signalized locations—starting with high-volume

⁴² NORPASS Website. Weigh Station Locations page, accessible at: <http://www.norpass.net/Coverage/WeighStations.aspx>

⁴³ PrePass Website. Service Map page, accessible at:

<http://www.prepass.com/services/prepass/SiteInformation/Documents/sitemap.pdf>

⁴⁴ Based on the number of ESS owned by transportation agencies reporting to the *Clarus* System as of January, 2014

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

intersections and proceeding to those with the most significant warrants—could reduce the total number of anticipated sites.

Table 9 - Total Number of Connected Vehicle Deployment Locations (Source: USDOT/AASHTO 2014)

Level of Deployment	20% Signalized + Unsignalized/ITS-Equipped Sites	50% Signalized + Unsignalized/ITS-Equipped Sites	80% Signalized + Unsignalized/ITS-Equipped Sites
Signalized Locations	62,200	155,500	248,800
Unsignalized/ITS-Equipped Locations	25,000	25,000	25,000
Total	87,200	180,500	273,800

Infrastructure Deployment Milestones and Timelines

As has been noted, the connected vehicle environment will develop over time as agencies deploy infrastructure and applications within their jurisdictions according to the warrants of each situation. This deployment strategy and its deployment pattern will likely resemble that of previous ITS and 511 deployments. The purpose of this section is to postulate reasonable timelines for activities leading and contributing to deployment throughout the nation.

Deployment Milestones

Setting a context for discussion of deployment activities and timelines is best accomplished by describing both the near-term milestones in connected vehicle programs that serve as launching points and by revisiting the vision described earlier in this report. Figure 9 captures these framing milestones for the infrastructure as they relate to vehicles, policy and regulation.

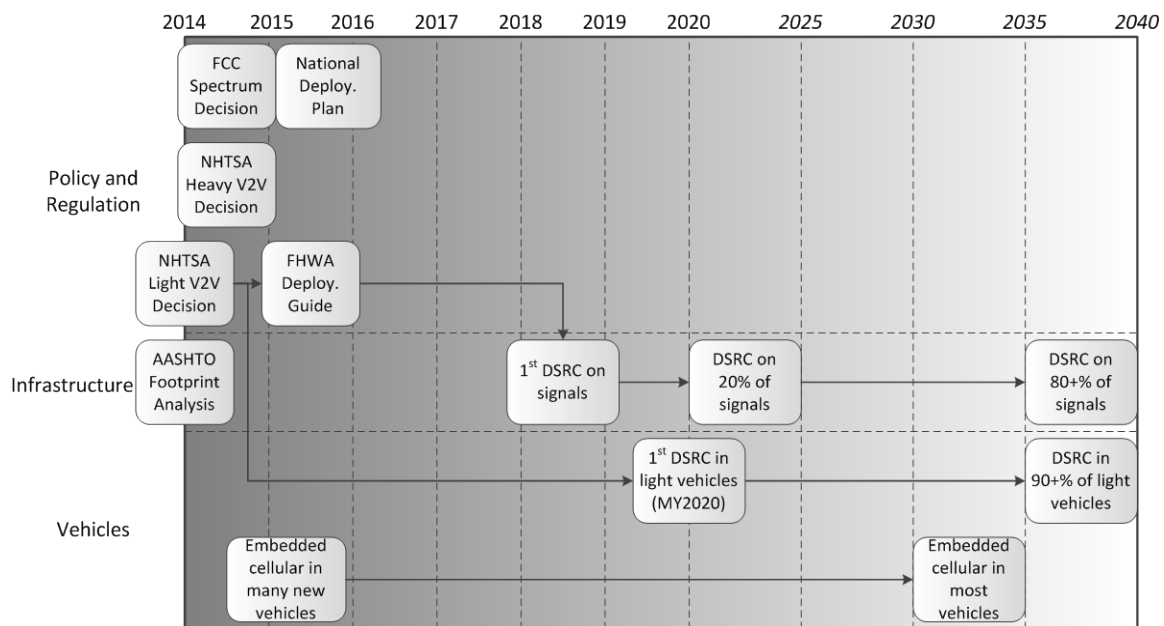


Figure 9 – Estimated Connected Vehicle Infrastructure Deployment Milestones (Source: USDOT/AASHTO 2014)

NHTSA has been preparing for some time for a decision on potentially requiring V2V communications on new light vehicles. A NHTSA press release dated February 3, 2014⁴⁵, stated that NHTSA would “begin taking steps to enable vehicle-to-vehicle communication technology for light vehicles.” The release went on to say that “NHTSA is currently finalizing its analysis of the data gathered as part of its year-long pilot program and will publish a research report on V2V communication technology for public comment in the coming weeks.” At the time of this report, the details of any potential rulemaking on V2V are still to be developed, but the decision to continue development of V2V capabilities signals that parallel development of V2I capabilities—infrastructure and applications—will be matched on the vehicle side.

NHTSA has similarly stated that it will be announcing a decision on V2V capabilities for heavy vehicles sometime later in 2014. Although it is reasonable to assume that light and heavy vehicles would use common V2V communications standards, the costs and benefits of deployment on heavy vehicles are presumably different than those on light vehicles. Heavy vehicles also have different on-board information systems than do light vehicles, and have different vehicle development life cycles. These factors may result in connected vehicle application deployment timelines for trucks, commercial freight, and transit applications that differ from the light vehicle timelines.

Further research and development of V2V communications will depend in large part on the continued availability and support for wireless spectrum allocated to that purpose. To that end, the FCC in 1999 allocated 75 MHz of spectrum for DSRC in the 5.9 GHz band to be used for the purpose of protecting the safety of the traveling public and published service rules for DSRC in 2003. DSRC research and development in the U.S. over the last decade has been predicated on that purpose and spectrum

⁴⁵ Accessed February 3, 2014, at <http://www.nhtsa.gov/About+NHTSA/Press+Releases/2014/USDOT+to+Move+Forward+with+Vehicle-to-Vehicle+Communication+Technology+for+Light+Vehicles>

allocation. The demand for spectrum for other public purposes has grown tremendously, however, and the FCC has come under increasing pressure to make more of the spectrum available. An FCC Notice of Proposed Rulemaking released in February 2013 requested public comment on the potential for the sharing of unlicensed bands in the 5 GHz band, including portions originally allocated for DSRC.⁴⁶ Numerous responses were received, but an FCC decision has not yet been made.

FHWA's development of V2I Deployment Guidance, to be initially issued in 2015, will be a significant next step in facilitating development and deployment of V2I infrastructure. The guidance will be based on USDOT research and on this AASHTO footprint analysis of deployment concepts and scenarios. Unlike the NHTSA V2V decisions described earlier, this will be strictly guidance rather than regulation. Its intent will be to describe what and how to implement infrastructure and supporting systems, in the form of guidelines, documentation of best practices, and toolkits. The guidance will be focused on Federal-aid eligibility, use of right-of-way and infrastructure, innovative financing, procurement processes, and interoperability. Over time the Guidance will be expanded to include toolkits, document best practices, and provide benefit and cost information to assist with conducting benefit-cost analysis and determining return on investment.

As a follow on to the V2I Deployment Guidance, AASHTO recommends that the development of a deployment strategy for the connected vehicle environment should be conducted through a National Deployment Plan. The Plan would provide a bridge from the technical guidance provided in the Deployment Guidance to programmatic planning by the deploying agencies. This activity should be led by USDOT and would identify specific deployment actions and timing by agencies, within a coordinated nationwide framework agreed upon by USDOT, AASHTO and the vehicle manufacturers.

Vehicle technologies continue to advance in parallel with policy and regulatory milestones. With respect to V2I communications, it is especially significant that embedded cellular connectivity appears to be increasing just as the NHTSA decision is poised to move on DSRC for V2V safety. Many auto manufacturers have announced over the last year that they intend to deploy cellular units in some or all of their new vehicles starting in the 2015 model year. This cellular connectivity will presumably be used to both provide on-board information and services—infotainment—for the driver and passengers, and to provide telematics services mutually benefitting the vehicle owner and manufacturer. Some manufacturers are creating application development environments for third-party applications to take advantage of this connectivity. From a transportation agency's connected vehicle perspective, cellular connectivity embedded in a vehicle provides an alternative to DSRC for providing traveler information and potentially for gathering vehicle probe data.

Although details of the NHTSA light vehicle decision have not yet been released, it appears likely that some level of DSRC deployment will be required as a means of enabling the potential V2V safety benefits. The timing for any potential DSRC mandate has not been announced, but it has been suggested that automakers could need up to seven years from that decision to get DSRC-equipped vehicles to market. As such, it appears that vehicles with embedded DSRC could begin to be deployed by about 2020.

As has been previously mentioned, deployment needs to be widespread and timely for V2V applications to be effective. This was previously described in the *AASHTO Connected Vehicle Infrastructure Deployment Analysis* and has been a subject of much discussion since then. Figure 10

⁴⁶ Accessed in February 2014 at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-13-22A1.pdf.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

illustrates the fraction of connected vehicles within the vehicle fleet with an average 13-year replacement cycle based on three different scenarios. In the least aggressive case, labeled “15 Year Organic,” equipped vehicles would come into the fleet based on organic sales (from manufacturer marketing and cultural acceptance) of the new capability. The “5 Year Mandate” case illustrates a deployment wherein manufacturers would phase in the connected equipment in new vehicles over a five-year period. The “1 Year Mandate” case presumes 100% of new vehicles after a given model year were all equipped. As the figure shows, even in the best case “1 Year Mandate” it would take 20 years for 90% or more of the vehicle fleet to be equipped. This model can be applied equally to both DSRC and embedded cellular deployments. As such, the Figure 9 timelines show a best-case 20-year deployment period between first use of the technology and saturation within the fleet for both embedded cellular and for DSRC.

Deployment of the infrastructure components will also take time. New technology for roadside equipment and ITS is subject to the same development and market adoption models as any other technology. Without external forces to accelerate change, connected vehicle infrastructure deployment would grow organically over time to a saturation level determined by the warrants for its deployment. As described earlier, that level is presumed in this analysis to be at about 80% of signalized intersections. Based on current rates of intersection and signal system upgrades, reaching that level will take twenty to twenty-five years.

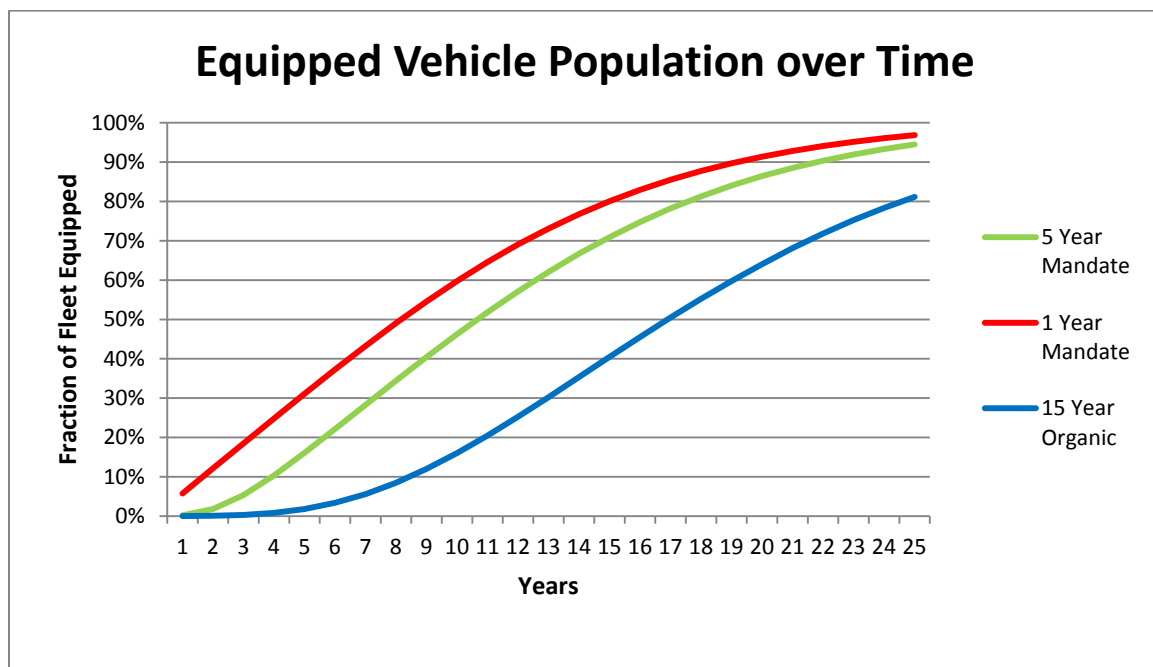


Figure 10 - Equipped Vehicle Population over Time (Source: USDOT/AASHTO 2014)

Timelines

The deployment milestones provide the starting point and general timeframe for the connected vehicle infrastructure deployment in terms of current activities and projections for growth of connected vehicle capabilities in vehicles and infrastructure. The next task is to describe the path and timelines by which individual agencies might move from the current state into actual deployment.

The deployment process will generally fit the same model as any other transportation technology deployment. As described later in this document in the *Operational and Organizational Impacts* section, the process by which transportation infrastructure projects are programmed, funded, designed and developed is a multi-year process with multiple stakeholders. Once the need has been identified, the deployment timeline will play out in planning, piloting, evaluating, deploying, and expanding the connected vehicle infrastructure.

- **Plan.** The planning process in transportation agencies is continuous but cyclical. Agencies vary as to the precise number and duration of planning cycles; most will have a Long-Range Plan looking twenty to thirty years ahead and a Transportation Improvement Plan (TIP) that identifies specific projects and funding for the next four years (or so).
- **Pilot.** Pilot projects provide an opportunity to deploy and evaluate new technologies before making a commitment to broader system-wide deployments. These projects could take many forms—as research or small-scale operational implementations, temporary or able to transition to regular operations. Pilot projects for connected vehicle applications will be desirable for early-adopter agencies.
- **Evaluate.** An evaluation phase assesses the outcomes of application research, development, and pilot implementation relative to the original deployment objectives in preparation for a deployment decision. It may be based on an agency's own pilot project or on the results of research projects and deployments by other agencies. It may also not be a distinct phase, but rather a series of ongoing assessments that begin even before projects begin to be identified as part of the planning.
- **Deploy.** The deployment phase itself consists of the series of project activities that build out the infrastructure to support the applications and objectives. These projects are likely to follow an agency's established project development procedures and will look very much like other ITS projects.
- **Expand.** The first connected vehicle infrastructure deployments are likely to represent only the highest-value sites. The longer main phase of deployment will expand from those initial sites to state and nationwide deployments.

As shown in Figure 11, these phases are present for all of the deployment objectives, but on different timelines.

Safety applications have been the ongoing subject of significant research and pilot demonstrations, and the USDOT V2I safety program is using a systems engineering process to identify potential high-value V2I safety applications for further development and testing. The NHTSA decision to proceed with V2V deployments then effectively provides a “green light” for planning for eventual deployment. An agency wanting to deploy connected vehicle infrastructure for safety applications would be justified in beginning to plan for projects in 2014, monitoring the progress of the USDOT programs and applications pilots, and starting their evaluation process. It would not be unreasonable to plan for deployment of selected safety applications—for example, intersection violation or curve speed warnings—as soon as 2017. Planning through the remainder of the decade could see deployment on a significant fraction of an agency's intersections by 2025, with increasing deployments as warranted toward eventual full deployment.

Mobility applications are potentially less dependent on agency-deployed infrastructure than are the safety applications. Most of the mobility applications do not require low communications latencies and

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

could be developed around either DSRC infrastructure or cellular services. They are also in many cases similar to or enhancements of existing ITS applications and may be able to leverage existing ITS—TMCs and 511 systems, for example—to bootstrap their development and deployment. USDOT is currently facilitating the design and development of many of the mobility applications and packages identified in the *Applications Analysis*. As such, it would be appropriate for agencies interested in mobility applications to begin to plan for pilots and downstream deployments. Deployment and expansion may be somewhat faster than the safety applications since mobility applications are somewhat less dependent on infrastructure deployment and vehicle fleet penetration. System-wide active traffic management might be achieved, however, only when integration with traffic signals reaches full deployment.

Freight mobility applications in this context include both the traveler information applications included described above and the freight-specific Smart Roadside applications. While these applications could all conceivably use cellular communications, it seems likely at this point that agency infrastructure deployment for freight applications will wait until a NHTSA decision on V2V for heavy vehicles has been announced. If this is the case, planning for these applications will likely lag that of the more general mobility applications. Once announced, however, it is likely that planning, pilots, evaluation and deployment will proceed on a pace similar to that of the mobility applications. Full deployment of freight applications may actually take less time since freight operations frequently cross jurisdictions and tend to drive compatibility of applications across state lines.

Border crossings are inherently complex operations with multiple stakeholder agencies at national, state, and local levels. It is likely that applications developed for freight (and general) mobility would provide the first potential applications at border crossings and by implication might then provide infrastructure around which other border crossing applications might develop. Although there appears to be significant potential for improving border crossing operations, operational concepts still need to be formally developed before any planning would be appropriate. Deployment of connected vehicle applications at border crossings would involve longer planning times and pilots than any of the other scenarios.

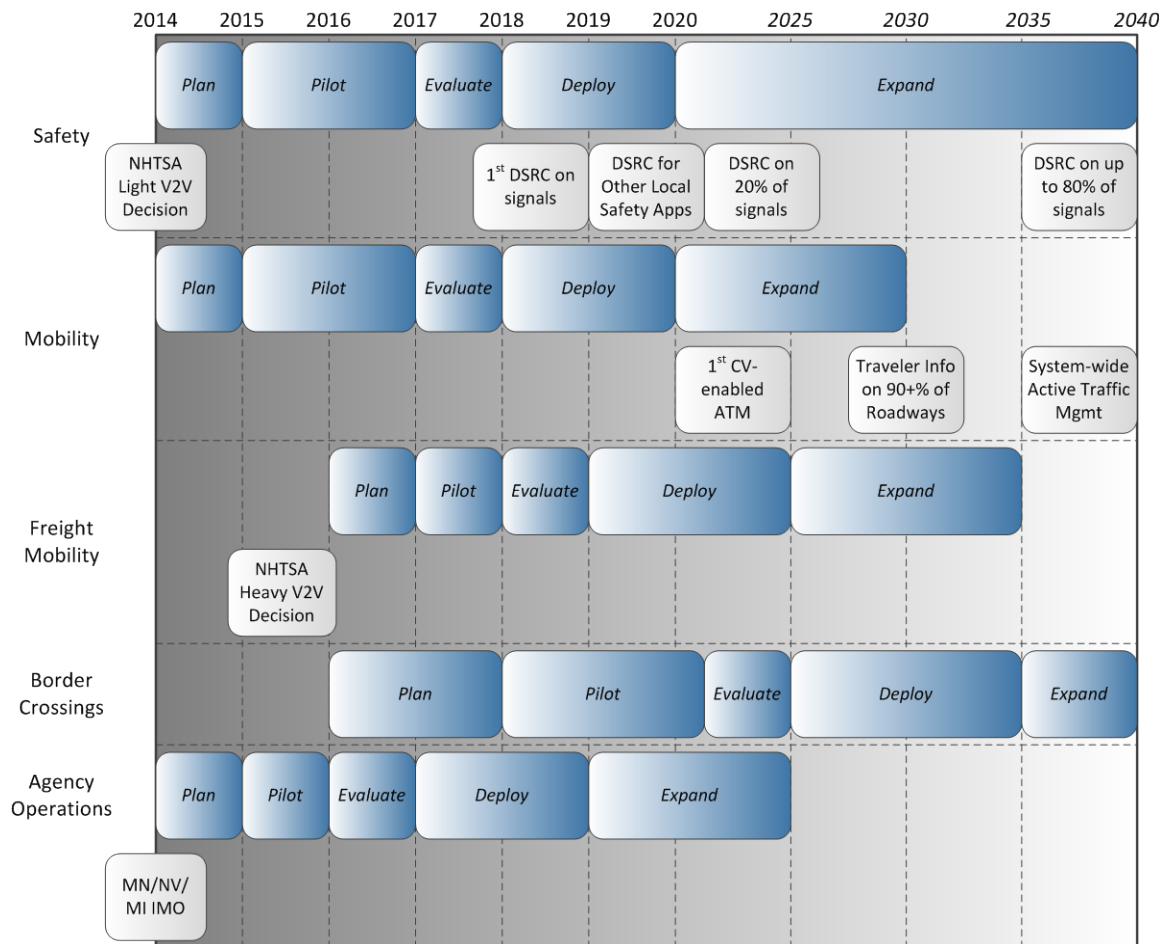


Figure 11 - Deployment Timelines (Source: USDOT/AASHTO 2014)

Improving agency operations may have the shortest timelines of the major application areas being described here. As shown in Figure 11, several agencies are already deploying connected vehicle applications for agency operations. FHWA, through the Road Weather Management Program, has been working with the state DOTs in Minnesota, Nevada, and Michigan to deploy applications for Integrating Mobile Observations (IMO) in support of weather operations. These projects have used cellular and 900 MHz radio networks to communicate between maintenance vehicles gathering road weather condition observations and back office systems that aggregate the weather data and in some instances provide operational guidance to the vehicles. In Minnesota's case, the system has been operationalized and is deployed on hundreds of snow plows and light duty trucks. Applications such as Motorist Advisories and Warnings and the Enhanced Maintenance Decision Support System can then leverage the data collected from these connected agency vehicles. These types of applications are driven by agency internal operations and do not go through the formal roadway projects planning process; they can be justified within the agency by demonstrating a net reduction in the cost of operations. With successful examples already being deployed and a potentially less complicated funding process, it is likely that many such applications could be deployed on a shorter timeline than with the other scenarios.

Preliminary Infrastructure Deployment and Operations Cost Estimation

The purpose of this section is to provide an estimate of deployment, operation and maintenance costs required to implement an effective national connected vehicle field infrastructure footprint. The analysis aggregates cost estimates from vendor quotes and previous implementations and extrapolates those figures to a national scale, with adjustments to accommodate for region-specific characteristics and site-specific priorities for applications. Estimated costs are provided for individual components—such as roadside units, communications backhaul, and signal controller upgrades—of the field infrastructure needed to support a national deployment. Cost estimates included are accompanied by an explanation of relevant assumptions and contingencies.

It is also important here to reiterate the anticipated benefits of connected vehicle infrastructure deployment before detailing the estimated costs. Losing sight of the opportunities in programs of this magnitude can make the challenges seem larger; keeping both the benefits and costs in view provides a balanced perspective. As was described in the *Deployment Scenarios*, deployment of connected vehicle capabilities has the potential to significantly benefit users and operators of the surface transportation system.

- 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 are described in some detail in a 2012 FHWA report on *Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications*.⁴⁷ 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” in a national connected vehicle application deployment.

⁴⁷ USDOT Research and Innovative Technology Administration; *Crash Data Analysis for Vehicle-to-Infrastructure Communications for Safety Applications*; Publication Number FHWA-HRT-11-040; November 2012.

And benefits of deployment are not isolated to transportation system users. The NCHRP 03-101 study on *Costs and Benefits of Public Sector Connected Vehicle Deployment*⁴⁸ assessed benefits to the deploying agency. Potential benefit categories in the analysis included items such as crash response and cleanup cost reduction, work zone accident reduction, lower cost of pavement condition detection, adaptive lighting, and deduction of infrastructure required to monitor traffic. The report concluded that a significant portion of the costs of deployment can be directly offset by operational savings to the transportation agency itself and that these cost savings would likely increase over time with increasing levels of deployment.

Deployment Costs

DSRC Field Infrastructure Deployment Costs

As described earlier in this document, there have been only limited deployments of connected vehicle infrastructure to date. As a result, there are very few data points for the deployment costs. Through the development of the NCHRP 13-101 cost-benefit analysis for connected vehicles, those agencies and organizations that have been responsible for the deployment, operations and maintenance of infrastructure-based systems were surveyed to identify costs associated with deployment. This section provides background information on each of the deployment sites that responded to qualify the cost variation across deployments, both regionally and temporally. A typical deployment cost based on 2013 data will be developed from these costs. This analysis does not account for equipment cost reductions that may result from larger production volumes in the future.

Fifty (50) sites were deployed in Novi for the US DOT Southeast Michigan Connected Vehicle Test Bed, which used early versions of the DSRC equipment. The US DOT Southeast Michigan Connected Vehicle Test Bed is currently going through a technology refresh for the roadside equipment, and the unit cost per device is significantly lower today than during the initial deployment. Over the past 24 months, DSRC hardware costs have stabilized, but costs may continue to come down as the market grows to support manufacturing devices at a greater rate and as the technology and specifications stabilize.

The Northern Virginia Test Bed has deployed fifty-five (55) DSRC RSUs to cover approximately four square miles of an urban region that includes a mix of commercial and residential land uses, schools, pedestrian trails, fire stations, and covers I-66, US-29 (Lee Highway), US-50 (Arlington Blvd), Gallows Road and I-495.

The cost information for Arizona was generated from a deployment plan developed for a region-wide installation in Maricopa County, Arizona. This data was included in a cost-benefit analysis conducted by Arizona State University to estimate the incremental infrastructure costs and requirements for a region-wide network of connected vehicle technology, based on the existing deployment of six (6) RSUs at equipped intersections. The Maricopa County deployment would cover a much larger region, encompassing both county-managed roadways as well as right-of-way from more than twenty (20) different municipalities, townships, and cities within the County, which is one of the most populous regions in the nation.

⁴⁸ 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.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

The Intelligent Intersection at TFHRC in McLean, Virginia, is currently being equipped with new infrastructure to support the deployment of DSRC equipment. The cost data available from this deployment was collected and maintained specifically for use in future deployments and is more detailed than what was available from the other sites. The reported cost for labor and installation is significantly higher (\$25,365) than the other deployment sites because the Intelligent Intersection deployment was designed to be more flexible and robust than other research deployments, to be used for testing and future expansion. Because the scale of this deployment exceeds the amount of equipment and network connectivity than is necessary to support general operations and applications, only \$2,500 of the total installation cost is considered in this analysis.

Table 10 and Table 11 provide information about the deployment size and relevant cost elements, including both hardware and installation labor.

Table 10 - Average Equipment Costs per DSRC Site (Source: USDOT/AASHTO 2014)

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Number of Sites	50	2680	55	1	-
DSRC RSU*	<u>\$3,750</u>	\$1,000	<u>\$3,500</u>	<u>\$3,500</u>	\$3,000
RSU Incidentals*	<u>\$1,000</u>	\$1,000	No data	<u>\$1,100</u>	\$1,030
Communication Connection Equipment*	<u>\$1,300</u>	\$1,300	<u>\$1,300</u>	<u>\$600</u>	\$1,125
Power Connection Equipment*	<u>\$300</u>	\$300	<u>\$300</u>	<u>\$400</u>	\$325
Additional Installation Equipment*	<u>\$3,500</u>	\$600	<u>\$3,300</u>	<u>\$600</u>	\$2,000
Total Cost for Hardware	\$9,850	\$4,200	\$8,400	\$6,100	\$7,450

* Costs reported by deployed sites are underlined.

Table 11 - Average Installation Costs per DSRC Site (Source: USDOT/AASHTO 2014)

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Total Cost for Installation Labor*	<u>\$2,500</u>	\$2,400	<u>\$2,500</u>	\$2,500	\$2,475
Construction Inspection (15% of Hardware Cost)	\$1,500	\$600	\$1,200	\$1,000	\$1,075
Total Installation Cost	\$4,000	\$3,000	\$3,700	\$3,500	\$3,550

* Costs reported by deployed sites are underlined.

Other estimated costs specifically associated with the deployment of DSRC RSUs include all necessary activities associated with planning, design, and installation. The hardware and installation costs assume that the RSU deployment takes place at a location that is already equipped with power supplies and a pole or other suitable mounting location. Other costs, including planning, design,

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

construction inspection and others are based on estimates for the design and implementation of a typical ITS deployment. Table 12 describes additional cost elements associated with RSU deployment.

Table 12 - Planning and Design Costs per DSRC Site (Source: USDOT/AASHTO 2014)

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Radio Survey per site	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Map / GID Generation	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Planning	\$700	\$400	\$600	\$500	\$550
Design	\$2,100	\$1,100	\$1,800	\$1,400	\$1,600
System Integration & License	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
Traffic Control	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Total Implementation Cost	\$7,300	\$6,000	\$6,900	\$6,400	\$6,650

The additional cost elements described in Table 12 are:

- Radio Survey – \$1,000/site – The radio survey is the cost of identifying radio interference and determining the optimal location for the DSRC radio (or multiple radios) and antenna at a specific location to maximize coverage.
- Map/GID generation – \$1000/site – This effort includes the cost for highly accurate mapping of the intersection. This can be done either through as-built plans, accurate satellite (or other overhead) images or a survey crew.
- Planning – 5% of implementation (hardware and installation labor) cost – This effort includes the costs of developing a general regional plan for deploying a connected vehicle environment throughout an entire region. This includes the analysis of where to deploy DSRC radios in a region based on traffic and safety analysis.
- Design – 20% of implementation cost – Design includes all of the design costs associated with deploying the DSRC infrastructure at a specific location.
- Construction inspection – 15% of implementation cost. – Construction Inspection includes the cost of overseeing construction, reviewing contractor submittals for radios and other hardware to be deployed. This cost also includes testing at the site to ensure full functionality.
- System Integration and License - \$1500/site – This effort includes the costs associated with licenses for the radios (cost to do paperwork as there is not anticipated to be a license cost), the cost to set the radios up within the overall system (IP addresses, etc.) and the costs to add a site to a central system (this does not include the cost to implement the overall central system, just to update the database).
- Traffic Control - \$1000/site – The cost for basic traffic control during deployment of a DSRC radio unit. This could include signage specific to a region for advance warning of road construction or the traffic control necessary in the event the traffic signal needs to be turned off during installation of the DSRC radio equipment.

Table 13 summarizes the total costs listed in previous tables for DSRC hardware, installation labor, and site design and planning efforts that are necessary for an operational deployment. Ranging from \$13,000 to \$21,000, the average cost per site for deployment of all connected vehicle infrastructure is estimated to be \$17,600.

Table 13 - Average Total Direct Costs per DSRC Site (Source: USDOT/AASHTO 2014)

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Connected Vehicle DSRC Hardware	\$9,850	\$4,200	\$8,400	\$6,100	\$7,450
Installation Labor	\$4,000	\$3,000	\$3,800	\$3,400	\$3,550
Design and Planning	\$7,300	\$5,900	\$6,900	\$6,400	\$6,600
Total Direct Connected Vehicle Costs	\$21,150	\$13,100	\$19,100	\$15,900	\$17,600

Backhaul Deployment Costs

This section outlines the estimated costs for establishing connectivity to back end servers and TMCs. Installing new backhaul connectivity or upgrading existing equipment requires additional planning, design and deployment efforts that are specific to the deployment jurisdiction and are separate from the deployment of the RSU and supporting local site infrastructure. These costs nonetheless need to be considered as part of a national deployment since potential connected vehicle applications may require backhaul communications to achieve their full benefit to safety and mobility.

The individual cost estimates listed in Table 14 were derived from the deployment costs observed at test bed sites and are based on a number of assumptions as outlined below. The total cost estimate of deploying sufficient backhaul connectivity to support a national deployment will be heavily dependent on the type of backhaul systems currently used by the local jurisdiction deploying the RSU. Costs for backhaul vary based on the number of sites that have existing infrastructure that can support connected vehicle applications (and the required bandwidth) versus those that will require an upgrade or new equipment, as well as a number of sites that will use leased lines for backhaul. This aspect of the deployment cost will be addressed in the next section.

Table 14 - Costs Associated with Backhaul Installation (Source: USDOT/AASHTO 2014)

Deployment Site	Michigan	Arizona	Virginia	TFHRC	Average
Reported Backhaul Cost*	<u>\$31,100</u>	\$1,700	<u>\$2,000</u>	<u>\$18,900</u>	\$13,400
Planning	\$4,700	\$300	\$300	\$2,800	\$2,000
Design	\$6,200	\$300	\$400	\$3,800	\$2,700
Construction Inspection	\$4,700	\$300	\$300	\$2,800	\$2,100
System Integration & License	\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
Traffic Control	\$0	\$0	\$0	\$0	\$0

Total Backhaul Cost	\$48,200	\$4,100	\$4,500	\$29,800	\$21,700
----------------------------	-----------------	----------------	----------------	-----------------	-----------------

* Costs reported by deployed sites are underlined.

Qualifying assumptions include:

- Planning – 15% of implementation cost – The costs of the development of a communications plan (or modification of an existing plan) to determine how the connected vehicle backhaul will be implemented. This cost also includes the development of an Internet Protocol addressing plan and an overall network plan.
- Design – 20% of implementation cost – Design includes all of the design costs associated with deploying the new backhaul infrastructure at a specific location.
- Construction inspection – 15% of reported backhaul cost – Construction Inspection includes the cost of overseeing construction, reviewing contractor submittals for radios and other hardware to be deployed. This cost also includes testing at the site to ensure full functionality.
- System Integration and License - \$1500/site – This effort includes the costs associated with licenses for any backhaul radios and any other integration of a new or upgraded backhaul into an existing system. This does not include hardware, rather the cost to change settings in databases, network monitoring software, firewalls, switches, routers, etc.
- Traffic Control - \$0/site, if done in conjunction with DSRC installation

Backhaul connectivity will be implemented differently across the nation and consequently the estimated backhaul costs per site are subject to more variability. For example, some sites require minimal backhaul investment where current capacity is sufficient, such as the Anthem, Arizona, and Northern Virginia deployments. At these sites, the costs are limited to design and integration with existing backhaul infrastructure with minimal additional costs for hardware. Where existing capacity is insufficient to handle the anticipated bandwidth requirements for connected vehicle communications, other sites will require new or upgraded backhaul infrastructure. The costs for these sites are dependent upon the specific architecture and design of the local agency and can range from low capital cost options with ongoing operational expenses (as in the case of leased lines) which will increase ongoing operational costs as a result of subscription contracts and fees, to dedicated wireless communications, to higher cost options, such as the deployment of new fiber optic communications, as discussed in the *Deployment Concepts* appendix. For the purposes of the overall 20-year cost, the initial cost for backhaul per site, including planning, design, hardware and labor, will range from approximately \$3,000 per site to over \$40,000 per site based on the data points used for this cost analysis. For the purpose of generating total national cost, the following assumptions are being made:

- Existing Traffic Signal Backhaul⁴⁹
 - 10% of all traffic signals have a high bandwidth backhaul connection and do not require significant upgrades, but will require integration of existing equipment.
 - 20% of all traffic signals have an existing backhaul connection that requires an “easy⁵⁰” upgrade.

⁴⁹ This distribution is purely an estimate based on feedback received from the AASHTO Connected Vehicle Working Group Members and the Institute of Transportation Engineers (ITE) Connected Vehicle Task Force; at present, there is no identified research or data to serve as a more formal basis for these numbers.

- 30% of all traffic signals have an existing backhaul connection that requires either a “hard”⁵¹ upgrade or a completely new backhaul system.
- 40% of all traffic signals have either no existing backhaul or will require a completely new backhaul system
- Freeway Sites
 - 75% of all freeway sites have a high bandwidth backhaul connection and do not require significant upgrades
 - 25% of all freeway sites do not have a high bandwidth backhaul connection and will require a significant upgrade or a completely new backhaul system.
- Backhaul Cost Estimates
 - For those sites with sufficient backhaul capacity, it is estimated that planning, integration of existing equipment, etc. will cost \$3,000 per site
 - For those sites with an existing backhaul connection that require an easy upgrade, the upgrade is estimated to cost \$22,000 per site
 - For those sites requiring a completely new backhaul deployment or a hard upgrade, it is estimated to cost \$40,000 per site to provide sufficient backhaul for connected vehicle applications.

Table 15 - Estimated Backhaul Upgrade Costs (Source: USDOT/AASHTO 2014)

Backhaul Upgrade Categories	Estimated Cost Per Site
Integration of Existing Equipment	\$3,000
“Easy” Upgrade of Existing Equipment	\$22,000
“Hard” Upgrade of Existing Equipment	\$40,000
Installation of New Backhaul	\$40,000

These costs do not include the cost of upgrading some or all networking components to support Internet Protocol version 6 (IPv6) functionality needed for DSRC. Rather, it is assumed that most of the affected network switches, firewall, and routers support IPv6 functionality, and that existing tunneling solutions will be used where IPv6 networks are separated by Internet Protocol version 4 (IPv4) connections.

Table 16 below illustrates the distribution of costs across both signalized and freeway deployment locations for different types of backhaul upgrades.

⁵⁰ An “easy” upgrade assumes that the majority of the backhaul system is in place but an upgrade to support the higher bandwidth is necessary. An example would include upgrading a wireless system that already has all of the power, antenna mountings, cabinets, etc. to a more robust system.

⁵¹ A “hard” upgrade would include replacing a 900MHz or spread spectrum radio system or an old twisted pair or coaxial cable backhaul system that cannot be upgraded to support higher bandwidth. In essence, a “hard” backhaul upgrade is the cost equivalent of deploying a completely new backhaul.

Table 16 - Estimated Total Cost of Backhaul Upgrade (Source: USDOT/AASHTO 2014)

	Type of Location/Backhaul	Number of Sites	Cost Per Site
Signalized Locations	Integration of Existing Equipment (10%)	24,880	\$3,000
	"Easy" Upgrade (20%)	49,760	\$22,000
	"Hard" Upgrade (30%)	74,640	\$40,000
	Installation of New Backhaul (40%)	99,520	\$40,000
Freeway Locations	Integration of Existing Equipment (75%)	18,750	\$3,000
	"Hard" Upgrade or Installation of New Equipment (25%)	6,250	\$40,000

Signal Controller Replacement Estimates

Many of the potential benefits of connected vehicle infrastructure deployment at signalized intersections are only achievable with corresponding interface modifications to the signal controllers. Over the assumed twenty-year connected vehicle infrastructure deployment cycle, many of the controller upgrades will be accounted for through routine maintenance and replacement of those devices, especially as controller manufacturers standardize DSRC interfaces into their controllers. As such, the cost of replacing controllers is estimated in this report as an adjunct cost for infrastructure upgrades needed to derive the maximum safety and mobility benefits from DSRC deployment.

Estimates of the number of signal controllers that might need to be replaced or upgraded were compiled for the *AASHTO Connected Vehicle Infrastructure Deployment Analysis*^{52,53} published in June 2011. Table 17 below, copied from that document, provides an estimate as of that time of the number of controllers that need to be replaced nationally and the cost for the hardware to replace those controllers.

For the purposes of providing a national estimate, based on data in Table 17 from the 2011 report, 199,000 (of 311,000) controllers need to be upgraded to support connected vehicle activities, or approximately 2/3 of all of the controllers in the United States. To provide a conservative estimate, the hardware cost to upgrade these controllers is anticipated to be \$2,200 per site. Assuming that no additional work is required at each controller location, an additional cost is required for cables and labor to install and program each controller. It is estimated that that cost will be approximately \$1,000 per site, for a total controller replacement cost of \$3,200 per site.

⁵² *AASHTO Connected Vehicle Infrastructure Deployment Analysis*; Publication Number FHWA-JPO-11-090; June 17, 2011.

⁵³ Note that these costs do NOT include labor or cabinet upgrade costs.

Table 17 - Estimated Number of Controller Replacements (Source: USDOT/AASHTO 2011)

Controller Type	Number to be Replaced
ATC 5.2b	0
Model 2070L	0
NEMA Modern: Standard OS (33%) Non-Standard OS (67%)	0
NEMA Legacy (Shelf)	91,000
Type 170 Modern	0
Type 170 Legacy (Rack)	102,000
Electromechanical Controllers	6,000
Total Number of Controllers	199,000

Table 18 - Total Cost Estimate to Upgrade Signal Controllers (Source: USDOT/AASHTO 2014)

Cost Element (per Site)	Cost
New Controller Equipment	\$2,200
Labor to Install/Program Controller	\$1,000
Total Cost Per Controller	\$3,200
Number of Controllers	199,000

The original AASHTO report also did not address costs for upgrades to an intersection outside of the specific costs of the traffic signal controller. The costs for modernizing a traffic signal controller can include a variety of additional costs, including upgrading the cabinet and cabinet foundation and other electronics within the cabinet, detection, conduit, traffic signal poles and heads and, in some instances, pedestrian ramps to ensure that the intersection complies with requirements of the Americans with Disabilities Act (ADA). Those costs are not part of the upgrade to a DSRC environment. Those costs should rather be considered part of the cost of regular operations, maintenance and upgrade of a traffic signal or traffic signal system.

Total DSRC Site Deployment Costs

Total potential costs associated with deploying connected vehicle infrastructure at a field site with DSRC are summarized below in Table 19. Component costs at a particular site may include the costs directly associated with the deployment of DSRC equipment, the cost of upgrading backhaul equipment at each deployment site, and traffic signal controllers at signalized locations.

Table 19 - Total Potential DSRC Site Costs of Connected Vehicle Infrastructure Deployment
 (Source: USDOT/AASHTO 2014)

Element	Cost (2013\$) at Signalized Intersection with Controller Upgrade	Cost (2013\$) at Signalized Intersection without Controller Upgrade	Cost (2013\$) at Other (Non-signalized) Location
(DSRC) Equipment and Site Deployment	\$17,600	\$17,600	\$17,600
Backhaul Upgrades and Deployment (Weighted Average)	\$30,800	\$30,800	\$30,800
Traffic Signal Controller Upgrades	\$3,200	-	-
Total Potential Site/Unit Cost	\$51,600	\$48,400	\$48,400

Additional Costs

DSRC Site Operation and Maintenance Costs

Previous sections have documented the cost of procurement and installation of connected vehicle infrastructure. As with traditional traffic operations equipment, however, this infrastructure will require regular maintenance and incur ongoing operational costs. This section outlines the estimated costs for operation and maintenance of the hardware and backend systems to ensure that the deployment remains functional over time.

Field Infrastructure Operations Costs

The costs associated with operation of this equipment include standard considerations for power and communication (in the case of leased lines), as well as the additional cost to existing Operations Centers for additional hardware and personnel to monitor system performance.

Power consumption of the communication and data processing equipment at the intersection is not expected to require new or upgraded infrastructure, but will draw more energy per site than traditional traffic controller equipment. A DSRC radio is expected to have power consumption similar to a typical home Wi-Fi router (10 Watts (W) per hour). Additional equipment required for operating a DSRC unit at a local intersection is not expected to draw more power than a typical computer workstation (100 W per hour). At an average price of \$0.10 per kilowatt-hour (average price in North America) and operating for 24 hours per day, seven days per week, the anticipated annual power cost per site is \$97⁵⁴.

⁵⁴ Data from www.energyusecalculator.com; 24 hours of energy use per day, 110 Watts of Power used per hour at a price of \$0.10 per kWh.

The ongoing costs associated with maintenance of backhaul networks deployed for ITS should also be noted. The cost of this maintenance, as discussed in the NCHRP 03-101 report, will vary between two and five percent of the original hardware and labor costs, but are not included in this report because these costs will be incurred independent of any national connected vehicle field infrastructure deployment.

Field Infrastructure Maintenance Costs

Regular maintenance costs are expected to be comparable to those required for maintaining similar existing equipment such as traffic signals and the signal controller. As identified in the NCHRP 03-101 report, the annual maintenance costs are anticipated to be between 2 to 5 percent of the hardware and installation costs per year. Routine maintenance includes such items as realigning the antennas, rebooting hardware, checking the system to confirm operation status and other typical checks. This maintenance is likely done by visiting each site two to four times per year. The assumed hardware and installation costs per device are \$10,677, so the annual cost for maintenance, assuming a 5 percent per year per device cost, is approximately \$533. (Note: The reader may notice that the total maintenance cost is the same as the average deployment cost; this is not an error, but based on the estimated 5 percent (.05) of the total cost being aggregated over 20 years.)

As with most technologies, there will also likely be an annual license or maintenance fee for the device for support from the manufacturer. This fee is intended to cover the costs of developing and distributing firmware updates that improve functionality and security of the device (similar to service patches and updates with commercial computer operating systems). The annual maintenance fees for these devices currently vary significantly by manufacturer and range from a fixed cost per test bed site to an annual cost that is set per device. For planning purposes, an estimate of \$200 per device per year is being used.

Finally, assuming that the SCMS will be a privately operated program, all agencies should plan on recurring costs to keep the security credentials on the system up to date⁵⁵. Because the business models for the SCMS are evolving at this point, an estimate of \$50 per year per device is assumed.

Field Infrastructure Replacement Costs

As with traditional traffic operations equipment, the connected vehicle infrastructure will need to be replaced as it reaches the end of its lifecycle. Because these are new technologies, their anticipated life span is unproven. DSRC radios share similar components to home Wi-Fi routers which can last anywhere from one year to ten or more years before needing replacement, although not subject to an outdoor environment. Cisco routers and switches, based on industry experience, have an expected lifespan of seven to eight years. Traffic signal controllers, if undisturbed (not physically damaged within the cabinet or by a power surge), often remain operational for ten to twenty years or longer.

For the estimated lifecycle and replacement cost, it is assumed based on stakeholder input that the hardware deployed for connected vehicles will have a life-span of ten years. The operational lifespan of the RSUs is not, however, solely a function of the hardware. It is expected that the RSU software

⁵⁵ This is not intended to be a philosophical discussion about the merits of who should pay for the credentials. There will be a cost to develop, operate and maintain the SCMS and RSUs will be a subscriber to the SCMS in terms of certificate use. As such, a cost for the maintenance of the security certificates on the RSUs needs to be assumed to develop a more accurate estimate of the annual operating costs.

will be updated on a regular basis to assure that the devices have the latest security and application updates. It is also likely that the operational software lifetime, even with regular updates, is less than that of the hardware—potentially as low as five years.

The cost to replace the DSRC RSUs, assuming a direct replacement of the complete hardware/software unit, should be limited to the unit itself and original installation costs. Other deployment costs for design, inspection, and so forth would not be incurred for a direct replacement. Therefore, the anticipated costs for replacement are \$10,677 per site every five to ten years.

Table 20 - Estimated Annual DSRC Site Operations, Maintenance and Replacement Costs
(Source: USDOT/AASHTO 2014)

Cost Element	Per Device Cost per Year
Power	\$100
Traditional Maintenance	\$500
License/Maintenance Agreements	\$200
SCMS Certificate License	\$50
Annualized Replacement Cost (every five to ten years)	\$1100 - \$2200
Total	\$1950 - \$3050

Backend System O&M Cost Estimates

The final components of a connected vehicle system that might be used by state and local agencies for data collection for operations and planning activities are the backend systems. These components collect, store and process the raw data from vehicles and roadside systems and convert that data into information that is distributed back to the vehicle, through an in-vehicle system over the DSRC network, through mobile devices over the cellular network, or to traditional traveler information systems such as 511, dynamic message signs and state and local agency web sites. As is more fully discussed in the next section on *Third-Party Traffic Data*, some commercial services are already available to provide data gathering services and sell the value-added data to interested agencies. Those services do not, however, provide the processing needed to convert the traffic data into actionable operations and controls. The development of connected vehicle applications for operations is still a work in progress and the complete application designs are not yet detailed enough to support a full cost analysis. The following sections, however, document the cost elements of the software, personnel and infrastructure components of potential back office systems supporting connected vehicle applications.

Software Components

The software components have five primary objectives:

- **Validate Data.** As data enters the system, the first objective is to ensure that the data is coming from a valid or trusted source. Data needs to be checked to ensure that it is correctly

signed and, if applicable, encrypted⁵⁶. Once it has gone through this initial validation, secondary data validity checks can take place, such as ensuring that the data is coming from an appropriate location or contains the desired data points.

- **Route Data.** Once data is deemed to be valid, the software needs to route the data to the appropriate processes and recipients. For example, some data elements may be sent to traffic management subsystems that determine traditional traffic information, such as link speed, delay, and travel times. Other data may be sent to an electric vehicle subsystem for locating and reserving electric vehicle charging stations. Other data packets may include payment information for toll facilities or parking management and reservations. Because of the projected potential volume of data, appropriate routing of data will minimize the load on the systems if they are only required to process relevant data.
- **Process Data.** Once applications are developed to utilize connected vehicle data and data is routed to the appropriate application, these applications will process the data packets as necessary, whether they are financial data for parking or basic traffic data that needs to be converted into information.
- **Distribute Information.** Once the data is converted into information, the information needs to be distributed to the proper users, whether through the media, traditional ATIS devices or directly to the automobile through the DSRC or cellular network. That distribution can happen through a warehouse-like function or another system or method. Additionally, for transaction-based systems (e.g., parking), the distribution function includes transaction confirmation.
- **Store Data or Information.** Whether referring to the raw data or the processed information, the data storage function moves the data or information into a persistent storage for future analysis, processing, research or use in real-time applications to supplement the real-time data. The data storage function, with data rates (speed and volume) anticipated in the connected vehicle program, will likely require many “big data” concepts and tools.

Each of these components is necessary for a functional connected vehicle back end software solution. At this point, none of these components have been developed. Additionally, the development of each of these components will need to go through a formal systems engineering process to define the required functionality. Once the functionality is defined for each component, a cost estimate can be developed for the software.

In the past, there have been discussions and efforts by consortiums of states to pool resources to go through some, if not all, of the software design and development efforts. While there is customization likely required for each implementation, this may be a role the Connected Transportation Systems Pooled Fund Study (CTS PFS) group may wish to undertake to cooperate and share the costs of design and development of the base software systems.

Personnel Components

The personnel in day-to-day operations of the connected vehicle system are responsible for two key elements:

⁵⁶ The security component, or Security Credential Management System (SCMS), is a separate component that is not addressed in this section as it is not likely that a state or local agency will be responsible for designing, building, operating or maintaining the system. The local agency will likely only be a subscriber to the SCMS.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

- **System Monitoring.** While a connected vehicle system, like a traditional traffic signal system, may not require constant human intervention (unlike an arterial or freeway management system which currently requires human intervention to manage incidents and work with emergency responders, for example), there is the need for personnel to monitor the overall day-to-day operations of the system. This includes overseeing security and responding to traditional cyber-attacks that monitoring systems identify, responding to outages and other issues, and supporting other operational issues that may arise.
- **System Upgrades & Enhancements.** One of the biggest challenges envisioned with deployment of a connected vehicle system is the ongoing development of enhancements based on feedback from various consumers of the data and information throughout the system. Especially with early deployments, once the data and information start to be used, many requirements for new components, applications and other improvements to the software system will be identified. It will be important that agencies investing in connected vehicle systems provide flexibility with regards to improving the system and developing new applications to support additional users and uses which will ultimately improve the overall system and make the connected vehicle deployment more valuable across the entire deployment agency.

The personnel costs are ultimately a function of the size of the deployment. Smaller deployments may not need 24x7 monitoring or dedicated personnel for system upgrades and enhancements. Large regional or statewide systems may require multiple people dedicated to system monitoring and response, with staff either on site or on call.

Aligning staff skills with these operational needs will be critical to successful connected vehicle systems operations. Agencies will need to determine whether to acquire and train in-house staff or to contract out to a service provider, similar to current traffic system operations in some areas. While this may not reduce the overall cost, this technique can be used for agencies where headcounts and training are an issue. Additionally, not all expertise is required at all times. For example, cybersecurity experts and database operators can be shared amongst multiple deployment agencies in a contracting model, permitting agencies to have experts in each field, as opposed to a jack-of-all trades who may be versed in many areas, but is not a full expert in any of the disciplines and thus cannot respond to every request or situation.

Infrastructure Components

The infrastructure components within the backend system are the framework on which the entire backend system operates. Without the infrastructure components, the software and personnel components will not have the facilities they need. The key infrastructure components are:

- **Computer Hardware.** The computer hardware component refers to the hardware on which the software components all run. This includes routers, servers, storage devices, power supplies, backup power supplies, network security devices and other components in a data center. This also refers to the operating system and any commercial-off-the-shelf (COTS) software, including database software, security and monitoring software and virus protection.
- **Physical Facilities for Hardware.** The physical facilities in the back end refer to the physical data center building which house the computer hardware. For older signal systems, this was often housed in a closet as the computer system was essentially a personal or desktop computer. Current ATMS software systems for a large region or state are often housed in a

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

data center, which is essentially a room in a traffic management center designed to house such facilities (raised floor, additional cooling, etc.). Based on the projected data rates for connected vehicles, assuming all data received at the roadside device is transmitted in raw form to the back end systems, there will be significantly more data flowing through the system (and being stored and processed) than in a traditional ATMS. As a result, it is likely that existing physical facilities within a TMC may not be sufficient for the computer systems operating connected vehicle back-end components. This includes the power supplies and cooling systems required for operations.

- **Physical Facilities for Personnel.** The personnel that operate and maintain the systems will need desk space at or near the data center. The personnel that manage the software assets, data bases and other applications will need desk space but their work can be performed remotely as they don't need direct or frequent access to the computer hardware.

The challenge with the physical requirements is that they are dependent on the software and data rates that are anticipated, which at this point are not known. As the designs for the software system mature, the designers need to take into consideration the requirements for the hardware.

Outsourcing

There are two other types of options for supporting the back office infrastructure. The first is to outsource the hardware procurement, operations and maintenance activities. The software developers may have the ability to procure, operate and maintain the hardware at their own off-site facility. The costs for outsourcing these components would probably be comparable to the costs of insourcing but may provide more flexibility in location and maintenance as many public sector information technology (IT) departments are separate from the transportation department which may impose additional requirements on hardware and policies that increase costs.

A second option is the maturing cloud computing market, which is a means of outsourcing services to support applications deployment. Currently there are hundreds of vendors who provide hosting services for applications and data management. Under the cloud-based model, the user typically pays a monthly access fee as well as monthly (or daily) fees based on actual usage, such as processing unit cycles for applications and per unit of storage.

Vehicle Fleet Data Collections

The current DSRC-based connected vehicle technologies have a set of related issues that have the potential to limit the amount of data collected and the range of applications that might benefit state and local agencies. The first issue derives directly from the connected vehicle principle of "privacy by design." Data is anonymized as a result of this design decision, and can be identified as part of a set only over a limited period of time (a vehicle can only be "tracked" for 5 minutes before its identity is changed). Data can also only be acquired from a vehicle when it is within range of a DSRC radio, limiting the geographic reach of the system.

One solution being considered by AASHTO, the CTS PFS and others is to outfit their own vehicle fleets with additional data collection and storage capacity and multiple mechanisms by which to download that data into back office data management system. By equipping their own vehicle fleet, an agency could have access to more data elements than by relying on the BSM or other agreed-upon message sets from the vehicle manufacturing community. These agency-owned fleets will benefit

transportation operations by providing an additional set of data that can be used for a variety of purposes, including tracking heavy maintenance vehicles, such as snow plows or rolling road repair crews, or evaluating ride quality and road smoothness across a state or a region. The Michigan Department of Transportation, for example, in their Data Use, Analysis, and Processing (DUAP) program, used an Android application to collect ride roughness data across the state and transmitted that data back over the cell network. The CTS PFS has initiated a pilot program with the New York State DOT to outfit winter maintenance vehicles with DSRC radios and an enhanced message set that is being used to evaluate the use of DSRC on winter maintenance vehicles for monitoring responses to snow events.

The Volpe Center and FHWA's Office of Operations, Research and Development have existing fleets of research vehicles that are instrumented with data collection equipment sufficient to meet the needs of transportation management/operations centers (TMCs/TOCs), State DOTs, MPOs, among other agencies who may be interested in monitoring fleet operations, as well as having some probe vehicle data to monitor system performance. This equipment includes a DSRC aftermarket safety device (ASD), which is an in-vehicle radio unit that generates the Vehicle Situation Data Message (VSDM), which transmits information to backend servers about the vehicles speed, direction, and location, as well as information from vehicle sensors to include status, environmental and weather information. Additionally, these fleets may be equipped with camera logging systems that monitor the vehicle's external surroundings to provide insight into local traffic conditions, incident information, and other visual updates to remote operators. Although there are multiple vendors and configurations for this type of equipment, cost information from the video data collection system implemented on the Volpe and FHWA fleets is used for this estimate and assumed to be representative of systems from alternative vendors. Finally, an additional cost element is included to cover the cable management and accessories that are used for installation.

The costs associated with this fleet include the cost of hardware, installation, and monthly service charges. Table 21 outlines these cost elements, based on previous implementations for government research fleets for the following projects:

- Volpe, Field Operational Experiment and Data Analysis of Driver Adaptation to Crash Warning and Avoidance Products, 2013.
- FHWA-HRDO, Development of a Platform Technology for Automated Vehicle Research, 2013.

Table 21 - Unit Costs for DSRC-based Data Collection Equipment (Source: USDOT/AASHTO 2014)

Equipment Component	Unit Cost
DSRC After-market Safety Device	\$1,000
Cabling Management/Installation Kits	\$150
Installation Labor	\$3,000
Video Data Collection System (optional)	\$5,050
Total Cost Per Vehicle (with video)	\$9,200

The in-vehicle costs for fleet-based systems depend on the application(s) being deployed. The costs shown in Table 21 are based on the Volpe and FHWA-HRDO deployments which required a

significant investment in the in-vehicle device, both in terms of capital cost and installation. For the initial Michigan DOT demonstration of a ride quality application, data collection ran on an Android-based smart phone. Outside of the cost of developing the application to collect the data from the sensors in the phone, the only deployment costs were the phone, a suction cup mount for the phone and a power cable with a cigarette lighter adapter, all of which could be installed by the driver in less than five minutes.

Fleet systems will likely use a combination of connectivity types, including DSRC at DSRC hotspots, Wi-Fi for batch downloads at Wi-Fi hotspots, and cellular for service when more continuous connectivity is desired. The cost for cellular service varies by carrier and by contract type. Sprint, for example, offers unlimited data plans, while AT&T and Verizon offer plans based on specific data use, typically in 2 GB increments (although Sprint also provides a 3/6/12 GB data-only plan). Additionally, each of the carriers has different rates based on who holds the contract. The prices on each carrier's web site are representative of the plans paid by the typical consumer. Each carrier also negotiates separate rates for corporations and government entities. The cost for the device varies based on the plan selected and the length of the contract and can range from free to over \$600 for a new, current-generation smart phone. Table 22 shows some of the pricing variability in the cellular marketplace.

Table 22 - Example Cellular Data Plan Rates (Source: USDOT/AASHTO 2014)

Source & Service	Monthly Rate
Sprint government quote (January 2014), unlimited data and free modem	\$35
Sprint consumer price, www.sprint.com , 12GB data, 3G/4G modem	\$80
Sprint consumer price, www.sprint.com , unlimited data and voice, smart phone	\$110
AT&T consumer price, www.att.com , 10GB data and data modem	\$60
AT&T consumer price, www.att.com , 10GB data, unlimited voice, smart phone	\$100
Verizon consumer price, www.verizon.com , 10GB data, unlimited voice, smart phone	\$100

Sprint, Verizon, and T-Mobile have provided data modems free of charge with the \$35 monthly service fee for unlimited data use for government entities in the past. For 12 months of service, this totals \$420 per year for each vehicle.

Third-Party Traffic Data

This section outlines the cost estimates associated with the procurement of third-party traffic data to support connected vehicle applications. Third-party vendors such as HERE (formerly known as NAVTEQ) and INRIX have deployed data collection equipment and monitor mobile-based traffic data sources to cover a much larger portion of the national road network than state and local governments are currently monitoring. Access to these data sources provides rich speed and travel time data, as well as incident, construction, road closure and weather information. Additionally, these sources have implemented quality assurance to meet the Real-Time System Management Information Program (RTSMIP) requirements, including data reporting in 20 minutes or less with 85 percent accuracy and 90 percent availability.

Additionally, other providers are emerging in this market with consumer-focused traffic data applications. These include Google and Apple, who have implemented real-time traffic information into their mapping systems based on data collected from users of the system. For example, the license agreement for Google Maps permits Google to collect data from users' cell phones for this purpose.

Purchasing data from these service providers allows a state or local agency to quickly collect basic traffic data—speed, volume, travel time—on the majority of the major roads in their area. While the data are somewhat limited (volumes and turning counts, for example, are not available), the accuracy and quantity of the data over a large area permits agency users to quickly develop applications for their internal use. The Michigan DOT, for example, uses data from HERE to display travel times on dynamic message signs across the state. Adding this information to new signs as they are deployed is a relatively simple process since all of the data are readily available.

The cost of these commercially available systems varies by types of data desired (speed, volume, travel time, etc.), desired accuracy and timeliness of the data (e.g., 90% accurate within five minutes), types of roads for which data is desired (freeways, major arterials, minor arterials, etc.) and geographic boundaries (city, region, state, etc.). Unfortunately, this is a competitive marketplace for these data providers and they are unable to provide any detailed costing for this report. Costs in the past have ranged from \$250,000 for a statewide system (Michigan) to approximately \$750 per centerline mile (original I-95 Corridor Coalition contract).

Table 23, from a 2010 report on data systems⁵⁷, provides the estimated costs at that time for collecting data through traditional methods (traffic detectors) and purchasing information from a service provider.

Table 23 - Traditional and Third-Party Data Service Cost Comparison (Source: USDOT 2010)

	Infrastructure Based/Typical	Probe Based (I-95 Corridor)
Initial capital cost (per centerline mile)	\$26,000	\$900
Annual Recurring Cost	\$150	\$750
5-year Est. Cost	\$26,600	\$3,900
10-year Est. Cost	\$27,350	\$7,650

⁵⁷ *Real Time Traveler Information Market Assessment White Paper*; Publication Number FHWA-JPO-10-055, EDL Document Number 14961; February 22, 2010.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Operational and Organizational Impacts

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.⁵⁸

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 Plan*⁵⁹ 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.⁶⁰ 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

⁵⁸ 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 an earlier section of this document.

⁵⁹ NCHRP 03-101: *Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies Deployment Plan*; Version 1.0; August 30, 2013

⁶⁰ An analysis of the likely rate of deployment among the vehicle population will be part of the next *Deployment Footprint* deliverable under this project.

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 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 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 USDOT, and the Office of the Assistant Secretary for Research's (previously 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 RSU radio is licensed for a particular site and the radio frequency (RF) characteristics will vary from site to site. The *Deployment Concepts* section 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, RSUs with applicable software, data provided by OBUs). 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, RSUs will need to be

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

registered with the SCMS and have active certificates before being tested and deployed in a live environment.

- Connected vehicle 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, 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 the 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.

Conclusions and Recommendations

The *National Connected Vehicle Field Infrastructure Footprint Analysis* represents an important step in defining the nature and scale of the deployment activities facing state and local transportation agencies. Following this analysis, however, there will be a number of additional activities that must be undertaken by the agencies to ensure that a nationwide connected vehicle environment can be realized. Recommended near-term actions are described in this section.

Importantly, AASHTO recommends that the development of a deployment strategy for the connected vehicle environment should be conducted through a National Deployment Plan. This activity should be led by USDOT and would identify specific deployment actions and timing by agencies, within a coordinated nationwide framework agreed upon by USDOT, AASHTO and the vehicle manufacturers.

An initial step for state and local agencies will be to develop their own Deployment Strategies. This is anticipated to comprise tasks that may include:

- Convene public sector stakeholders from appropriate state and local transportation agencies, as well as potentially from public transportation providers, law enforcement, and public safety agencies depending on applications under consideration. Metropolitan and regional planning agencies may also participate, and could be responsible for this activity within the bounds of the conventional transportation planning processes.
- Identify connected vehicle concepts and applications that are of interest to the stakeholders and create scenarios under which these applications are realized.
- Review and update relevant plans and other documents to reflect potential connected vehicle deployments. Documents to be revisited could include regional ITS architectures, Sec. 1201 plans, and Strategic Highway Safety Plans⁶¹.
- Identify the specific locations at which connected vehicle infrastructure deployments will take place and the scope of the deployment, which may include consideration of the need for a pilot or prototype demonstration initially.
- Consider funding options for deployment, and address needs for inclusion of connected vehicle activities in long-range transportation plans and subsequently in statewide TIPs (STIPs) or local TIPs.
- Develop procurement documents, which must be consistent with future federal deployment guidance, the Connected Vehicle Reference Implementation Architecture (CVRIA), and federal decisions on the SCMS.

AASHTO recommends that USDOT consider making available Connected Vehicle Deployment Incentive Grants, similar in nature to (but probably on a larger scale than) the approach used during the development of the 511 program, which will encourage state and local agencies to develop the deployment strategies described here.

⁶¹ <http://safety.fhwa.dot.gov/hcip/>

Beyond the development of Deployment Strategies, state and local agencies will have additional preparatory steps to undertake depending on the types of connected vehicle applications they have selected for deployment. Many V2I safety applications will require changes to signalized or unsignalized intersections or other roadway locations. Most notably, agencies will likely need to make changes to existing traffic signal controllers to incorporate SPaT capabilities, as well as to ensure that suitable backhaul communications are available from the intersection infrastructure to central data processing facilities. Any upgraded backhaul communication systems will also require an agency to adopt robust network protection processes to improve performance against potential network disruptions. It will be important for agencies to coordinate these activities with regular signal maintenance and upgrade programs. In addition, agencies will need to ensure that they have gathered roadway geometry data at an appropriate level of detail to support the V2I safety applications that will be deployed at intersections and curves.

Deployment of V2I mobility applications will similarly create additional actions for state and local agencies to ensure coordination and integration with other agency initiatives. Probe data on road and traffic conditions may be collected for specific mobility applications but is likely to have greater value when integrated into legacy ATMS programs or integrated with data from road weather information systems (RWIS) to enhance road-weather management programs. These data may also help agencies in meeting the requirements of the Real-Time Systems Management Information Program (Sec. 1201 rule) and so appropriate coordination between the initiatives will be important. Similar coordination will be important with regional and statewide traveler information systems, such as 511, and efforts to satisfy performance management goals identified in MAP-21.

State and local deploying agencies will also deploy their systems and applications within a framework of national connected vehicle policies that will be promulgated by USDOT. In particular, it can be envisioned that USDOT will establish governance policies and policies relating to privacy and security. Notably, state and local agencies will likely be required to deploy systems using the SCMS for connected vehicles that is currently under development by USDOT. It can be anticipated that future deployment guidance from USDOT will address agency requirements in this area.

AASHTO, in partnership with USDOT and the carmakers, has shared national leadership of the connected vehicle program since its inception. In particular, AASHTO has taken on research and planning initiatives that reflect its unique insight into the needs of the state transportation agencies. AASHTO has also used its position and relationships to engage other transportation owner-operators and planning organizations, including county and municipal agencies and MPOs, which will be critical in the successful implementation of a connected vehicle field infrastructure. AASHTO has adapted and redefined its leadership role as the connected vehicle program has evolved. It is important for AASHTO to once again identify an appropriate role for the organization and its members as the connected vehicle program transitions from research to a strong focus on deployment.

AASHTO has convened a group of state and local agencies (notably early adopter agencies) to discuss deployment issues and research needs. The Deployment Coalition has been responsible for reviewing the key deliverables from the Footprint Analysis and other precursor projects. AASHTO will recast this group with a more formal charter, working in collaboration with the Subcommittee on Systems Operations and Management (SSOM) to represent the interests of AASHTO and its members in connected vehicle deployment activities. AASHTO's activities in advancing deployment activities will include:

- Connected vehicle policy analyses are conducted through the ITS JPO. AASHTO has monitored these efforts through briefings by JPO staff and discussions held at the Executive Leadership Team (ELT); where appropriate AASHTO has engaged more directly in these activities. Going forward, AASHTO should be directly involved in the following activities:
 - To collaborate with CAMP and the VIIC on SCMS technical design, organizational development, and deployment decisions that will impact the state and local agencies;
 - To support the ITS JPO in development and review of governance structures and approaches for implementation of privacy by design in infrastructure components and V2I applications.
- Through FHWA, the USDOT connected vehicle program has established an activity to develop Connected Vehicle Deployment Guidance that will be issued to state and local agencies in 2015. Early activities have included a stakeholder workshop attended by AASHTO staff and members in January 2014. It is critical for AASHTO to be actively engaged in the development of such guidance that is intended for use by its members by:
 - Providing input to the development and review of guidance materials;
 - Supporting the definition of an AASHTO-recommended deployment incentive grants program for state and local agencies embarking on connected vehicle infrastructure deployments.
- Provide general, ongoing support to national deployment activities, including:
 - Broadening the role of the Deployment Coalition to include state/local outreach, technical support and a peer exchange network in coordination with ITS JPO Professional Capacity Building (PCB) activities;
 - Supporting states in applying for and using the AASHTO-recommended program of deployment incentive grants;
 - Developing design standards in coordination with FHWA deployment guidance activities;
 - Facilitating knowledge exchange and best practices for establishing infrastructure public-private partnerships and other non-traditional contracting approaches to support deployment by agencies.

References

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *AASHTO Connected Vehicle Infrastructure Deployment Analysis*; Publication Number FHWA-JPO-11-090; June 17, 2011; downloaded at http://ntl.bts.gov/lib/43000/43500/43514/FHWA-JPO-11-090_AASHTO_CV_Deploy_Analysis_final_report.pdf

American Association of State Highway and Transportation Officials; *National Connected Vehicle Field Infrastructure Footprint Analysis: Applications Analysis*; Version 3, July 31, 2013; downloaded at http://ssom.transportation.org/Documents/Applications_Analysis%20v3%20july%202013.pdf

American Association of State Highway and Transportation Officials; *National Connected Vehicle Field Infrastructure Footprint Analysis: Deployment Concepts*; Version 2, September 20, 2013; downloaded at http://ssom.transportation.org/Documents/Deployment_Concepts.pdf

American Association of State Highway and Transportation Officials; *National Connected Vehicle Field Infrastructure Footprint Analysis: Deployment Scenarios*; Version 2, December 27, 2013; downloaded at http://ssom.transportation.org/Documents/Task%206a%20AASHTO_CV_Footprint_Deployment_Scenarios_v2.pdf.

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.

Applications Analysis

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Vehicle Information Exchange Needs for Mobility Applications: Version 2.0*, prepared by Noblis, FHWA-JPO-12-021; August 1, 2012; downloaded at http://ntl.bts.gov/lib/46000/46000/46089/Final_PKG_FHWA-JPO-12-021_508_PDF.pdf

USDOT Research and Innovative Technology Administration; *Concept of Operations for Road Weather Connected Vehicle Applications*; Draft Version 1.4.2, prepared by Booz Allen Hamilton; June 26, 2012.

AERIS Transformative Concepts and Applications Descriptions (v10); August 2012; downloaded at http://www.its.dot.gov/aeris/pdf/AERIS_Transformative%20Concepts%20and%20Applications%20Descriptions%20v10.pdf

USDOT Research and Innovative Technology Administration; *Freight Advanced Traveler Information System*; prepared by Cambridge Systematics; Final Report version 2.1; April 12, 2012.

USDOT Research and Innovative Technology Administration; *Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO)*, Draft 3.0; prepared by Science Applications International Corporation; June 14, 2012.

USDOT Research and Innovative Technology Administration; *Integrated Dynamic Transit Operations (IDTO) Concept of Operations*, v3.0; prepared by Science Applications International Corporation; May 11, 2012.

Multi-Modal Intelligent Traffic Signal System – Draft Concept of Operations, Version 1.0; prepared by the University of Arizona; July 13, 2012.

USDOT Federal Highway Administration, Office of Operations; *Response, Emergency Staging, Communications, Uniform Management, and Evacuation (R.E.S.C.U.M.E.) Concept of Operations*, v1.0; prepared by Battelle; May 29, 2012.

USDOT Research and Innovative Technology Administration; *Vision and Operational Concept for Enabling Advanced Traveler Information Services*; prepared by Kimley-Horn and Associates, Inc.; May 13, 2012.

USDOT Federal Highway Administration; *Crash Data Analyses for Vehicle-to-Infrastructure Communications for Safety Applications*; prepared by Vanasse Hanger Brustlin, Inc.; November 2012.

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Communications Data Delivery Systems Analysis: High Level Options for Secure Communications Data Delivery Systems*; FHWA-JPO-12-061; June 21, 2012; downloaded at:
http://ntl.bts.gov/lib/45000/45600/45615/FHWA-JPO-12-061_CDDS_Task_2_Rpt_FINAL.pdf

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Certificate Management Entities for a Connected Vehicle Environment*; April 5, 2012; downloaded at
http://www.its.dot.gov/connected_vehicle/pdf/CME_ReadAhead040912.pdf

USDOT Federal Highway Administration, Office of Freight Management and Operations; *Border Information Flow Architecture*; downloaded at
http://ops.fhwa.dot.gov/freight/freight_analysis/gateways_borders/freight_info/borderinfo/border.htm

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Footprint Analysis for the IntelliDriveSM V2V Applications, Intersection Safety Applications, and Tolled Facilities*; prepared by Noblis, Inc.; March 2009; downloaded at
http://www.its.dot.gov/research_docs/pdf/12Footprint.pdf

Safety Pilot Model Deployment Transit Safety Applications, ITS Workshop on Connected Vehicles, September 25, 2012, http://www.its.dot.gov/presentations/CV_Safety_sept2012/pdf/Day%201%20-%20Transit%20Activity%20-%20Mortensen.pdf

Investigation of Pavement Maintenance Applications of IntelliDriveSM; prepared for the Cooperative Transportation Systems Pooled Fund Study by Auburn University; May 2011.

Investigating the Potential Benefits of Broadcasted Signal Phase and Timing (SPaT) under IntelliDriveSM; prepared for the Cooperative Transportation Systems Pooled Fund Study by California PATH Program; May 2011.

IntelliDriveSM Traffic Signal Control Algorithms; prepared for the Cooperative Transportation Systems Pooled Fund Study by the University of Virginia; April 2011.

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Vehicle Information Exchange Needs for Mobility Applications Version 3.0*; FHWA-JPO-12-021, April 15, 2013.

Concepts

Illinois Department of Transportation, Bureau of Materials and Physical Research; *Regional Data Archiving and Management for Northeast Illinois*; Report ICT-09-050; June 2009.

Wyoming Department of Transportation; *Wyoming Department of Transportation Statewide TMC Weather Integration Plan*; December 15, 2010; downloaded at http://ntl.bts.gov/lib/38000/38600/38677/WY_Integration_Plan_Final_Corrected6.6.11.doc

The Regents of the University of Michigan; *Slippery Road Detection and Evaluation, Project Final Report*; May 31, 2012; downloaded at http://www.michigan.gov/documents/mdot/MDOT_Research_Report_RC1573_393940_7.pdf

Scenarios

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Deployment of ITS: A Summary of the 2010 National Survey Results*; Publication Number FHWA-JPO-11-132; August 2011; downloaded at <http://www.itsdeployment.its.dot.gov/documents/nationalreport.pdf>.

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

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.

Footprint

US Department of Transportation, Research and Innovative Technology Administration; *ITS Technology Adoption and Observed Market Trends from ITS Deployment Tracking*; Report Number FHWA-JPO-10-066; Final Report, October 2010.

Affiliated Connected Vehicle Test Bed Summit: Lessons Learned, Next Steps; Presented by Walton Fehr, Program Manager in the USDOT ITS Joint Program Office at the ITS Industry Forum on Connected Vehicles in Chicago Illinois; September 26, 2012;

http://www.its.dot.gov/presentations/CV_Safety_sept2012/pdf/Day%20%20-%20Affiliated%20Test%20Bed.pdf.

USDOT Research and Innovative Technology Administration, ITS Joint Program Office; *Deployment of ITS: A Summary of the 2010 National Survey Results*; Publication Number FHWA-JPO-11-132; August 2011; downloaded at <http://www.itsdeployment.its.dot.gov/documents/nationalreport.pdf>.

Volvo Technology for New York State Department of Transportation; *CVII Concept of Operations*; Document Number 6980-02941-01-03, December 17, 2009.

University of Arizona; *MMTISS Final Concept of Operations*; Version 3.0; October 21, 2012.

University of Alberta, The Centre for Smart Transportation; *The ACTIVE-AURORA Test Bed Network*; accessed February 2014 at

http://www.transportation.ualberta.ca/News%20and%20Events/2013/December/~/_media/transportation/PDFs/CV_Overview12-04-13.pdf.

National Highway Transportation Safety Administration; *Frequency of Target Crashes for IntelliDrive Safety Systems* Report Number DOT HS 811 381; October 2010.

National Highway Transportation Safety Administration; *Crash Factors in Intersection-Related Crashes: An On-Scene Perspective*; Report Number DOT HS 811 366; September 2010.

Noblis, Inc.; *Footprint Analysis for IntelliDriveSM V2V Applications, Intersection Safety Applications, and Tolled Facilities*; prepared for the USDOT / RITA / ITS JPO; March 2009; Accessed February 2014 at http://www.its.dot.gov/research_docs/pdf/12Footprint.pdf.

Traffic Operations and Safety Laboratory, University of Wisconsin-Madison; *Intersection Crash Summary Statistics for Wisconsin*; June 2005.

National Transportation Operations Coalition; *2012 National Traffic Signal Report Card – Technical Report*; accessed in February 2014 at <http://www.ite.org/reportcard/TechnicalReport.pdf>.

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

Real Time Traveler Information Market Assessment White Paper; Publication Number FHWA-JPO-10-055, EDL Document Number 14961; February 22, 2010.

2010 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance, A Report to Congress; data from Exhibit 2.4; <http://www.fhwa.dot.gov/policy/2010cpr/pdfs/cp2010.pdf>

Appendix A. Detailed Applications Analysis

Table 24 - Application Assessment (Source: USDOT/AASHTO 2014)

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
V2I Safety	Intersection Safety	Driver Gap Assist at Signalized Intersections	Equipment at signalized intersection determines the locations and speeds of oncoming vehicles (e.g. using Radar/Lidar). This information plus SPAT data is broadcast in vicinity of intersection. Vehicle OBU receives oncoming vehicle information (or gap info) and SPAT info, and determines if a warning is appropriate.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Critical	No	No	Low	Required	Benefits Realizable Day One	None	None	SPaT
V2I Safety	Intersection Safety	Railroad Crossing Violation Warning	RSU in vicinity of intersection and connected to RR crossing guard controller sends out Signal Phase and Timing Messages (or RRX equivalent). Vehicle OBU receives SPAT/RRX info and determines if a warning is appropriate.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Critical	No	No	Medium	Required	Benefits Realizable Day One	None	None	SPaT
V2I Safety	Intersection Safety	Red Light Violation Warning (Cellular)	Signal controller sends Signal Phase and Timing information to server. Vehicle contacts server and requests road warning/alert info based on its location and direction. Vehicle OBU receives SPAT info and determines if a warning is appropriate.	None	Yes	Required	Exclusive	Localized Geometric	Critical	No	No	Low	Required	Benefits Realizable Day One	None	BSM1	SPaT
V2I Safety	Intersection Safety	Red Light Violation Warning (DSRC)	RSU in vicinity of intersection and connected to signal controller sends out Signal Phase and Timing Messages. Vehicle OBU receives SPAT info and determines if a warning is appropriate.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Critical	No	No	Low	Required	Benefits Realizable Day One	None	None	SPaT
V2I Safety	Intersection Safety	Stop Sign Gap Assist (V2I Only)	Equipment at stop sign controlled intersection determines the locations and speeds of oncoming vehicles (e.g. using Radar/Lidar). This information plus stop sign info and intersection map is broadcast in vicinity of intersection. Vehicle OBU receives oncoming vehicle information (or gap info), and stop sign info and determines if a warning is appropriate.	Fixed	Yes	None	N/A	Localized Geometric	Critical	No	No	Low	Not Required	Benefits Realizable Day One	None	None	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
V2I Safety	Intersection Safety	Stop Sign Violation (Cellular)	Server has locations and directions of stop signs for a region. Vehicle contacts server and requests road warning/alert info based on its location and direction. Vehicle OBU receives stop sign info and determines if a warning is appropriate.	None	No	None	N/A	Localized Geometric	Non-Critical	No	No	Medium	Required	Benefits Realizable Day One	None	BSM1	None
V2I Safety	Intersection Safety	Stop Sign Violation (DSRC)	RSU in vicinity of stop sign sends out stop sign locations and directions. Vehicle OBU receives stop sign info and determines if a warning is appropriate.	Fixed	No	None	N/A	Localized Geometric	Non-Critical	No	No	Low	Required	Benefits Realizable Day One	None	None	GIDs/Maps
V2I Safety	Other Safety	Oversize Vehicle Warning (Cellular)	Server has locations and directions of overhead restrictions for a region. Vehicle contacts server and requests road warning/alert info based on its type, location and direction. Vehicle OBU receives restriction info and determines if a warning is appropriate. Ideally, an alert would be given so that the oversize vehicle can be rerouted before a warning to stop is required.	None	No	None	N/A	Road Network	Non-Critical	No	No	Medium	Not Required	Benefits Realizable Day One	None	BSM1+2	App-specific
V2I Safety	Other Safety	Oversize Vehicle Warning (DSRC)	RSU in vicinity of (i.e. on approach to) overhead restriction sends out overhead limit locations and directions. Vehicle OBU receives overhead limit info and determines if a warning is appropriate. Ideally, an alert would be given so that the oversize vehicle can be rerouted before a warning to stop is required.	Portable or Fixed	No	None	N/A	Road Network	Non-Critical	No	No	Medium	Not Required	Benefits Realizable Day One	None	None	GIDs/Maps
V2I Safety	Speed Safety	Curve Speed Warning (Cellular)	Server has info for road curves (locations, directions and speeds) for a region. Vehicle contacts server and requests road warning/alert info based on its location and direction. Vehicle OBU receives curve info and determines if a warning is appropriate.	None	No	None	N/A	None	Non-Critical	No	No	Medium	Required	Benefits Realizable Day One	None	Position	TI
V2I Safety	Speed Safety	Curve Speed Warning (DSRC)	RSU in vicinity of (e.g. on approach to) curve sends out curve information (location and recommended speed and directions). Vehicle OBU receives info and determines if a warning is appropriate.	Fixed	No	None	N/A	None	Critical	No	No	Low	Required	Benefits Realizable Day One	None	None	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
V2I Safety	Speed Safety	Reduced Speed Work Zone Warning (Cellular)	Workers provide info on work zone to server. Vehicle contacts server and requests road warning/alert info based on its location and direction. Vehicle OBU receives work zone info and determines if a warning/alert is appropriate.	None	No	None	N/A	None	Non-Critical	No	No	Medium	Not Required	Benefits Realizable Day One	None	Position	TI
V2I Safety	Speed Safety	Reduced Speed Work Zone Warning (DSRC)	Fixed RSU in vicinity of (e.g. on approach to) work zone, or portable RSU at work zone sends out alert information (e.g. location and recommended speed(s) and directions). Vehicle OBU receives info and determines if a warning/alert is appropriate.	Portable	No	None	N/A	None	Non-Critical	No	No	Low	Not Required	Benefits Realizable Day One	None	None	App-specific
V2I Safety	Speed Safety	Speed Zone Warning (Cellular)	Server has info for speed zones (locations, directions and speeds) for a region. Vehicle contacts server and requests road warning/alert info based on its location and direction. Vehicle OBU receives speed zone info and determines if a warning/alert is appropriate.	None	No	None	N/A	None	Non-Critical	No	No	Medium	Not Required	Benefits Realizable Day One	None	Position	TI
V2I Safety	Speed Safety	Speed Zone Warning (DSRC)	Fixed RSU in vicinity of (e.g. on approach to) speed zone, or portable RSU at temporary speed zone sends out alert information (e.g. location and recommended speed(s) and directions). Vehicle OBU receives info and determines if a warning/alert is appropriate.	Portable or Fixed	No	Optional	N/A	None	Non-Critical	No	No	Low	Not Required	Benefits Realizable Day One	None	None	App-specific
V2I Safety	Transit Safety	Pedestrian in Signalized Crosswalk Warning	RSU in vicinity of intersection and connected to pedestrian detection system sends out pedestrian info (presence and crosswalk) as part of Signal Phase and Timing Messages. Vehicle OBU receives info and determines if a warning/alert is appropriate.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Low	Required	Benefits Realizable Day One	None	None	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	Enable ATIS	ATIS (Cellular)	Vehicle contacts server and provides speed and location data. Back office app (server) determines travel times and other traveler information. Server provides this information to vehicle in same transaction, or vehicle subsequently contacts server and requests road info based on its location and direction. Vehicle OBU receives info and plans accordingly, informs driver.	None	No	None	N/A	Road Network	Non-Critical	No	Yes	High	Required	Benefits Realizable Day One	None	BSM1	App-specific
Mobility	Enable ATIS	ATIS (DSRC)	Vehicles broadcast location (possibly via BSM); RSU receives messages and sends info to back office. Local or back office app determines travel times and other traveler information and sends this to the RSUs in the area. RSUs broadcast information to vehicles. Data likely used by vehicle for routing and/or energy management.	Fixed	No	Required	Exclusive	Road Network	Non-Critical	No	Yes	High	Required	Benefits Realizable Day One	None	BSM1	TI
Mobility	Enable ATIS	Motorist Advisories and Warnings (Cellular)	Information is obtained from <u>external</u> sources and used to determine the locations of hazards and other localized warning/advisory content. Vehicles call server to obtain information on the road ahead.	None	No	None	N/A	Road Network	Non-Critical	No	Yes	High	Not Required	Benefits Realizable Day One	None	Position	SPaT
Mobility	Enable ATIS	Motorist Advisories and Warnings (DSRC)	Information is obtained from <u>external</u> sources and used to determine the locations of hazards and other localized warning/advisory content. System used to inform vehicles appropriately based on their location.	Portable or Fixed	No	Required	Exclusive	Road Network	Non-Critical	No	Yes	High	Not Required	Benefits Realizable Day One	None	None	TI
Mobility	Enable ATIS	WX-INFO (Cellular)	Provides real-time route-specific weather information for motorized and non-motorized vehicles; part of the Enable ATIS bundle.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+other	TI
Mobility	Enable ATIS	WX-INFO (DSRC)	Provides real-time route-specific weather information for motorized and non-motorized vehicles; part of the Enable ATIS bundle.	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+other	TI

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	FRATIS	Dynamic Route Guidance (F-DRG) (DSRC)	Vehicle passes an RSU and provides speed, location and destination information. RSU relays information to central server where data is compounded with other data to derive the optimum route. Route is passed back to RSU and on to vehicle.	Fixed	No	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	Privacy	BSM1+other	TI
Mobility	FRATIS	Dynamic Route Guidance (F-DRG) (Cellular)	Vehicle provides speed, location and destination information over wireless connection to central server where data is compounded with other data to derive the optimum route. Route is passed back to vehicle.	None	No	None	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	Privacy	BSM1+other	TI
Mobility	FRATIS	Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS) (Cellular)	FRATIS shall provide a specialized output interface to public sector agencies that will provide open-source data collected in the FRATIS system, such as sanitized route, speed, congestion, and alternative route selection information. This information shall support public sector freight planners and other public agencies in assessing both the needs and impacts of truck traffic in a metropolitan region (e.g., air quality reductions due to FRATIS applications, assessment of the best alternative routes, and information on where to potentially plan new connectors to support better dynamic routing). The format of the public sector output data shall be determined during the FRATIS System Development and Limited Testing phase.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1	TI
Mobility	FRATIS	Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS) (DSRC)	FRATIS shall provide a specialized output interface to public sector agencies that will provide open-source data collected in the FRATIS system, such as sanitized route, speed, congestion, and alternate route selection information. This information shall support public sector freight planners and other public agencies in assessing both the needs and impacts of truck traffic in a metropolitan region (e.g., air quality reductions due to FRATIS applications, assessment of the best alternate routes,	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+other	TI

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			and information on where to potentially plan new connectors to support better dynamic routing). The format of the public sector output data shall be determined during the FRATIS System Development and Limited Testing phase.														
Mobility	IDTO	Connection Protection (T-CONNECT)	The proposed transit multi-modal and multi-agency application will enable public transportation providers and travelers to communicate to improve the probability of successful transit transfers. Travelers can initiate a request for connection protection anytime during the trip using a personal mobile device, or potentially via transit vehicle or personal automobile on-board equipment/interface, and receive a confirmation based on a set of criteria indicating whether the request is accepted.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	other	TI
Mobility	IDTO	Dynamic Ridesharing (D-RIDE)	This proposed application will make use of personal information gathering systems (such as in-vehicle and hand-held devices) to allow ride-matching, thereby reducing congestion, pollution, and travel costs to the individual with a low initial investment. Under one implementation scenario, it is proposed that the D-RIDE application will integrate carpooling functions into a vehicle computer so voice activated ridesharing technology can be built into the vehicle's interface enabling the driver to find and accept potential ride matches along his/her route without having to divert concentration from the roadway. By combining existing mobile ridesharing applications (phone, web, kiosk) with in-vehicle and roadway based technology, a number of problems associated with carpooling can be solved.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	other	TI

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	IDTO	Dynamic Transit Operations (T-DISP)	This application will allow travelers to request trips using a variety of media and seeks to enhance existing on-board and central systems to provide public transportation and shared-ride services. A central system, such as a Travel Management Coordination Center, or decentralized system would dynamically schedule and dispatch or modify the route of an in-service vehicle by matching compatible trips together. The application may consider both public and private (e.g., taxi) transportation providers and may include paratransit, fixed -route bus, flex-route bus, and rail transit services.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	other	TI
Mobility	INFLO	Cooperative Adaptive Cruise Control	Cooperative adaptive cruise control can significantly increase traffic throughput by tightly coordinating in-platoon vehicle movements to reduce headways between vehicles. The lead vehicle broadcasts location, heading and speed. CACC-enabled following vehicles automatically adjust speed, acceleration and following distance. A traffic management center observes traffic flow and adjusts the gap policy to manage road capacity. This is primarily a V2V application and the assessment here describes only the V2I component addressing the gap policy.	Fixed	No	Required	Exclusive	Lane Level	Non-Critical	Yes	Yes	Low	Not Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific
Mobility	INFLO	Queue Warning (Q-WARN) (Cellular)	Vehicle contacts server and provides speed and location data. Back office app (server) correlates data from this and other vehicles and determines that a queue is forming. Server provides this information to vehicle in same transaction, or vehicle subsequently contacts server and requests road warning/alert info based on its location and direction. OBU receives queue warning info and determines if a warning is appropriate.	None	No	None	N/A	Lane Level	Non-Critical	No	Yes	Medium	Required	Benefits Require Threshold Deployment Level	Privacy	BSM1	TI

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	INFLO	Queue Warning (Q-WARN) (DSRC)	DSRC equipped vehicles transmit Basic Safety Messages. RSUs along the corridor receive these messages and a server determines, from them, that a queue is forming at some location on the corridor. RSUs along the corridor broadcast queue warning messages (location and direction). OBUs along corridor receive queue warning messages and determine if a warning/alert is appropriate.	Fixed	No	Required	Exclusive	Lane Level	Non-Critical	No	Yes	Low	Required	Benefits Require Threshold Deployment Level	None	BSM1	TI
Mobility	INFLO	Speed Harmonization SPD-HARM (Cellular)	The INFLO SPD-HARM application concept aims to utilize connected vehicle [V2V and] V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles.	None	No	None	N/A	Lane Level	Non-Critical	Yes	Yes	Medium	Not Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific
Mobility	INFLO	Speed Harmonization SPD-HARM (DSRC)	The INFLO SPD-HARM application concept aims to utilize connected vehicle V2V and V2I communication to detect the precipitating roadway or congestion conditions that might necessitate speed harmonization, to generate the appropriate response plans and speed recommendation strategies for upstream traffic, and to broadcast such recommendations to the affected vehicles.	Fixed	No	Required	Exclusive	Lane Level	Non-Critical	Yes	Yes	Low	Not Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific
Mobility	MMITSS	Emergency Vehicle Preemption	Emergency vehicle approaching signalized intersection broadcasts signal preemption/priority request. RSU in vicinity of intersection receives request and, based on state of signal, other preemptions/extensions in progress, and authority of emergency vehicle, determines if the request will be honored. RSU sends response message, and may change the signal timing to support the request	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Low	Required	Benefits Realizable Day One	None	BSM1+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	MMITSS	Freight Signal Priority (FSP)	Freight vehicle approaching signalized intersection broadcasts signal priority request. RSU in vicinity of intersection receives request and, based on state of signal, other preemptions/extensions in progress, and authority of freight vehicle, determines if the request will be honored. RSU sends response message, and may change the signal timing to support the priority request	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Low	Required	Benefits Realizable Day One	None	BSM1+other	App-specific
Mobility	MMITSS	Intelligent Traffic Signal System (I-SIG)	The use of high-fidelity data collected from vehicles through wireless communications will facilitate accurate measurements and predictions of lane-specific platoon flow, platoon size, and other driving characteristics. Real-time data availability has the potential to transform how traffic signal systems are designed, implemented and monitored. Developing new systems that use data via V2V and V2I wireless communications to control signals in order to maximize flows in real-time can improve traffic conditions significantly. The ISIG plays the role of an over-arching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall arterial network performance. In addition, the interface (or data flow) between arterial signals and ramp meters (essentially traffic signals installed on freeway onramps) must be considered also. Note, however, that the development of ramp metering algorithms — the metering rates to optimize freeway flow — is not included in the scope of this application.	Fixed	Yes	Optional	Exclusive	Lane Level	Non-Critical	No	Yes	Low	Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	MMITSS	Pedestrian Mobility	MMITSS will facilitate pedestrian mobility at intersections for meeting pedestrians' special needs or for balanced utilization of the intersection by vehicles and pedestrians. This application will integrate traffic and pedestrian information from roadside or intersection detectors and new forms of data from wirelessly connected pedestrian-carried mobile devices (nomadic devices) to activate dynamic pedestrian signals or to inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time Signal Phase and Timing (SPaT) information. In some cases, priority will be given to pedestrians, such as handicapped pedestrians that need additional crossing time, or in special conditions (e.g. weather) where pedestrians may warrant priority. This application will enable a "pedestrian call" to be sent to the traffic controller from a nomadic device of registered handicapped pedestrian after confirming the direction and orientation of the roadway that the pedestrian is intending to cross. The MMITSS will be able to manage pedestrian crosswalks when certain predetermined conditions occur in order to improve efficiency of the intersection utilization or to avoid overcrowding pedestrian at intersections.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Critical	No	Yes	Low	Required	Benefits Require Threshold Deployment Level	Privacy	BSM1+other	SPaT
Mobility	MMITSS	Transit Signal Priority (TSP)	Transit vehicle approaching signalized intersection broadcasts signal priority request. RSU in vicinity of intersection receives request and, based on state of signal, other preemptions/extensions in progress, and authority/schedule of transit vehicle, determines if the request will be honored. RSU sends response message, and may change the signal timing to support the priority request	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Low	Required	Benefits Realizable Day One	None	BSM1+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	R.E.S.C.U.M. E.	Emergency Communications and Evacuation (EVAC) (Cellular)	The purpose of the EVAC application is to facilitate coordination for evacuees. During an incident, the EMA would have the ability to push information such as evacuation orders by evacuation zone to registered users of the system (either those that have pre-registered, or real-time registration during the event) through the EVAC application. The TMC working with the EOC will use the EVAC application to coordinate the listing of available transportation resources to assist with special needs evacuation. The EVAC application will dispatch and route the transportation resources to the appropriate location, while providing communications updates to those individuals in need of assistance. For non-special needs evacuees, the EVAC application will provide evacuation route guidance that accounts for road conditions, traffic conditions, and final destination. If the evacuee intends to go to a shelter or hotel, the EVAC application will provide a shelter matching function to help the evacuee determine where he should go based upon shelter availability and capability (e.g., does the shelter accept pets?). Should the evacuee need a resource such as food or fuel along the evacuation route, the EVAC application can provide recommended stops and will incorporate user input feedback to provide information (though not necessarily validated information) on the availability of the needed resource. Additionally, the EVAC application will provide a Return of Evacuees Function to provide evacuees with information regarding when they can return to their area of the jurisdiction and provide recommended routes taking into consideration road conditions (i.e., roadway infrastructure and traffic lights).	None	No	None	N/A	Lane Level	Non-Critical	No	Yes	High	Not Required	Benefits Realizable Day One	None	Position	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Mobility	R.E.S.C.U.M. E.	Emergency Communications and Evacuation (EVAC) (DSRC)	The purpose of the EVAC application is to facilitate coordination for evacuees. During an incident, the EMA would have the ability to push information such as evacuation orders by evacuation zone to registered users of the system (either those that have pre-registered, or real-time registration during the event) through the EVAC application. The TMC working with the EOC will use the EVAC application to coordinate the listing of available transportation resources to assist with special needs evacuation. The EVAC application will dispatch and route the transportation resources to the appropriate location, while providing communications updates to individuals in need of assistance. For non-special needs evacuees, the EVAC application will provide evacuation route guidance that accounts for road conditions, traffic conditions, and final destination. If the evacuee intends to go to a shelter or hotel, the EVAC application will provide a shelter matching function to help the evacuee determine where he or she should go based upon shelter availability and capability (e.g., does the shelter accept pets?). Should the evacuee need a resource such as food or fuel along the evacuation route, the EVAC application can provide recommended stops and will incorporate user input feedback to provide information (though not necessarily validated information) on the availability of the needed resource. Additionally, the EVAC application will provide a Return of Evacuees Function to provide evacuees with information regarding when they can return to their area of the jurisdiction and provide recommended routes taking into consideration road conditions (i.e., roadway infrastructure and traffic lights).	Portable	No	Required	Limited Domains	Lane Level	Non-Critical	No	Yes	High	Not Required	Benefits Realizable Day One	None	Position	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
AERIS	AERIS	Dynamic Eco-Routing (Cellular)	The Dynamic Eco-Routing application determines the most eco-friendly route, in terms of minimum fuel consumption or emissions, for individual travelers. This application is similar to current navigation systems, which determine the route based on the shortest path or minimum time. This application also recommends routes that produce the fewest emissions or reduce fuel consumption based on historical, real-time, and predicted traffic and environmental data (e.g., prevailing weather conditions).	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	Privacy	BSM1	App-specific
AERIS	AERIS	Dynamic Eco-Routing (DSRC)	The Dynamic Eco-Routing application determines the most eco-friendly route, in terms of minimum fuel consumption or emissions, for individual travelers. This application is similar to current navigation systems, which determine the route based on the shortest path or minimum time. This application also recommends routes that produce the fewest emissions or reduce fuel consumption based on historical, real-time, and predicted traffic and environmental data (e.g., prevailing weather conditions).	Fixed	No	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	Privacy	BSM1+other	TI
AERIS	AERIS	Eco-Approach and Departure at a Signalized Intersection	The Eco-Approach and Departure at Signalized Intersections application uses wireless data communications sent from roadside equipment (RSU) to vehicles and encourages green approaches to signalized intersections, including broadcasting signal phase and timing (SPaT) and geographic information description (GID). The application also considers vehicle status messages, sent from nearby vehicles using V2V communications. Upon receiving this information, onboard equipment (OBU) units perform calculations to provide speed advice to the vehicle driver, allowing the driver to adapt the vehicle's speed to pass the next traffic signal on green or to	Fixed	Yes	Required	Exclusive	Localized Geometric	Critical	Yes	Yes	Medium	Required	Benefits Realizable Day One	None	BSM1+2	SPaT+GIDs

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			decelerate to a stop in the most eco-friendly manner. This application also considers a vehicle's acceleration as it departs from a signalized intersection.														
AERIS	AERIS	Eco-Freight Signal Priority	Freight vehicle approaching signalized intersection broadcasts signal priority request. RSU in vicinity of intersection receives request and, based on state of signal, other preemptions/extensions in progress, environmental factors, and authority of freight vehicle, determines if the request will be honored. RSU sends response message, and may change the signal timing to support the priority request.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Medium	Required	Benefits Realizable Day One	None	BSM1+other	App-specific
AERIS	AERIS	Eco-Integrated Corridor Management Decision Support System (Cellular)	The Eco-Integrated Corridor Management Decision Support System application involves using historical, real-time, and predictive traffic and environmental data on arterials, freeways, and transit systems to determine operational decisions that are environmentally beneficial to the corridor. The Eco-Integrated Corridor Management (Eco-ICM) Decision Support System is a data-fusion system that collects information from various multimodal systems. Data from these systems is then used to determine operational strategies for arterials, freeways, and transit that minimize the environmental impact of the corridor. For example, on a code red air quality day, the Eco-ICM Decision Support System may recommend eco-signal timing plans, eco-ramp metering strategies, eco-speed limits, and recommendations for increased transit service.	None	Yes	Required	Exclusive	Lane Level	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	Policy	BSM1	TI

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
AERIS	AERIS	Eco-Integrated Corridor Management Decision Support System (DSRC)	The Eco-Integrated Corridor Management Decision Support System application involves using historical, real-time, and predictive traffic and environmental data on arterials, freeways, and transit systems to determine operational decisions that are environmentally beneficial to the corridor. The Eco-Integrated Corridor Management (Eco-ICM) Decision Support System is a data-fusion system that collects information from various multimodal systems. Data from these systems is then used to determine operational strategies for arterials, freeways, and transit that minimize the environment impact of the corridor. For example, on a code red air quality day, the Eco-ICM Decision Support System may recommend eco-signal timing plans, eco-ramp metering strategies, eco-speed limits, and recommendations for increased transit service.	Fixed	Yes	Required	Limited Domains	Lane Level	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	Policy	BSM1+2	App-specific
AERIS	AERIS	Eco-Speed Harmonization (Cellular)	Vehicle contacts server and provides speed and location data. Back office app (server) determines optimal speed for traffic flow to minimize environmental impact. Server provides this information to vehicle in same transaction, or vehicle subsequently contacts server and requests road info based on its location and direction. Vehicle OBU receives speed info and informs driver about optimal speed.	None	No	None	N/A	Road Network	Non-Critical	No	Yes	High	Required	Benefits Require Threshold Deployment Level	None	Position	TI
AERIS	AERIS	Eco-Speed Harmonization (DSRC)	Vehicles broadcast speed and location data (BSM) RSU receives BSMs and either determines optimal speed locally (at RSU) or sends info to back office. Local or back office app determines optimal speed for traffic to minimize environmental impact, and sends this to the RSUs in the area. RSUs broadcast speed advisories to vehicles. Vehicles inform drivers about optimal speed.	Fixed	No	Optional	Exclusive	Road Network	Non-Critical	No	Optional	High	Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
AERIS	AERIS	Eco-Traffic Signal Timing	Vehicles Broadcast data such as vehicle location, speed, GHG and other emissions data to RSUs. RSU application (or remote app at TMC) determines the optimal operation of the traffic signal system based on the data, and adjusts the signal system timing.	Fixed	Optional	Optional	Exclusive	Road Network	Non-Critical	No	Yes	Medium	Required	Benefits Require Threshold Deployment Level	None	BSM1+other	SPaT
AERIS	AERIS	Eco-Transit Signal Priority	Transit vehicle approaching signalized intersection broadcasts signal priority request. RSU in vicinity of intersection receives request and, based on state of signal, other preemptions/extensions in progress, environmental factors, and authority/schedule of transit vehicle, determines if the request will be honored. RSU sends response message, and may change the signal timing to support the priority request.	Fixed	Yes	Optional	Exclusive	Localized Geometric	Non-Critical	No	No	Medium	Required	Benefits Realizable Day One	None	BSM1+other	App-specific
Smart Roadside	Smart Roadside	E-Screening / Virtual Weigh Station (Cellular)	E-Screening is a key component of the information collection systems and communications networks that support commercial vehicle operation – referred to as the Commercial Vehicle Information Systems and Networks (CVISN). E-Screening defined at the highest-level is when a commercial vehicle is identified automatically and assessed for safety while the vehicle is in motion. With E-Screening, safe and legal vehicles are allowed to continue on their route. Enforcement resources can be used to target unsafe vehicles and carriers. Currently, E-Screening occurs at fixed stations and on-demand verification sites. Truck Size and Weight researchers conducted an Enforcement Study in 2008 and 2009 to develop the foundation for roadside technologies that can be used to improve truck size and weight enforcement. Outcomes of this study include a concept of operations for a virtual weigh station and a virtual weigh station/e-Permitting architecture. The	None	No	None	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			virtual weigh station concept will further increase the number of electronic screenings and depending upon the virtual weigh station configuration, will provide a more enhanced safety and credentials assessment.														
Smart Roadside	Smart Roadside	E-Screening / Virtual Weigh Station (DSRC)	E-Screening is a key component of the information collection systems and communications networks that support commercial vehicle operation – referred to as the Commercial Vehicle Information Systems and Networks (CVISN). E-Screening defined at the highest-level is when a commercial vehicle is identified automatically and assessed for safety while the vehicle is in motion. With E-Screening, safe and legal vehicles are allowed to continue on their route. Enforcement resources can be used to target unsafe vehicles and carriers. Currently, E-Screening occurs at fixed stations and on-demand verification sites. Truck Size and Weight researchers conducted an Enforcement Study in 2008 and 2009 to develop the foundation for roadside technologies that can be used to improve truck size and weight enforcement. Outcomes of this study include a concept of operations for a virtual weigh station and a virtual weigh station/e-Permitting architecture. The virtual weigh station concept will further increase the number of electronic screenings and depending upon the virtual weigh station configuration, will provide a more enhanced safety and credentials assessment.	Fixed	Yes	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	Medium	Required	Benefits Realizable Day One	None	BSM1+2+other	App-specific
Smart Roadside	Smart Roadside	Smart Truck Parking (Cellular)	Truck Parking research currently includes two projects, which will provide commercial vehicle parking information so that commercial drivers can make advanced route planning decisions based on hour-of-service constraints, location	None	No	None	Limited Domains	Localized Geometric	Non-Critical	Yes	Yes	High	Not Required	Benefits Realizable Day One	None	other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			and supply of parking, travel conditions, and loading/unloading.														
Smart Roadside	Smart Roadside	Smart Truck Parking (DSRC)	Truck Parking research currently includes two projects, which will provide commercial vehicle parking information so that commercial drivers can make advanced route planning decisions based on hour-of-service constraints, location and supply of parking, travel conditions, and loading/unloading.	Fixed	No	Required	Limited Domains	Localized Geometric	Non-Critical	Yes	Yes	Medium	Not Required	Benefits Realizable Day One	None	other	App-specific
Smart Roadside	Smart Roadside	Wireless Roadside Inspection (Cellular)	WRI research is being done to increase the number and frequency of safety inspections at the roadside and obtain data about the commercial vehicle and its driver. This safety data is termed the Safety Data Message Set (SDMS) and can be transmitted directly from the vehicle to the roadside and from a carrier system to a government system. The initial SDMS will contain basic identification data (for driver, vehicle, and carrier), the driver's log, a small set of vehicle measurement data, and selected vehicle status information. Enforcement systems and staff will use the SDMS to support E-Screening and inspections at locations such as staffed roadside sites, virtual weigh stations, and on-demand verification sites.	None	No	None	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2+other	App-specific
Smart Roadside	Smart Roadside	Wireless Roadside Inspection (DSRC)	WRI research is being done to increase the number and frequency of safety inspections at the roadside and obtain data about the commercial vehicle and its driver. This safety data is termed the Safety Data Message Set (SDMS) and can be transmitted directly from the vehicle to the roadside and from a carrier system to a government system. The initial SDMS will contain basic	Fixed	Yes	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	Medium	Required	Benefits Realizable Day One	None	BSM1+2+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			identification data (for driver, vehicle, and carrier), the driver's log, a small set of vehicle measurement data, and selected vehicle status information. Enforcement systems and staff will use the SDMS to support E-Screening and inspections at locations such as staffed roadside sites, virtual weigh stations, and on-demand verification sites.														
IBC	IBC	Approach Lane Use Management	One of the contributing factors to long wait times at international border crossings is improper management of approach lanes where different types of vehicles (e.g., trucks, cars, NEXUS, FAST, non-SENTRI) merge and cross paths. Lanes are segregated close to the inspection facilities, but not further inland. This situation is especially true in MX. With adequate density of OBUs, wait times of different lane types can be estimated and subsequently directed to appropriate lanes. RSUs to identify OBUs could be fixed or portable, but backhaul to central location is optional since approach management can be done locally. Lane level mapping support will be required to identify different approach lanes. Siting dependencies of RSUs are not critical if OBUs can be read in any direction. Management of data collected by RSUs is not required and so is the back office service since a central server connected to all RSUs can evaluate approach lane management strategies and send messages to overhead signs and OBUs inside vehicles. Data connection between vehicle and OBU is not required. Larger the deployment of OBUs more effective would be lane approach management strategies because they would require accurate estimation of vehicular volume on different approach lanes.	Fixed	Yes	Optional	Exclusive	Lane Level	Non-Critical	No	No	Medium	Not Required	Benefits Require Threshold Deployment Level	None	Position	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
IBC	IBC	Automated Toll/User Fee Collection and Administration	Majority of border crossings are tolled in different ways (e.g., cash, electronic) by local government agencies. Commercial vehicles to enter US also have to purchase user fees from CBP, which in turn provides RFID transponder (sticker) to identify these vehicles. Similar to highway tolling operation, physical location of RSUs are fixed with backhaul communication to a central location to credit toll usage. Latency is critical since toll collections are typically done close to Federal facility and faster toll collection means less chance of longer queue to the Federal facility. Vehicle to OBU is not required. However, larger deployments of OBUs, toll collection agencies will find it to be more cost effective.	Fixed	Yes	Required	Exclusive	Lane Level	Critical	Yes	Yes	Low	Not Required	Benefits Realizable Day One	None	None	App-specific
IBC	IBC	Automated Toll/User Fee Collection and Administration (DSRC)	Vehicle encounters RSU at or prior to tolled facility (bridge, roadway entrance, etc.); RSU announces toll requirement. Vehicle sends request for toll payment (possibly indicating type of vehicle) to RSU. RSU executes payment (either directly or via back office account transaction). RSU provides receipt (generally including occupancy data) to vehicle. During subsequent RSU encounters on tolled facility, RSU requests validation of paid toll; vehicle sends receipt to RSU to avoid enforcement actions.	Fixed	Optional	Required	Limited Domains	Localized Geometric	Critical	Yes	Yes	Low	Not Required	Benefits Realizable Day One	Privacy	BSM1+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
IBC	IBC	Border Crossing Performance Monitoring	Border crossing performance monitoring is primarily based on wait and crossing times experienced by vehicles crossing the border. This application is directly tied to Wait Time and Traveler Information application. The same RSUs and OBUs can be used for both applications. Backhaul communication is required to send the identification information to a central database. Lane level mapping support will be required since different types of lanes are designated based on various programs implemented by Federal agencies (e.g., FAST, NEXUS/SENTRI, READY). Location of RSUs or siting dependency is not critical if OBUs as long as a good sample of OBUs can be identified. Management of collected is required, however back office services are not critical since database can be maintained with significant downtime because performance measurement does not have a real-time need. The same latency that applies to Wait Time application applies here as well. OBU does not communicate with the vehicle. Because statistically significant sample is required, benefits require minimum threshold of deployment.	Fixed	Yes	Required	Limited Domains	Lane Level	Non-Critical	Yes	No	High	Not Required	Benefits Require Threshold Deployment Level	None	BSM1+2+other	App-specific
IBC	IBC	Excess Emission Identification from Trucks and Cars [Emissions Analysis]	Goal is to identify vehicles with unacceptable emissions levels at border crossings. Data from the vehicle's engine management system is sent to infrastructure. Emissions are rated and a message sent to locals to hold or pass vehicle as appropriate. Very likely interface to local external sensors.	Portable or Fixed	Yes	Required	Exclusive	None	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	Policy	BSM1+2+other	None

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
IBC	IBC	Excess Emission Reduction from Trucks and Cars [Emissions Analysis]	Long wait times at international border crossings have contributed to proliferation of greenhouse gas and particle matter emissions for communities close to the border. This situation is especially true in MX. Idling and emissions data from properly designed CAN bus and OBUs can be read by RSUs to estimate environmental performance of border crossings. RSUs would send the data collected from OBUs to a central location. Siting dependencies of RSUs are not critical if OBUs can be read in any direction. Management of data collected by RSUs is not required and so is the back office service since a central server connected to all RSUs can determine environmental performance parameters using a pre-designed algorithms and data warehouse. Data connection between vehicle and OBU is required to send CAN bus data and other emissions data. The larger the deployment of OBUs the more samples would be available for more precise estimation of emissions.	Fixed	Yes	Required	Limited Domains	None	Non-Critical	No	No	High	Required	Benefits Require Threshold Deployment Level	None	BSM1+2+other	App-specific
IBC	IBC	HAZMAT Monitoring and Response	Millions of tons of HAZMAT cross the international border daily, which has created HAZMAT corridors going through border towns and cities. Responding to HAZMAT related incidents typically fall under the jurisdictions of local governments (and some state/province). However, they have no clue as to where, how, what kind of HAZMAT will be passing through their jurisdictions. On the one hand Federal agencies (CBP, CBSA, Aduanas) know before HAZMAT arrives at the border. The information can be easily shared with local agencies, but they would also want to know the fidelity of the HAZMAT being transported so that they can prepare necessary resources to respond to HAZMAT incidents.	Portable	Yes	Required	Limited Domains	Road Network	Non-Critical	No	No	High	Required	Benefits Realizable Day One	Privacy	BSM1+other	None

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			Companies have developed OBUs that monitor vital stats of the HAZMAT content, which can be easily transmitted through RSUs and on to local agencies. These RSUs can be fixed or portable with backhaul communication to inform first responders. Road network level mapping support would be required with non-critical siting dependencies. At this time, there is no critical need to manage data collected by RSUs and have a back office service. Latency to read OBUs in milliseconds is not critical. HAZMAT content sensors would be connected to other OBU or could be the only OBU.														
IBC	IBC	Pre-Clearance, Expedited Screening of Cars and Trucks	The purpose of this application is electronically screen carriers, shippers, motorists, and vehicles while they enter US, CA, MX border with a goal of reducing long wait times at border and for enforcement agencies to focus resources on high value targets. Pre-clearance of vehicles can only be performed at certain fixed locations e.g., CBP, CBSA, Aduana, FMCSA inspection facilities. Backhaul communication is required to query identified vehicles and bring up security and safety related information back to terminals to inspection officers. Mapping support is not required since proximity between RSU and vehicles with OBU would be enough. Location of RSUs or siting dependency is critical since OBUs should be read at close to 100% rate. Management and back office services and applications are required to secure and maintain databases and also integrate with other security related databases shared between international, federal and state agencies. Latency does not have to be in milliseconds, but should not be in minutes either. OBU does not have to communicate with the vehicle.	Fixed	Yes	Required	Exclusive	None	Critical	Yes	Yes	Low	Not Required	Benefits Realizable Day One	Privacy	BSM1+2+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
IBC	IBC	Shipment (Trailer) Tamper Monitoring [Cargo Security]	One of the biggest concerns of Federal enforcement agencies in all three countries is the fidelity of trailers or containers crossing the border. The big question is "are they carrying what they had reported to the agencies that they would be carrying?" Trailers can be easily tampered without the knowledge of shippers en-route. To reduce tampering, fidelity of trailers can be read at fixed locations or preferably portable locations and information sent to a central location to verify that the trailer has not deviated from its original route or opened by unauthorized personnel. Tamper seals constantly communicate with OBUs, which will alert carrier/shipper and enforcement agencies through RSUs. Backhaul could happen through cellular network or through wireline communication depending on where RSUs are placed and how they are connected to a central repository. Road level mapping support is sufficient, and RSUs do not have siting dependencies unless they can receive data from OBUs even with some latency.	Portable	Yes	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	Privacy	BSM1+other	None
IBC	IBC	Truck Safety Condition Monitoring and Reporting	Millions of trucks cross the border every day and enter local/state/provincial roadways. Their safety is important to rest of the traveling public. Millions of labor hours are spent on random inspections of trucks by agencies in all three countries. If OBU can be integrated with a vehicle CAN bus, then some vehicle diagnostic information (e.g., brake conditions, engine conditions) can be relayed back to carriers/drivers and enforcement officers to remove unfit vehicles from crossing the border. Information on truck's diagnostics and physical condition along with its identification information will be read at fixed locations e.g., FMCSA and	Fixed	Yes	Required	Exclusive	None	Critical	Yes	No	High	Required	Benefits Realizable Day One	Policy	BSM1+2+other	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			state/provincial inspection facilities and provided to enforcement officers for review. Backhaul communication is required to query historical safety records of carriers, drivers. Mapping support is not required since proximity between RSU and vehicles with OBU would be enough. Location of RSUs or siting dependency is critical since OBUs should be read at close to 100% rate. Management of collected data is required to update archive of safety related databases and citation records. Latency does not have to be in milliseconds, but should not be in minutes either. OBU have to communicate with vehicle's CAN bus to record vehicle defects.														
IBC	IBC	Wait Time and Other Traveler Information	Wait times for vehicles crossing the border are measured by identifying a sample of vehicles at several fixed locations while they are waiting to cross the border. Backhaul communication is required to send the identification information to a central database. Lane level mapping support will be required since different types of approach lanes are designated based on various programs implemented by Federal agencies (e.g., FAST, NEXUS/SENTRI, READY). Location of RSUs or siting dependency is not critical for OBUs as long as a good sample of OBUs can be identified. Management and back office services and applications are required to secure and maintain databases and provide expected wait and crossing times of vehicles to motorists, and other users. Latency does not have to be in milliseconds, but should not be in minutes either. OBU does not have to communicate with the vehicle. Because statistically significant sample is required, benefits require minimum threshold of deployment.	Fixed	Yes	Required	Exclusive	Lane Level	Non-Critical	Yes	Yes	High	Not Required	Benefits Require Threshold Deployment Level	None	BSM1	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Road Weather	Road Weather	[Weather] Information for Freight Carriers (Cellular)	This application can be considered a special case of the Road-Weather Motorist Advisory and Warning System. Truck drivers have similar access to the variety of traveler information systems that are available to all road users. However, the available traveler information options are almost always intended for use by passenger car drivers. The limitations of the existing systems with respect to the type and quality of information provided have particular impacts on motor carriers.	None	No	None	N/A	Lane Level	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	[Weather] Information for Freight Carriers (DSRC)	This application can be considered a special case of the Road-Weather Motorist Advisory and Warning System. Truck drivers have similar access to the variety of traveler information systems that are available to all road users. However, the available traveler information options are almost always intended for use by passenger car drivers. The limitations of the existing systems with respect to the type and quality of information provided have particular impacts on motor carriers.	Fixed	No	Required	Limited Domains (Whitelist)	Lane Level	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	Enhanced Maintenance Decision Support System (Cellular)	Enhanced Maintenance Decision Support System will provide the existing federal prototype MDSS with expanded data acquisition from connected vehicles. Snow plows, other agency fleet vehicles, and other vehicles operated by the general public will provide road-weather connected vehicle data to the Enhanced-MDSS, which will use this data to generate improved plans and recommendations to maintenance personnel. In turn, enhanced treatment plans and recommendations will be provided back to the snow plow operators and drivers of agency maintenance vehicles.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Road Weather	Road Weather	Enhanced Maintenance Decision Support System (DSRC)	Enhanced Maintenance Decision Support System will provide the existing federal prototype MDSS with expanded data acquisition from connected vehicles. Snow plows, other agency fleet vehicles, and other vehicles operated by the general public will provide road-weather connected vehicle data to the Enhanced-MDSS, which will use this data to generate improved plans and recommendations to maintenance personnel. In turn, enhanced treatment plans and recommendations will be provided back to the snow plow operators and drivers of agency maintenance vehicles.	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	Information and Routing Support for Emergency Responders (Cellular)	Emergency responders, including ambulance operators, paramedics, and fire and rescue companies, have a compelling need for the short, medium, and long time horizon road-weather alerts and warnings. This information can help drivers safely operate their vehicles during severe weather events and under deteriorating road conditions. Emergency responders also have a particular need for information that affects their dispatching and routing decisions. Information on weather-impacted travel routes, especially road or lane closures due to snow, flooding, and wind-blown debris, is particularly important. Low latency road-weather information from connected vehicles for specific roadway segments, together with information from other surface weather observation systems, such as flooding and high winds, will be used to determine response routes, calculate response times, and influence decisions to hand-off an emergency call from one responder to another responder in a different location.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Road Weather	Road Weather	Information and Routing Support for Emergency Responders (DSRC)	Emergency responders, including ambulance operators, paramedics, and fire and rescue companies, have a compelling need for the short, medium, and long time horizon road-weather alerts and warnings. This information can help drivers safely operate their vehicles during severe weather events and under deteriorating road conditions. Emergency responders also have a particular need for information that affects their dispatching and routing decisions. Information on weather-impacted travel routes, especially road or lane closures due to snow, flooding, and wind-blown debris, is particularly important. Low latency road-weather information from connected vehicles for specific roadway segments, together with information from other surface weather observation systems, such as flooding and high winds, will be used to determine response routes, calculate response times, and influence decisions to hand-off an emergency call from one responder to another responder in a different location.	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	Information for Maintenance and Fleet Management Systems (Cellular)	In this concept, connected vehicle information is more concerned with non-road-weather data. The data collected may include powertrain diagnostic information from maintenance and specialty vehicles; the status of vehicle components; the current location of maintenance vehicles and other equipment; and the types and amounts of materials onboard maintenance vehicles, and will be used to automate the inputs to Maintenance and Fleet Management Systems on year-round basis. In addition, desirable synergies can be achieved if selected data relating to winter maintenance activities, such as the location and status of snow plows or the	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			location and availability of deicing chemicals, can be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies.														
Road Weather	Road Weather	Information for Maintenance and Fleet Management Systems (DSRC)	In this concept, connected vehicle information is more concerned with non-road-weather data. The data collected may include powertrain diagnostic information from maintenance and specialty vehicles; the status of vehicle components; the current location of maintenance vehicles and other equipment; and the types and amounts of materials onboard maintenance vehicles, and will be used to automate the inputs to Maintenance and Fleet Management Systems on year-round basis. In addition, desirable synergies can be achieved if selected data relating to winter maintenance activities, such as the location and status of snow plows or the location and availability of deicing chemicals, can be passed to an Enhanced-MDSS to refine the recommended winter weather response plans and treatment strategies.	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	Motorist Advisories and Warnings (Cellular)	Information on segment-specific weather and road conditions is not broadly available, even though surveys suggest that this information is considered to be of significant importance to travelers. The ability to gather road-weather information from connected vehicles will dramatically change this situation. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to travelers through a variety of means as alerts and advisories within a few minutes. In combination with observations and forecasts from other sources and with additional processing, medium-term advisories of the next two to	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
			twelve hours to long-term advisories for more than twelve hours into the future can also be provided to motorists.														
Road Weather	Road Weather	Motorist Advisories and Warnings (DSRC)	Information on segment-specific weather and road conditions is not broadly available, even though surveys suggest that this information is considered to be of significant importance to travelers. The ability to gather road-weather information from connected vehicles will dramatically change this situation. Information on deteriorating road and weather conditions on specific roadway segments can be pushed to travelers through a variety of means as alerts and advisories within a few minutes. In combination with observations and forecasts from other sources and with additional processing, medium-term advisories of the next two to twelve hours to long-term advisories for more than twelve hours into the future can also be provided to motorists.	Fixed	No	Required	Limited Domains	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Realizable Day One	None	BSM1+2	App-specific
Road Weather	Road Weather	Variable Speed Limits for Weather-Responsive Traffic Management (Cellular)	Connected vehicle systems provide opportunities to enhance the operation of VSL systems and dramatically improve work zone safety during severe weather events. Additional road-weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed limits to reflect prevailing weather and road conditions.	None	No	None	N/A	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	None	BSM1+2	App-specific
Road Weather	Road Weather	Variable Speed Limits for Weather-Responsive Traffic Management (DSRC)	Connected vehicle systems provide opportunities to enhance the operation of VSL systems and dramatically improve work zone safety during severe weather events. Additional road-weather information can be gathered from connected vehicles and used in algorithms to refine the posted speed limits to reflect prevailing weather and road conditions.	Fixed	Yes	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Required	Benefits Require Threshold Deployment Level	None	BSM1+2	App-specific

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Agency Data Applications	CV-enabled Traffic Studies	CV-enabled Origin-Destination Studies (Cellular)	Obtain a general location near a vehicle's start and end of trip, provides path in between.	None	No	None	N/A	None	Non-Critical	Yes	No	High	Not Required	Benefits Realizable Day One	Privacy	Position	None
Agency Data Applications	CV-enabled Traffic Studies	CV-enabled Origin-Destination Studies (DSRC)	Obtain a general location near a vehicle's start and end of trip, or when the vehicle passes certain locations (freeway on ramps and off ramps).	Portable or Fixed	No	Optional	Exclusive	None	Non-Critical	Yes	No	High	Required	Benefits Realizable Day One	Privacy	BSM1	None
Agency Data Applications	CV-enabled Traffic Studies	CV-enabled Traffic Model Baselineing & Predictive Traffic Studies (DSRC)	Vehicles provide speed information as a function of location and time in order to build a baseline model for analysis, optimized timing plans and predictive studies. Does not require real time connection for the model, real time traffic necessary to capture perturbations to the model.	Portable or Fixed	No	Optional	Exclusive	Road Network	Non-Critical	Yes	No	High	Not Required	Benefits Realizable Day One	None	BSM1	None
Agency Data Applications	CV-enabled Traffic Studies	CV-enabled Turning Movement & Intersection Analysis (DSRC)	Use self-reported paths of vehicles to determine turning ratios, delays by maneuver and other characterizations of an intersection. Not intended for real time optimization of traffic flows. No data provided to vehicles.	Portable or Fixed	No	Optional	Exclusive	None	Non-Critical	Yes	No	High	Not Required	Benefits Realizable Day One	None	BSM1	None
Agency Data Applications	CV-enabled Traffic Studies	Vehicle classification-based Traffic Studies (DSRC)	Ability to associate vehicle type with vehicle behaviors.	Portable or Fixed	No	Optional	Exclusive	Road Network	Non-Critical	Yes	No	High	Not Required	Benefits Realizable Day One	Privacy	BSM1+2	None
Agency Data Applications	Probe Data	Probe-based Pavement Maintenance (Cellular)	Vehicles report the location (and size) of potholes or gross surface roughness. Detection based on vertical wheel movement or body acceleration. Provides quantitative measurement of road quality. Would require additional data for normalization.	None	No	Required	Exclusive	None	Non-Critical	Yes	Optional	High	Required	Benefits Realizable Day One	None	BSM1+2+other	None
Agency Data Applications	Probe Data	Probe-based Pavement Maintenance (DSRC)	Vehicles report the location (and size) of potholes or gross surface roughness. Detection based on vertical wheel movement or body acceleration. Provides quantitative measurement of road quality. Would require additional data for normalization.	Portable or Fixed	No	Required	Exclusive	None	Non-Critical	Yes	Optional	High	Required	Benefits Realizable Day One	None	BSM1+2+other	None

Application Group	Application Bundle	Application	Brief Description	Physical RSU Install.	Roadside Interface to Local Systems	Backhaul Comm.	Backhaul Restrict.	Mapping Support	Siting Depend.	Management of Collected Data	Back Office Services/ Applications	Latency	Vehicle Data Connection	Benefits vs. Deployment Level	Other Depend.	Data Needs from OBU	Data Needs from Infrastruct.
Agency Data Applications	Probe Data	Probe-enabled Traffic Monitoring (Cellular)	Real Time traffic data supplied by connected vehicles.	None	No	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Not Required	Benefits Require Threshold Deployment Level	None	Position	None
Agency Data Applications	Probe Data	Probe-enabled Traffic Monitoring (DSRC)	Real Time traffic data supplied by connected vehicles.	Portable or Fixed	No	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Not Required	Benefits Require Threshold Deployment Level	None	Position	None
Fee Payment	Fee Payment	Congestion Pricing	RSU at boundary of congestion management area sends out announcement that vehicles entering the area will be charged a specified toll/fee. Vehicles send request for fee payment to RSU, and RSU communicates with Back office system to execute payment transaction. Back office provides payment receipt to RSU, and RSU forwards receipt to vehicle. During subsequent RSU encounters, RSU requests validation of paid toll; vehicle sends receipt to RSU to avoid enforcement actions	Fixed	Optional	Required	Exclusive	Road Network	Non-Critical	Yes	Yes	High	Not Required	Benefits Realizable Day One	Privacy	other	App-specific
Fee Payment	Fee Payment	High-occupancy Toll Lanes (DSRC)	Vehicle encounters RSU at or prior to entry to HOT lane; Vehicle sends request for entry to HOT Lane to RSU. Request may include statement of vehicle occupancy. RSU executes payment (either directly or via back office account transaction). RSU provides receipt (generally including occupancy data) to vehicle. During subsequent RSU encounters RSU requests validation of paid toll; vehicle sends receipt to RSU to avoid enforcement actions.	Fixed	Optional	Required	Limited Domains	Localized Geometric	Critical	Yes	Yes	Low	Not Required	Benefits Realizable Day One	Privacy	BSM1+other	App-specific

Appendix B. Detailed Deployment Concepts

Rural Roadway

Current State

Rural roadways include arterials and freeways with higher speeds and infrequent intersections due to the low density of the surrounding land uses. Rural roadways may not follow linear segments or incorporate grid systems due to the locations of connecting towns and availability of right-of-way. Most intersections are un-signalized and have low-volume side street approaches, although some locations, such as rural highways, may have higher traffic volumes. The most common form of this roadway type is a two-lane undivided highway with intermittent warning signs of upcoming roadway conditions. Some of the most important needs for travelers in these areas are warnings of highway configurations that may present safety hazards (for example, curves, intersections and rail grade crossings), road weather information so travelers know if it is safe to take a certain route, and road work information to know if there are lane closures or detours.

Minor rural roads are also included in this section, but are not specifically illustrated in this analysis since deployment on these roads would likely be linked to deployment on intersecting higher-capacity roadways. When there are deployments, they would include applications such as stop sign violation and gap assist applications for intersection approaches.

While some rural areas may have deployed ITS equipment this is not widespread, typically due to limited availability to communication or power. For the purposes of this setting description, it has been assumed no ITS infrastructure has been deployed.

Concept Description

The concept for the rural roadway setting focuses on safety applications conditioned by roadway configuration—such as curves, intersections and work zones—and on roadway conditions. Some of these applications would operate by providing information about the roadway strictly from the infrastructure—the roadside or a back office system. Other applications appropriate to a rural setting would collect probe data messages containing location, speed, heading and other data (for example, traction control system actuations, air temperature, and windshield wiper state) from vehicles for aggregation and synthesis into traveler information.

DSRC Concept

The deployment of connected vehicle field equipment in a rural roadway setting could include a DSRC radio to communicate with a suitably-equipped vehicle. Appropriate installation locations for the DSRC roadside unit (RSU) will be in advance of the point where a vehicle or operator must react to the

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

particular situation and may therefore depend on performance requirements specific to the application. If the application is intended to provide a message to a vehicle operator, the placement of the RSU should be such that the location of the message delivery to the operator along the roadway is similar to the location of static signage that would provide a like message, according to the Manual on Uniform Traffic Control Devices (MUTCD).

If the deployed applications include collecting probe data, the data would be cached on the vehicle until it could be transmitted to an RSU. RSU placement for probe data collection could coincide with RSUs deployed for other purposes and would depend primarily on the geography over which data collection was desired.

In certain rural settings with clear lines of sight, DSRC radios could be expected to have a reliable communication range of up to one-quarter mile. However, terrain issues, such as hills, curves, and trees, would be expected to limit this range. This range is also dependent upon the power of the radio, the directionality of the antenna, and the height of the antenna.

Cellular Concept

Vehicles equipped with cellular data (for example, LTE) modems would send information requests to a server at periodic intervals (e.g., every 100 meters or three seconds) as they travel along the roadway. The request would include the current location and direction of travel. The server would then provide back a message including any roadway alerts associated with segments or timeframes for which the driver would need actionable information. The vehicle system would then alert/inform the driver accordingly. The original request could also include vehicle operational data (speed, location, etc.) so that the message transaction would implement both probe data collection and roadway messages simultaneously.

This concept could support several potential applications in a rural roadway setting. The illustration in Figure 12 shows one example for a curve speed warning application using DSRC or cellular communications where advanced driver information is provided to help negotiate the downstream roadway conditions.

Field Infrastructure

The connected vehicle field infrastructure for a rural roadway setting would consist of connected vehicle field equipment that includes a DSRC radio and associated communication equipment mounted to a utility pole or sign pole. Power would be provided by a connection to a utility power drop providing utilization voltage of 120VAC at a service cabinet, or a solar panel providing DC voltage, mounted to a cabinet atop a warning sign pole. The use of solar power would be dependent on the area, especially in northern climates where daylight is limited in the winter and where panels get covered in snow, as well as the region's predictability for cloud cover. Other power considerations are discussed in Section 3.8.

For a rural setting, available roadside infrastructure will generally be limited to existing utility poles or a new pole dedicated to connected vehicle applications as there are generally very few existing ITS device, traffic signal, or lighting installations.

Backhaul Communications

Backhaul communication in the form of copper or fiber line communications is typically not available in a rural setting as the roadway facility is often remote and far from an established wireline communications network. If cellular coverage or a state-operated communications network (such as 800 MHz radio) exists in the rural region of interest, these networks can provide any required communication capabilities to a back-office facility for remote monitoring or for applications where a backend server is utilized. The Common Considerations section discusses various backhaul technology alternatives.

If backhaul coverage does not exist, the connected vehicle rural applications would need to be localized in the case of DSRC just at the region of interest, and the roadside equipment would need to rely on localized updates to, for example, support security updates.

Management Centers and Information Services

Within the rural roadway setting, communications to a remote facility would enable vehicle-related data collection capabilities that could support other applications. Data collected from vehicles could include weather and road condition data with other probe data and might be used, for example, to create roadway warnings for other vehicles.

Although some rural interstate locations may be the exception, a rural setting is assumed to have relatively low traffic volumes, resulting in a low to moderate level of connected vehicle data. This will affect backhaul bandwidth and data warehousing requirements for collection and storage of data desired for historical analysis or use in other applications. In developing backhaul and storage requirements, consideration should be provided to analyze rural routes that experience seasonal traffic volume fluctuations. These roadway facilities may require added communications, processing, and storage capabilities. Storage capacity for redundancy and to satisfy data retention policies must also be considered. A connected vehicle equipment installation used in this capacity is similar to a traffic count station whereby data is not required to be near real-time but can be obtained periodically from the field site.

Applicability

Applications that may be supported by a connected vehicle infrastructure deployment within the illustrated rural roadway setting include, but are not limited to:

- Motorist Advisories and Warnings (emergencies, weather, variable speeds, curve speed, oversize vehicle)
- Stop Sign Assist
- Intersection Violation Warnings
- Reduced Speed Work Zone Warnings
- Dynamic Eco-routing based on roadway conditions or congestion issues

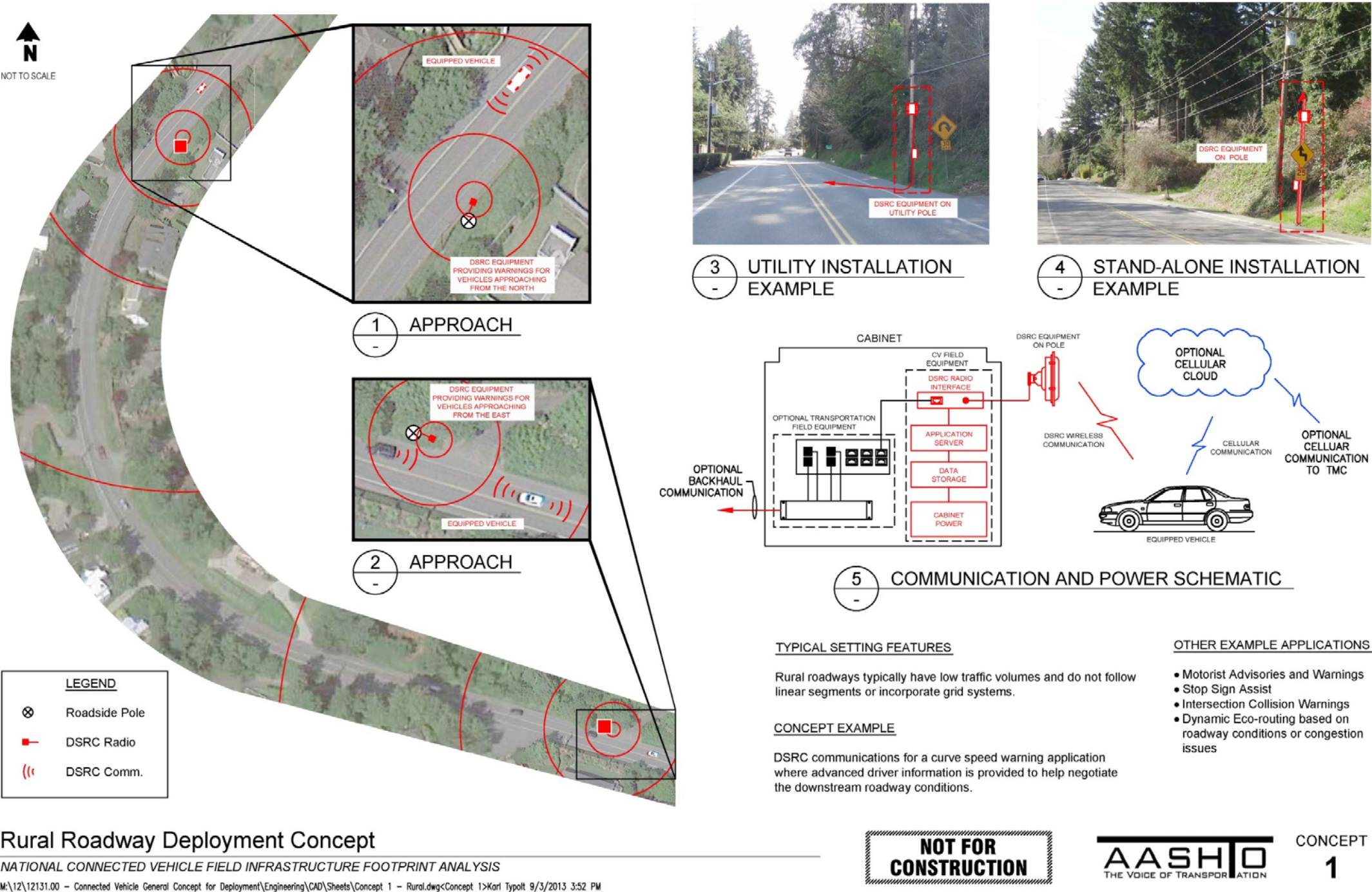


Figure 12 - Rural Roadway Deployment Concept (Source: USDOT/AASHTO 2014)

Urban Highway

Current State

Urban highways are part of the principal arterial system that carries some of the highest traffic volumes and proportion of total urban travel. These roadways provide connections within urbanized areas, to outlying suburban centers, and ultimately to rural roadways. In urbanized areas, which typically have populations greater than 50,000, these highways are fully or partially controlled access facilities due to high traffic volumes and roadway speeds. AASHTO separates urban highways into three categories: interstates, other freeways, and other principal arterials (with partial or no control of access).

In many cases, ITS deployments exist on the urban interstate network and provide the appropriate operating agency with the means to monitor and optimize their regional freeway system. ITS infrastructure on an urban interstate typically supports traveler information (e.g. dynamic message signs, highway advisory radios), traffic control (e.g. ramp meters), data collection (e.g. vehicle data stations, traffic cameras, weather stations), user fees (e.g. tolling, congestion pricing), commercial vehicle services (e.g. weigh stations), and control centers (e.g. traffic management center, active traffic management). These ITS systems rely heavily on dedicated communication systems typically installed within the freeway right-of-way. Traveler information and data collection will be the focus in this concept with specific applications falling under each of these two system types.

Traveler information systems disseminate useful information to users of the urban highways. Congestion management and traffic incident management are typically key focuses of such systems; they may also provide information about work zones. For congestion management, agencies have implemented ITS systems intended to spread demand across the highway network, attract users to mass transit, and make effective use of the existing freeway capacity. For traffic incident management, ITS systems typically detect and promote the removal of incidents, restoring urban highway capacity in a fast and safe manner. For work zones, the traveler information both tries to alleviate congestion associated with the zone and to protect workers.

A typical traveler information system installation consists of a display such as a dynamic message sign or website application, a communication network which includes cabinet, associated equipment, and backhaul communications, and a control center that delivers traveler information to the system.

Data collection systems provide operators at management centers a means to evaluate the conditions or performance of the urban interstate network. Traffic data detectors, such as inductive loops, radar, and video imaging, provide speed, occupancy, and, in some cases, travel time data. Closed-circuit traffic cameras help detect and verify incidents and congestion; information that can then be distributed to the web or other forms of media. These examples of data collection systems consist of detection equipment, a communication network, and a control center that receives and evaluates traveler information from these installations.

Concept Description

The concept for this urban highway setting is focused on support for traveler information and data collection systems using DSRC or cellular technology. Safety-focused applications such as work zone or weather advisory warnings would also likely be deployed for urban highways. Other examples of typical applications in this setting are described in section 2.3.3 below.

DSRC Concept

Vehicles equipped with DSRC would receive and transmit data periodically along the highway system when the vehicles are within range of an RSU. For example, roadway alerts, arterial management recommendation messages, and traffic information would be provided over a backhaul link from a regional TMC to the RSUs, which transmit them to passing vehicles. The vehicle system then alerts or informs the driver accordingly. These vehicles can also transmit operational data (e.g. speed, location, etc.) back to the RSU, which then forwards it over a backhaul link to the TMC or other data aggregator. This data can be used for dynamic control of the corridor, for general traffic information reports or for historical analysis. Operators at the TMC can also use the information for congestion management or traffic incident management.

The illustration in Figure 13 shows one example of DSRC communications for data collection on a freeway to gather vehicle data for use at the TMC as an input for ramp meter rates on entrance ramps.

Cellular Concept

Vehicles equipped with cellular data (for example, LTE) modems would send information requests to a server at periodic intervals (e.g., every 100 meters or three seconds) as they travel along the roadway. The request includes the current location and direction of travel. The server would then provide back a message including any roadway alerts, arterial management recommendation messages and real time traffic data associated with segments or timeframes for which the driver would need actionable information. The vehicle system then alerts/informs the driver accordingly. The request could also include vehicle operational data (speed, location, etc.) so that the message transaction would implement both probe data collection and roadway messages simultaneously.

It is unclear if this system can support dynamic alerts such as traffic signal information because of latency issues, but this capability is expected to be tested in 2013 to determine what the latency and latency variation actually is.

Cellular implementations are more fully described in the Common Considerations section.

Field Infrastructure

The connected vehicle field equipment for an urban highway setting will be installed at highway access points and along highway segments. Fewer connected vehicle field equipment deployments will be required along segments with large distances between ramps, while more closely spaced placements will be necessary near urban and city centers to best serve TMC operators and to provide information to vehicle operators at critical locations. Locations expected to have a high density of

connected vehicle field equipment may include roadway stretches with historically high congestion, on and off ramps, major interchanges, and other spot locations.

Typically the DSRC radio will be mounted to an existing elevated structure such as a sign gantry, light or camera pole, overpass, etc. DSRC ranges will vary by location and data collection purpose, but are anticipated to be around 400 meters (1300 feet) in this setting. For mainline detection locations, the DSRC radio will most likely be installed at the highest possible mounting height consistent with FCC regulations on the existing structure to obtain the greatest possible range. At ramp meters the range of the DSRC radio could be reduced to 100 meters (330 feet) or less to facilitate interaction only with vehicles likely to use the ramp metering application. Mounting of the DSRC radio might occur on the existing ramp meter pole for communication over distances less than 100 meters.

When identifying installation locations, utilizing existing communication infrastructure will reduce installation costs. The connected vehicle field equipment will ideally connect into an existing ITS cabinet that is equipped with an Ethernet switch and a backhaul communication connection to a management center. Power would be supplied through the existing cabinet, solar, or nearby electrical service drop. Suitable locations could include existing data collection stations, dynamic message signs, traffic cameras, etc.

Backhaul Communications

Backhaul communications in an urban highway setting can be implemented in a wide variety of ways. These are described in the Common Considerations section. Roadside equipment could potentially communicate over the same backhaul network as existing ITS installations, provided that sufficient bandwidth is available for the various connected vehicle applications selected.

Management Centers and Information Services

Connected vehicle equipment deployments for the urban highway setting will provide two-way real-time communication between vehicles traveling on the freeway system and data acquisition and processing systems in a back-office facility. The systems at the back-office facility (or facilities) will process the data to support various applications and other ITS systems, and will archive the data for future use.

Applicability

Applications that may be supported by connected vehicle equipment deployments in the urban highway setting include, but are not limited to:

- Origin-Destination (with opt-in permissions or anonymization), Traffic Model Baselineing & Predictive Traffic Studies
- Active Traffic Management (lane control, dynamic speed harmonization, cooperative adaptive cruise control)
- Advanced Traveler Information System (dynamic route guidance, travel time)
- Motorist Advisories and Warnings (emergencies, weather, variable speeds, queue, speed zone, work zone, oversize vehicle)

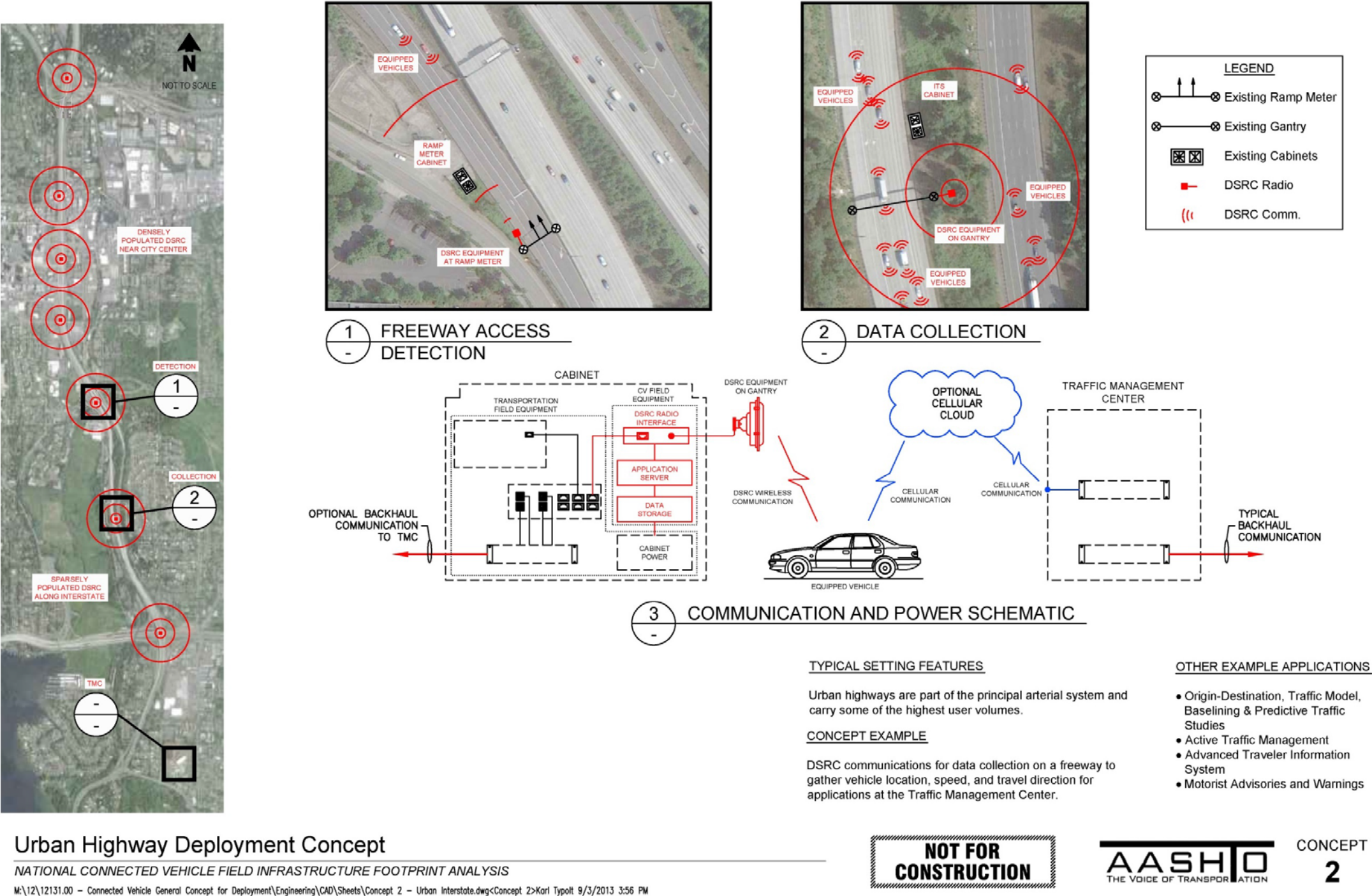


Figure 13 - Urban Highway Deployment Concept (Source: USDOT/AASHTO 2014)

Urban Intersection

Current State

An urban intersection is a junction of two or more roads within a city setting which typically includes features such as curbing, designated lane use markings, pedestrian crossings, and traffic control (traffic signals or stop signs). The simplest forms of urban intersections consist of 2-way or 4-way stop configurations. More complex settings may have a signalized intersection that is configured with a variety of lane usages, pedestrian and bicyclist facilities, and traffic signal equipment. At signalized intersections, controllers typically function on pre-timed, actuated, semi-actuated, and adaptive modes of operation with a dependence on current detector technology. The *AASHTO Connected Vehicle Infrastructure Deployment Analysis* included a description of traffic signal controllers and connected vehicle infrastructure needs.

Existing ITS infrastructure may include traffic signal and detection systems, red light cameras, transit signal priority (TSP), emergency vehicle preemption, CCTV cameras, and freight signal priority. Controller communication via Ethernet, optical fiber, or commercial wireless systems may be employed to relay backhaul communication to central servers, although use of 900 MHz radio systems or land-line telephone service is common.

In recent years, there have been an increasing number of adaptive signal control (ASC) system deployments that have proven to be an effective means of using ITS to improve operational efficiencies at an urban intersection and corridor in near real-time. An ASC system relies on vehicle detection and dynamically adjusts signal timing parameters to meet the roadway demands as necessary. Many adaptive signal systems rely on interconnected traffic signals which can be achieved through an Ethernet backbone. In the connected vehicle infrastructure deployments considered in this report, an Ethernet backbone would enable system-wide connectivity for multiple urban intersections.

Concept Description

The deployment of connected vehicle field equipment in an urban intersection setting may include a DSRC radio with associated communication equipment communicating with vehicles equipped with a DSRC OBE. Ideal mounting locations for a DSRC radio at an urban intersection would include a signal mast arm, luminaire pole or arm, or utility pole.

Applications supported by the urban intersection setting typically engage in two-way (symmetric) communication with vehicles approaching the intersection. A reliable range to accommodate the required data transfer rates is approximately 200 to 500 feet. Roadway features and the urban environment (such as buildings) will need to be considered when identifying the mounting location for connected vehicle equipment. In the event of radio interference from geometry or trees, multiple radios may need to be deployed to support a single intersection.

The illustration in Figure 14 for this setting shows omnidirectional DSRC communications to all approaches of the intersection and also an additional DSRC antenna at a mid-block location.

Field Infrastructure

The field infrastructure for an urban intersection setting will comprise connected vehicle field equipment sharing communication with transportation field equipment installed in a traffic signal control cabinet. Power would also be provided by the traffic signal cabinet, solar, or a nearby electrical service drop. It is recommended that there is a connection from the connected vehicle equipment to an Ethernet switch that would be capable of communicating with the traffic signal controller. This connection can also provide a backhaul communication connection to a management center. At an urban intersection, the practical installation height of the DSRC radio would be up to 25 feet in order to achieve optimal line of sight to the vehicles. This is the approximate height typically provided by signal mast arms, luminaire poles or arms, or utility poles. This may need to be further adjusted depending on specific site characteristics.

Backhaul Communications

Backhaul communications at urban intersections could be implemented in a variety of ways depending on the applications being supported; these are discussed in the Common Considerations section. Actual bandwidth requirements will depend on the number and types of applications to be supported in a particular deployment.

Management Centers and Information Services

A connected vehicle equipment deployment at the urban intersection setting allows a back-office facility to gather vehicle-related data. Data could include intersection delays, collision data, transit reliability data, and congestion data.

Depending on the number of vehicles that the intersection services, a moderate level of data warehousing may be useful to analyze historical data and provide data for future use. Storage capacity for data backup is also recommended for redundancy.

Applicability

Applications that may be supported by a connected vehicle equipment deployment at the urban intersection setting include, but are not limited to:

- Red Light Violation Warning and Stop Sign Violation
- Driver Gap Assist at Signalized Intersections and Stop Signs
- Multimodal Intelligent Traffic Signal Systems (freight signal priority, intelligent traffic signal system, transit signal priority, pedestrian mobility, emergency vehicle pre-emption)
- Advanced Arterial Management and Operations
- Advanced Signal Operations

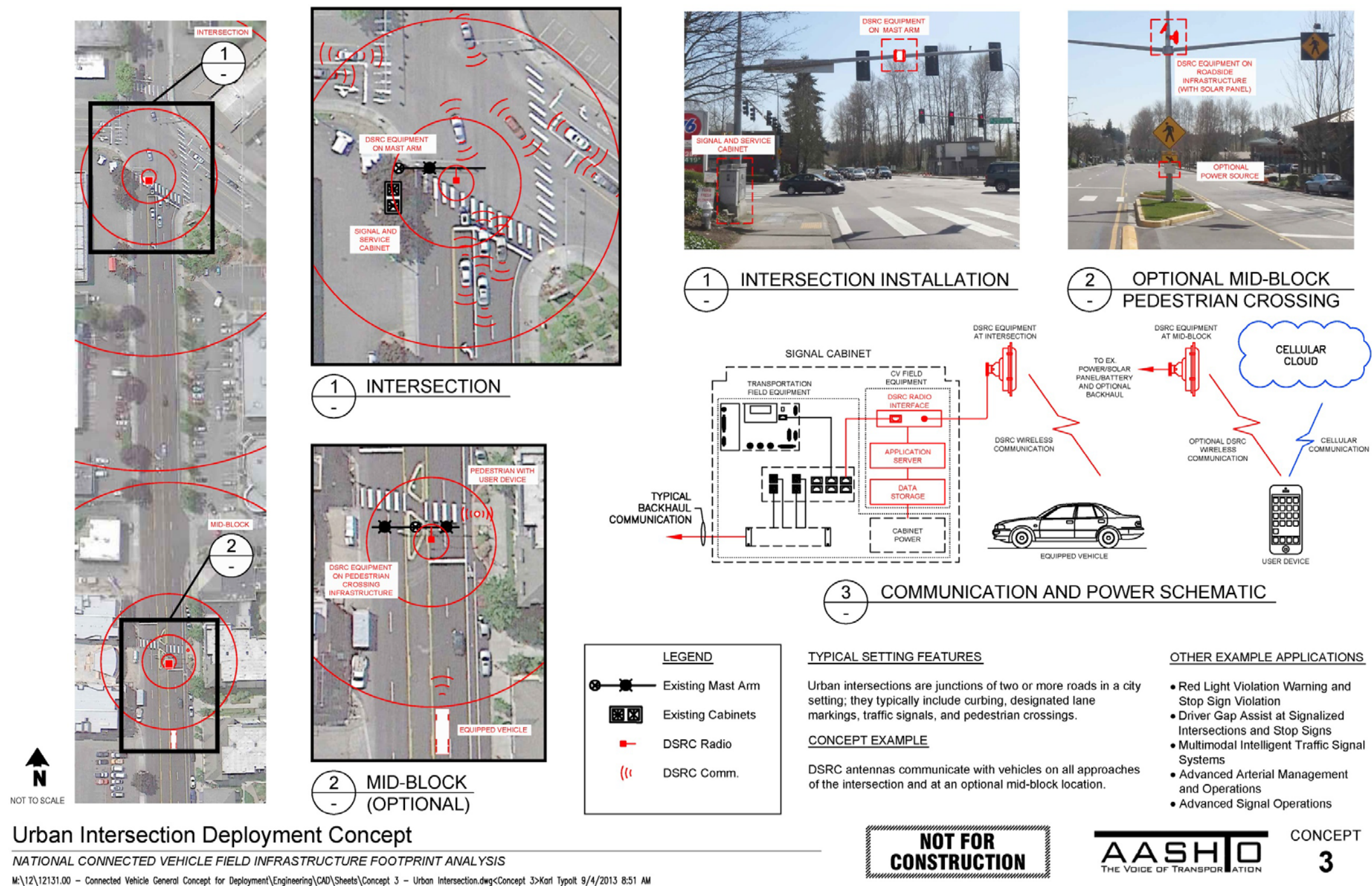


Figure 14 - Urban Intersection Deployment Concept (Source: USDOT/AASHTO 2014)

Urban Corridor

Current State

Urban corridors typically consist of multiple signalized intersections, spaced at regular intervals. These roadways have multiple types of roadway users, including pedestrians, bicyclists, transit vehicles, personal cars, and freight deliveries. Cross-sections and lane assignments vary and may include restricted lanes for transit-only vehicles, on-street parking, and center left turn lanes. The combination of modes and applications on an urban corridor make it a unique setting for incorporating traveler benefits across a range of transportation alternatives for a given corridor.

ITS infrastructure may include fixed time, semi-actuated or fully actuated signals, transit signal priority (TSP), emergency vehicle preemption, and freight signal priority to assist with the flow of traffic through the corridor. Controller communication over Ethernet, optic fiber, or wireless networks are typically employed for backhaul to central servers located at TMCs.

Concept Description

The urban corridor setting could include all of the applications described earlier for an urban intersection, but provides a richer context for discussion of modes, operations and technologies supporting integrated corridor management. In the example described in this section, applications could provide operators at a transportation management center with information to provide multimodal traveler information and improve the performance of transit routes. Figure 15 illustrates an example of DSRC communications for transit data on an urban corridor to transmit arrival times, passenger loadings, and other data to a Transit Control Center (TCC).

Connected vehicle mobile elements in transit vehicles could relay the location, passenger counts, and delay incurred at the signal to connected vehicle field equipment at intersections. The information from several DSRC RSUs located on an urban corridor could be sent to a communication hub, located at a transit center or other major transportation center, where data can be stored before it is sent to the control center for analysis.

The servers at the control center may contain preprogrammed bus schedules, time-points, and other route information that is compared to the field information gathered from the connected vehicle field equipment. Two-way communication could support changes to signal timings or phase operations to be updated at downstream intersections to anticipate the arrival of buses. The time and location of buses on the urban corridor could also be compared to schedules to determine whether transit service is operating on schedule.

In addition to communicating on-time information to transit operators, the arrival time of buses to stops and transit centers could be relayed to passengers. Real-time updates for onboard and waiting passengers could be provided via message boards. Transit users could also find information through cellular communication via phone applications. Additionally, some applications may provide an interface between transit users and a transit center communication hub.

Field Infrastructure

Connected vehicle field equipment in this setting consists of DSRC antennas and associated communication equipment mounted to existing infrastructure and housed at intersections and transit centers. Major transit centers include communication hubs that store information in on-site servers. The communication hub collects information from DSRC equipment installed at the transit center, as well as corridor installation locations and sends data to control center where the data is processed.

When identifying installation locations, existing infrastructure will play an important role in reducing installation costs. Connected vehicle field equipment installed at intersections will ideally connect into an existing transportation system cabinet (such as a signal cabinet) that is equipped with an Ethernet switch and a backhaul communication connection to a control center. Power will be supplied by the existing cabinet.

Backhaul Communications

Backhaul communications at urban intersections could be implemented in a variety of ways depending on the applications being supported; these are discussed in the Common Considerations section.

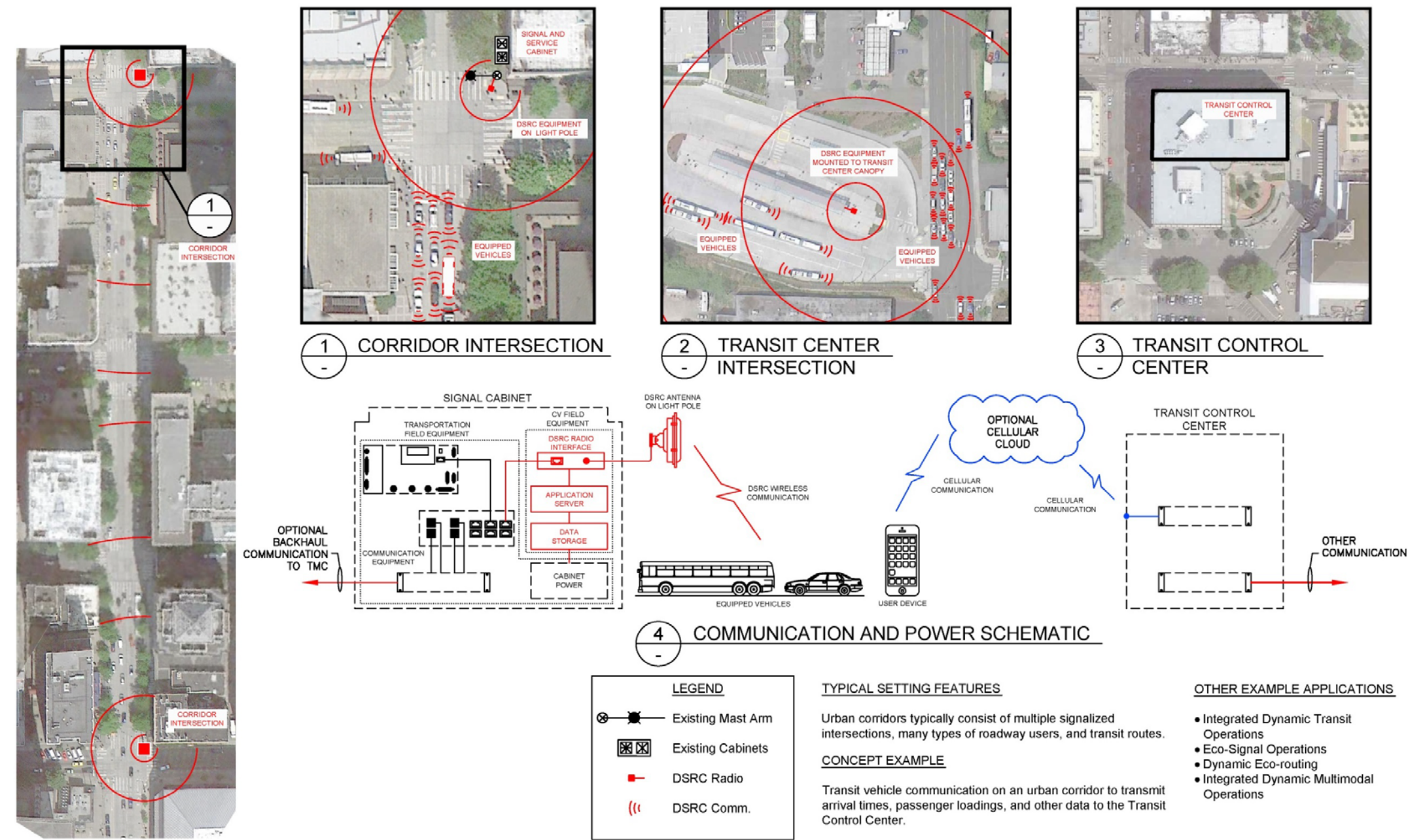
Management Centers and Information Services

This concept will require transit agencies to have schedules, time points, and transit route information readily available for processing based upon data coming into the control center. Two-way communication between the connected vehicle field equipment along the corridor and the control center is vital for the urban corridor setting to be effective. This information may also need to be relayed to transit riders. Standard protocols for exchanging data about multiple intersection types and locations may need to be established for transit routes that operate in multiple jurisdictions.

Applicability

Applications that may be supported by connected vehicle equipment deployment in the urban corridor setting include those described in the urban intersection setting and others such as, but not limited to:

- Integrated Dynamic Transit Operations (Connection Protection, Dynamic Transit Operations, Dynamic Ridesharing)
- Eco-Signal Operations (approach and departure, traffic signal timing, transit signal priority, freight signal priority, connected eco-driving)
- Dynamic Eco-Routing
- Integrated Dynamic Multimodal Operations



Urban Corridor Deployment Concept

NATIONAL CONNECTED VEHICLE FIELD INFRASTRUCTURE FOOTPRINT ANALYSIS

M:\12\12131.00 - Connected Vehicle General Concept for Deployment\Engineering\CAD\Sheets\Concept 4 - Urban Corridor.dwg<Concept 4>Karl Typolt 9/3/2013 4:03 PM

NOT FOR
CONSTRUCTION

AASHTO
THE VOICE OF TRANSPORTATION

CONCEPT
4

Figure 15 - Urban Corridor Deployment Concept (Source: USDOT/AASHTO 2014)

International Land Border Crossing

Current State

Cross-border transportation is an important element of the nation's transportation system. Because of increasing cross-border demand, limited infrastructure footprint at international border crossings (IBC) and staffing resources, wait times at IBCs continue to grow longer with negative impact on cross-border trade and travel.

Laws of the US, Canada, and Mexico require that every vehicle and passenger crossing the border must be screened and verified. Customs agencies stop and screen all incoming vehicles and verify proper documentation before letting them in their respective countries.

In both U.S.-Canadian and U.S.-Mexico international border crossings, once privately operated vehicles (POV's) are released by respective customs agencies, they proceed to their destinations. On the U.S.-Canadian border, vehicles entering Canada are screened and can be inspected by CBSA and Canadian provincial motor vehicle enforcement agency. Commercially operated vehicles (COVs) entering US from Canada are screened and/or inspected by CBP after which they may be screened and inspected by state agencies to enforce commercial vehicle safety regulations. On the U.S. side of the U.S.-Mexico border, there are permanent facilities adjacent to the custom's facility and all COVs entering the U.S. from Mexico are screened and/or inspected by the state agencies for safety. On the Mexican side, once COVs are released by Aduana (the custom's agency in Mexico), they proceed to their destination.

Each IBC is different in terms of traffic patterns, geography, configuration, and physical characteristics. However, key functions performed by customs agencies (of all three countries) are similar as well as some of the truck safety related activities performed by provinces and states.

Concept Description

CBP and the CBSA are two agencies that provide Border Wait Times (BWT) information to motorists. CBP and CBSA's method to estimate BWT rely on visual methods. They estimate BWT of vehicles inbound to the U.S. and Canada using one of five methods depending on the point of entry (POE): unaided visual observation, cameras, driver surveys, time-stamped cards, and license plate readers. CAPUFE and Aduana which are Mexican federal agencies that operate border crossings, do not relay wait times.

USDOT, Transport Canada, provincial transport ministries (in Canada), and state departments of transportation (in the U.S.) have implemented systems to measure, relay, and archive wait times of vehicles crossing the border. Some states have also implemented systems to measure crossing times for commercial vehicles. These systems use traditional vehicle detectors, RFID at 915 MHz, and Bluetooth technology.

These systems currently deployed at select IBCs on both the U.S.-Mexico and U.S.-Canada borders rely on fixed-location detectors that identify transponders, mobile devices, or presence of vehicles,

determine travel time between detectors, and estimate wait times. Detectors are isolated from each other and function independently. Data from individual detectors are sent to a central server using cellular communication. Servers then process the information and provide the wait and crossing times to users via Internet, dynamic message signs, 511 systems, etc.

In addition, vehicles on the roadway upstream of custom's inspection booths are not well managed. Some IBCs do have static overhead signs to separate COVs from POVs. At most IBCs there are several roadways leading to the customs area and providing static signs to direct traffic can be difficult. Also, signs that separate vehicles types (and vehicles registered with various trusted shipper and traveler programs) are at fixed locations and messages are not dynamic to be coordinated with number of inspection lanes open at the custom facility.

One objective of applications in this setting is to deploy a next generation wait time and approach management system that automatically and accurately estimates wait and crossing times, provides information to motorists using OBE using DSRC technology, and migrates from currently used RFID and Bluetooth technologies. While doing so, the application will also direct motorists to appropriate approach lanes based on type of vehicles (i.e., COV or POV) or various types of trusted shipper and traveler programs using dynamic processes that coordinate in real-time with inspection lanes open and types of lanes open. The system will create a dynamic and close to optimal management of approach lanes and deliver traveler information to motorists in a more effective format resulting in more effective management of inspection lanes, reduced wait/crossing times, and better allocation of staffing resources.

In a connected vehicle environment, the application would use DSRC technology to gather information on identification of vehicles, lanes on which vehicles are traveling, and types of trusted shipper and traveler program vehicles/motorists are registered to. With adequate density of OBEs, wait times for lane type will be predicted based on estimate of queue length, travel time between fixed points, and number of inspection lanes open.

RSUs strategically placed along the roadways approaching IBC will transmit messages to OBEs consisting of wait and crossing times, approach lane they should be on, lane changing suggestions to move to particular lanes. The concept diagram for this setting shows relative location of RSUs on approaches leading to IBCs on both the US-Canada and US-Mexico border. Number of RSUs and specific location of RSUs depend on the actual footprint of an IBC.

The system will however need to coordinate, in real-time with the number of inspection lanes open and which lanes are designated to process which trusted shipper and traveler programs. The customs agencies will also adjust their inspection process based on the wait and crossing times information they receive from the system, which in turn will influence the wait and crossing times of incoming vehicles.

IBC's include multiple lanes and types of credentials for vehicles passing through security checkpoints. The illustration in Concept 5 shows one example of DSRC communications to collect and disseminate traveler information, including border crossing wait times.

Field Infrastructure

The concept will be deployed on roadway approaches leading to primary inspection booths operated by customs agencies on both sides of the international border. Some RSUs will be inside the US State's facility, especially on the US-Mexico border. The number of RSUs will depend on the actual footprint of individual IBC.

The concept can either be developed as a single multi-jurisdictional application or as multiple applications exchanging data in real-time. In a single multi-jurisdictional environment, a single entity will operate and manage all the RSUs on both sides of the border and operate the application as one system. The other option is to run separate applications in different countries and share data between applications.

Two configurations of RSUs may be needed in this concept—one that only collects vehicle information from the field, and another that both collects information from the field and sends information to OBEs. Mexican and Canadian vehicles should be able to communicate with RSUs deployed inside US and vice versa.

Power for RSUs would likely be provided by an existing cabinet or electrical service drop, as the border crossing typically already supports powered infrastructure equipment.

Backhaul Communications

RSUs, especially those close to the customs inspection booths, may communicate simultaneously with hundreds of vehicles and will require high bandwidth backhaul communication. Options for backhaul are described in the Section 3 Common Considerations.

Because the applications will require data sharing between multiple jurisdictions and agency systems (e.g., between a US state system and CBP), data transmission between the application's central servers to servers of other jurisdictions can be done through a secured Internet connection. These agencies will have to agree on center to center data transfer protocols, communication security protocols, etc.

Management Centers and Information Services

The concept will require agencies responsible for deploying the IBC applications to provide a robust back-end system consisting of flexible database management, fault tolerance systems, standard operating protocols, fallback processes in case of RSU downtime etc. The server (or servers) will gather information from RSUs and archive the data for future reference, as well as use it to determine wait times. The server will also be responsible for sending wait time and approach lane guidance information to individual RSUs and on to OBEs. Standard operating procedures and guidelines on data archiving and processing will be required. Also, the server will require an interface to exchange data with other jurisdictions in the same country or a different one.

Applicability

The deployment concept is applicable at all IBCs on both the US-Canada and US-Mexico border, given there are justifiable needs in the form of perceivably long wait times, high vehicle demand, etc.

Some IBCs have extremely low demand (i.e., few hundred vehicles a day). Even though the application can be implemented at these IBCs, the cost of doing so may outweigh the need.

IBCs can vary in their configurations, mainly in the number of lanes available for inspection and type of vehicles inspected. IBCs with a large number of inspection lanes will require more RSUs than IBCs with fewer inspection lanes. Some IBCs process both commercial and personal vehicles and some only process one type of vehicles.

RSUs deployed for this application can also be used for other border applications, such as toll collection, dynamic pricing, and COV safety pre-clearance. RSUs deployed for toll collection, which is becoming more and more prevalent at IBCs can also be used for collecting wait times information.

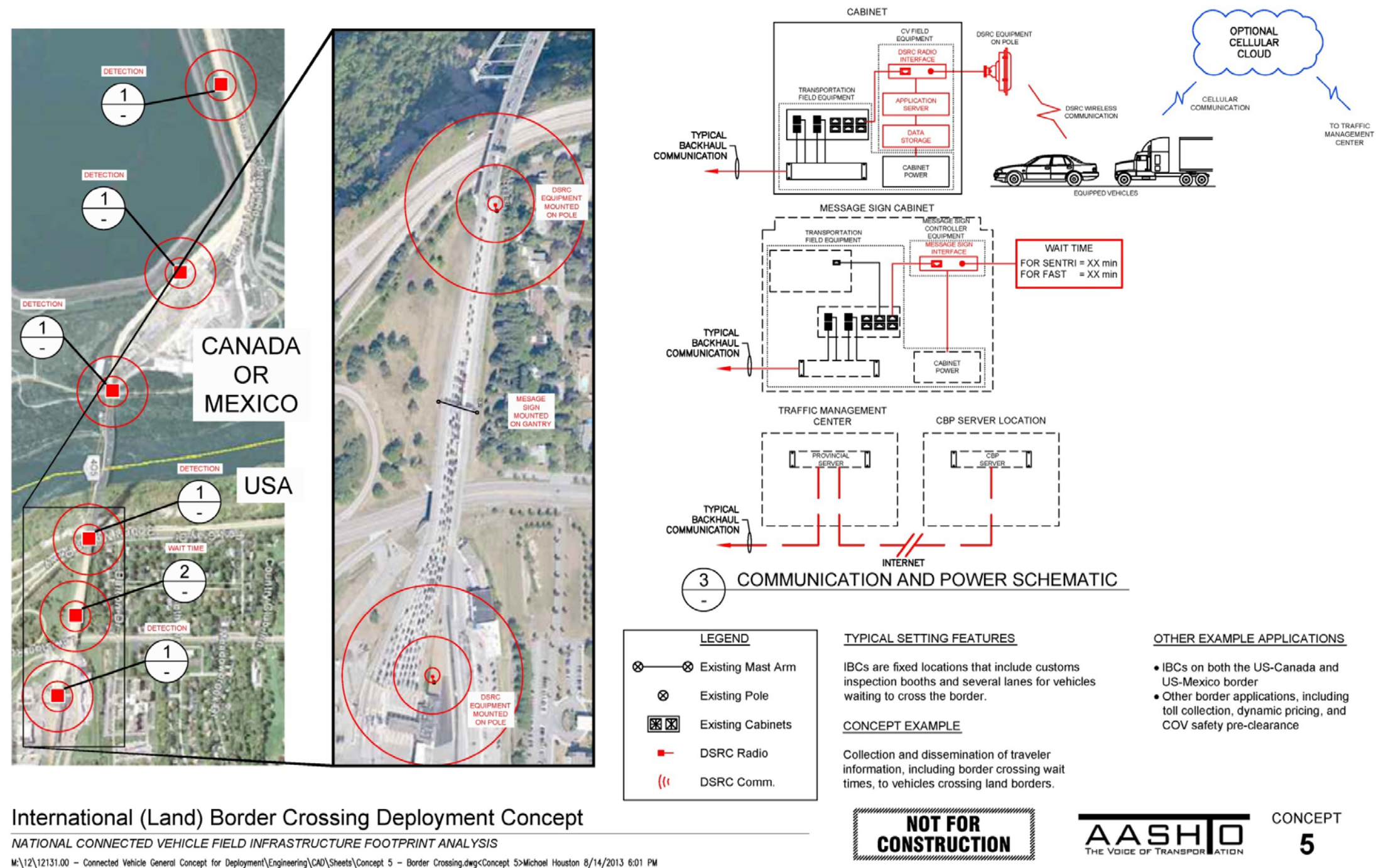


Figure 16 - International (Land) Border Crossing Concept (Source: USDOT/AASHTO 2014)

Freight Intermodal Facility

Current State

Freight intermodal facilities assist in long haul and drayage assignments where containers are transferred between rail and trucks. For the purpose of this report, freight trucks were the focus although there are likely multiple rail applications. Long haul and drayage activities that currently take place at an intermodal facility involve a complex interaction between facility personnel, trucking companies, end-customers, and rail lines. In order to coordinate freight activities, delays are often experienced and are commonly attributable to freight scheduling, dispatch activities, and congestion at the facility. Average in-gate to out-gate turnaround times at an intermodal facility are approximately 30-60 minutes per truck with about 20-30 minutes of this time spent in a queue. Efficiency is vital at intermodal facilities as most truck drivers involved in drayage activities are paid per move rather than by time. The typical process at an intermodal facility involves the following steps:

1. Rail arrives with manifest and goods containers.
2. Long haul or drayage firm is dispatched to pick-up container.
3. For long haul, container is loaded onto a chassis owned by the long haul company. For drayage, chassis is supplied at the facility.
4. Containers are shipped to their intended destination.
5. Drayage firm returns empty container to facility after delivery has been made to the end-customer.

A truck-to-rail process typically occurs in the opposite order as described above. Information that is shared between the intermodal facility and truck drivers include credential information, goods manifest, inspection information, and the availability and location of container for transport. This information is usually communicated in person at the processing in-gates and inspection gates at the facility entry. At some facilities, driver credential information is communicated through RFID technology established by the TSA. The National Cooperative Freight Research Program's (NCFRP) Report 11 indicates that many gate delays are attributable to misinformation and miscommunication. Trouble tickets are assigned when a planned transaction cannot be processed and an escalated level of assistance is required from facility authorities. Due to the extensive amount of the information that needs to be communicated and complex procedures, there are often long delays which can often cause extensive inbound queuing. When the truck driver has received their container load, they typically exit the site through an out gate processing area where facility personnel verify that the correct transaction and paperwork has taken place.

Concept Description

Within the freight intermodal facility setting, the connected vehicle field equipment would be installed at truck decision points and inspection points, such as in-gate stations, inspection stations, exit gates, and major truck decision points. The onboard equipment in the trucks would transmit and receive information to automate credentialing, inspection, customs, way finding, and traffic information at the facility. The two-way DSRC communication could help alleviate congestion and reduce turnaround

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

times by automating the transaction process. Additional DSRC field equipment could also be installed on roadways leading to the intermodal facility to enable inbound trucks to report their arrival and receive notification of expected wait times (it is likely these units would also support the Urban Highway deployment concept). This information can be communicated to the facility's control center through a local backhaul connection, or through the TMC of the adjacent community. The control center can utilize this information to coordinate scheduling, regulate and enforce inspection protocols, and direct traffic to and from the facility.

Figure 17 shows an example of DSRC communications at a freight facility to verify truck and rail entry at an intermodal facility. Upon entering the checkpoint lanes, driver credentials are checked for security purposes to pass through the entrance. Tracking shipments and destinations are also included in these messages to improve efficiency of facility operations once the vehicle has entered the drayage yard.

Field Infrastructure

Within the intermodal facility, connected vehicle field equipment could be installed at main gates and inspection checkpoints. These deployment locations are expected to have power available since the facility is generally equipped with lighting, inspection booths, and other monitoring and security equipment. The DSRC equipment should be mounted at a maximum height of 25 feet with adequate line-of-sight to communicate to vehicles within a 1000-foot radius. Where gates and inspection stations are separated by more than 1000 feet, an additional DSRC radio should be installed. All DSRC roadside units should be connected through a backhaul network to the control center where activity is monitored and a supervisory level of control is provided.

Backhaul Communications

These applications will require backhaul communications to the facility's control center. The control center would be able to monitor and react to the information communicated by the trucks and issue response actions as necessary to ensure efficient and safe goods movement.

Backhaul communications at these facilities could be implemented in a variety of ways depending on the applications being supported; these are discussed in the Common Considerations section.

Management Centers and Information Services

Operations within an intermodal facility are often managed through an administrative center where freight activity is monitored from a control facility. Critical to the facility's control center are the roles and responsibilities from various operating agencies which may include the Transportation Security Administration (TSA), the local department of transportation, the facility owner/operator and others. Each agency depends on different types of information distributed as part of the long haul and drayage operations to ensure that security is maintained, site logistics are efficient, and information is shared. The facility's terminal operating system, which monitors container status, should be integrated with the connected vehicle environment in order to automate gate processing, resolve trouble tickets, and increase traffic throughput.

Applicability

Applications that may be supported by a connected vehicle equipment deployment in the freight facility setting include, but are not limited to:

- Freight Real-Time Traveler Information with Performance Monitoring
- Shipment (Trailer) Tamper Monitoring
- Information for Freight Carriers

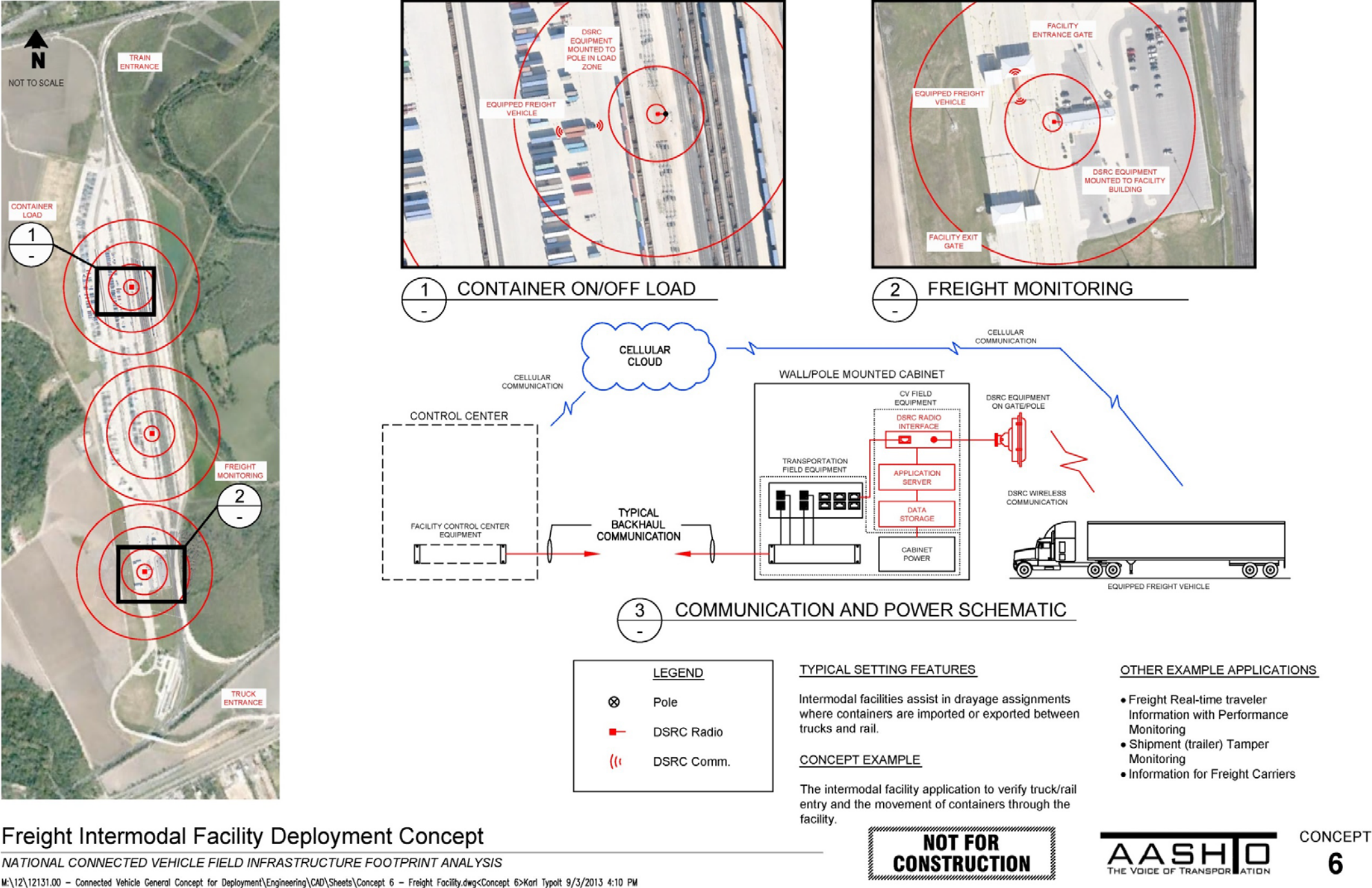


Figure 17 - Freight Intermodal Facility Deployment Concept (Source: USDOT/AASHTO 2014)

Smart Roadside Freight Corridor

Current State

Freight movement is a pivotal part of the US economy and relies on the nation's network of roadways, interstates, railways, waterways and airspace to transport goods. The National Highway System (NHS) identifies a strategic network of highways servicing major freight routes. Along these freight routes, various facilities exist to regulate commercial vehicle safety, security, and mobility. Some of these facilities include inspection checkpoints, border crossings, weigh stations, truck parking and rest facilities. The USDOT has developed a commercial vehicle information systems and networks (CVISN) nationwide initiative that focuses on the following functions:

- Safety Information Exchange
- Credentials Administration
- Electronic Screening

CVISN is currently used throughout the nation and falls under the National ITS Architecture, primarily leveraging DSRC, Weigh-in-Motion (WIM), Automatic Vehicle Identification (AVI), License Plate Readers (LPR) technology. The core goal of CVISN is to improve safety, simplify operations, improve efficiency, and improve security for freight movement.

Within the NHS, truck parking facilities are another major component of the existing freight infrastructure as they function as rest areas for truck drivers. Due to the large number of trucks on the roadway system, truck parking availability is often a concern at many public and privately-operated truck parking facilities. There are limited ways in which a truck driver ascertains information regarding truck parking availability. The Federal Motor Carrier Safety Administration (FMCSA) has commenced initiatives, such as Smart Park, to address these concerns. Smart Park provides real-time parking availability information to truckers by collecting space occupancy at a truck parking facility.

Concept Description

Within the connected vehicle environment, the freight corridor concept would further develop the applications established under the Smart Roadside Initiative using DSRC technology. The Smart Roadside Initiative is a joint program of the FHWA and FMCSA that identifies data sharing, e-screening, truck routing, inspection, data collection, and weight and dimension monitoring applications. Data is collected and shared between freight movers on a real time or near-real time basis and is used for multiple purposes.

The concepts illustrated in Figure 18 and Figure 19 would involve deploying DSRC radios on the roadside at key truck facilities such as truck parking facilities, weigh stations, truck fueling stops, and tolling facilities. Information that is shared at the key facilities would include truck parking availability, weight information, driver and truck credentials, and route information. In addition to the deployments at major truck facilities, the Smart Roadside application would also complement the connected vehicle field infrastructure within an urban interstate and rural roadway setting where available. Integration into

the urban interstate and rural roadway setting would allow truck drivers to share and obtain useful information along their freight routes.

Field Infrastructure

Within the smart roadside freight corridor setting, connected vehicle field equipment would be installed at major freight facilities including truck fuelling stops, weigh station facilities, truck parking facilities, highway rest stops and tolling facilities. These deployment locations are expected to have power available since these facilities are generally equipped with lighting, utilities and, often, retail establishments. The DSRC equipment should be mounted at a maximum height of 25 feet with adequate line-of-sight to communicate to vehicles within a 1000 feet radius. Depending on whether the freight corridor is situated in an urban or rural setting, backhaul communication to a management center could be provided through a fiber network or various other means.

For the WIM application presented in the concept schematic, a DSRC deployment would be consistent with the traditional approach for CVISN installations. DSRC radios are installed at the mainline WIM sensors location, dynamic message sign location, credentials verification location, and scale house facility. The spacing of these devices is typically dependent on state standards.

Backhaul Communications

Backhaul communications to the private business's or agency's central control facilities could be implemented in a variety of ways depending on the applications being supported. These are discussed in the Common Considerations section. The control center would be able to monitor and react to the information communicated by the trucks and issue response actions as necessary to ensure efficient and safe goods movement.

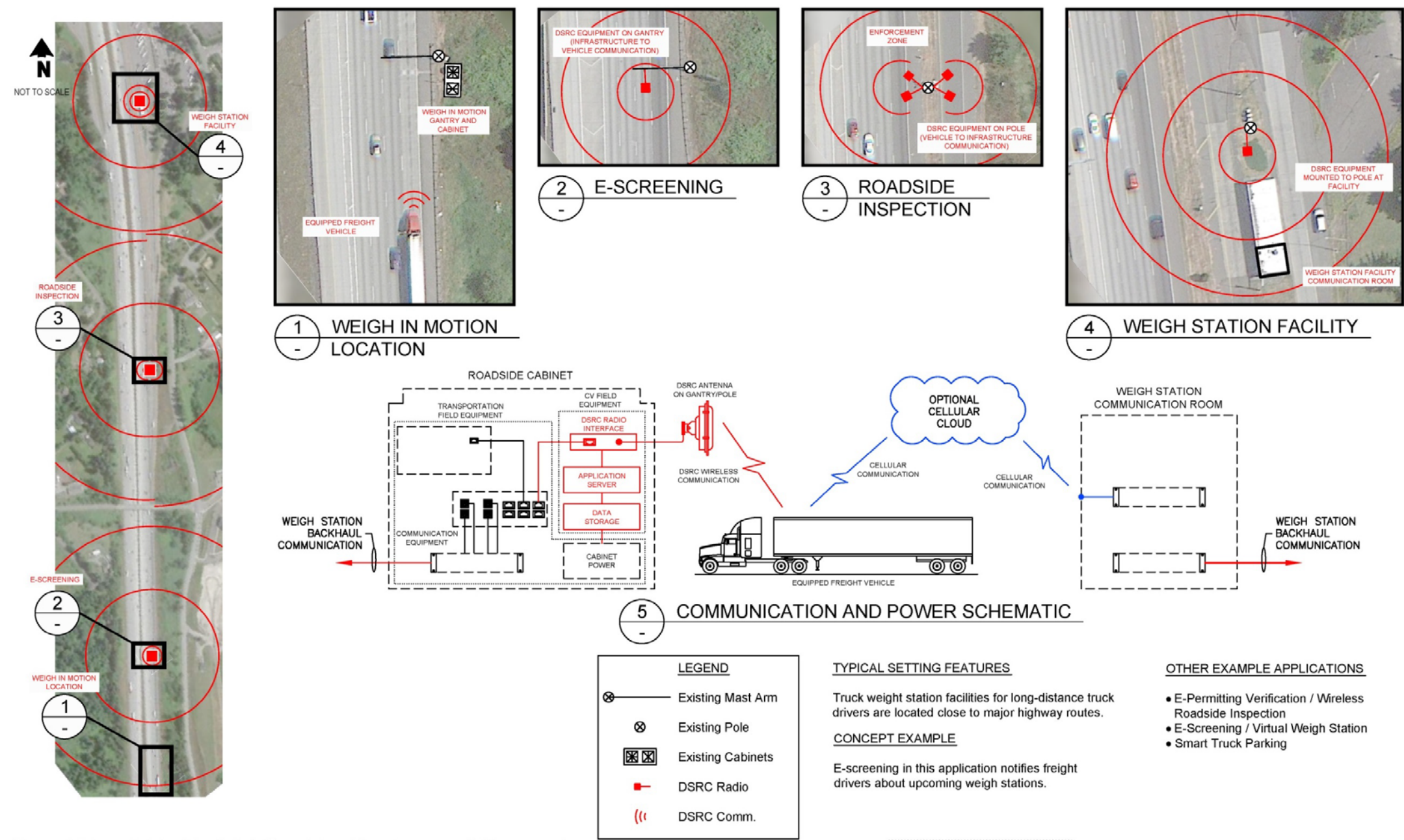
Management Centers and Information Services

Operations in the Smart Roadside initiative would involve various agencies that are involved in freight movement and have a need to communicate with trucks. Backhaul communications between the deployments at key truck facilities and agencies would include the USDOT FMCSA and state agencies that operate freight facilities such as weigh stations. A connected vehicle application would interface with management center systems that are already part of the CVISN program such as the ASPEN inspection reporting system, SAFER safety and fitness electronic records clearinghouse system, and CVIEW commercial vehicle information exchange window. In addition to these nationwide systems, each state agency will often have its own WIM systems, licensing databases, and law enforcement systems.

Applicability

Applications that may be supported by a connected vehicle equipment deployment in the freight corridor setting include, but are not limited to:

- E-Permitting Verification/Wireless Roadside Inspection
- E-Screening/Virtual Weigh Station
- Smart Truck Parking

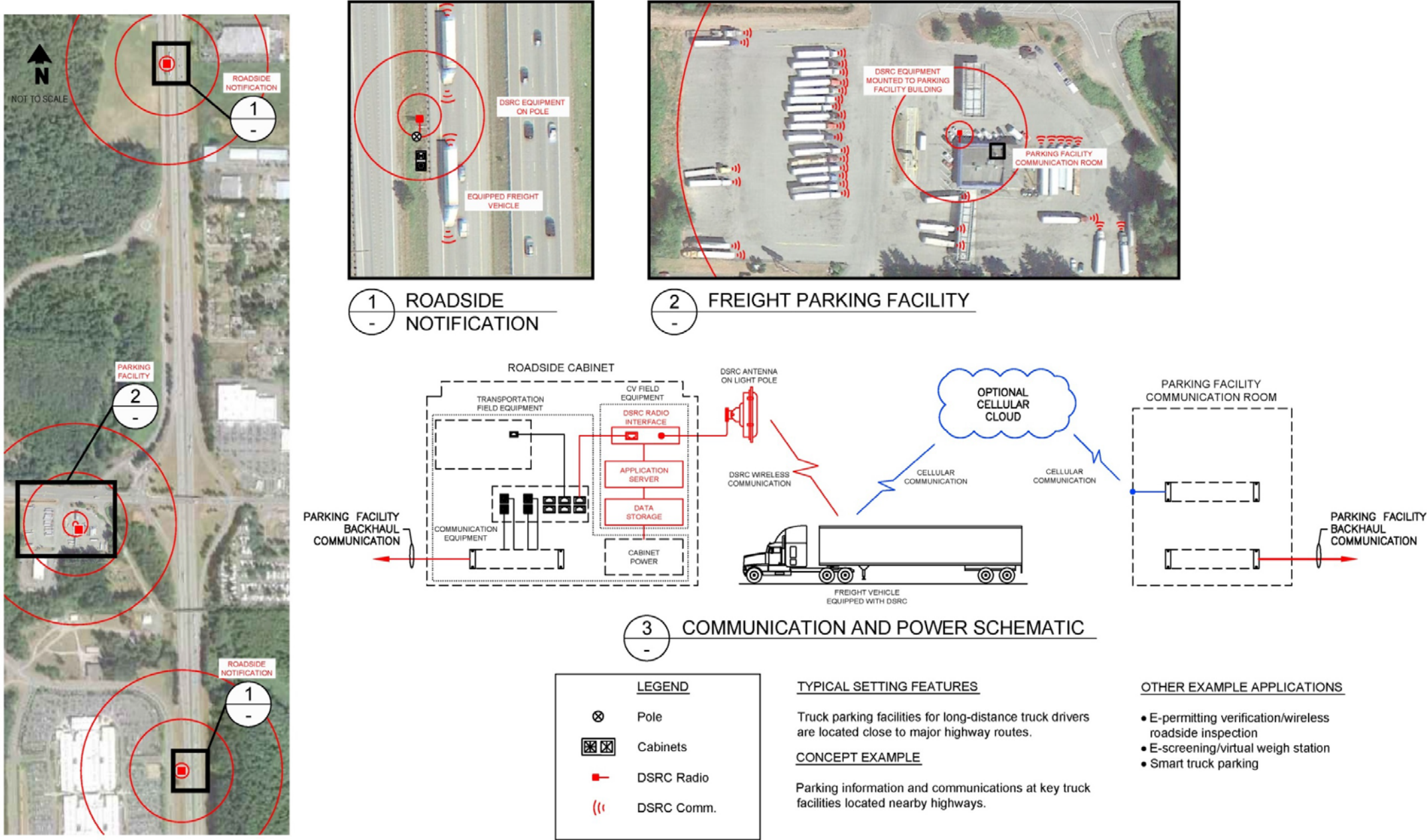


Smart Roadside Freight Corridor Deployment Concept

NATIONAL CONNECTED VEHICLE FIELD INFRASTRUCTURE FOOTPRINT ANALYSIS

M:\12\12131.00 - Connected Vehicle General Concept for Deployment\Engineering\CAD\Sheets\Concept 7 - Freight Roadside.dwg<Concept 6>Karl Typolt 9/3/2013 4:17 PM

Figure 18 - Smart Roadside Freight Corridor Deployment Concept - Weigh Station (Source: USDOT/AASHTO 2014)



Smart Roadside Freight Corridor Deployment Concept

NATIONAL CONNECTED VEHICLE FIELD INFRASTRUCTURE FOOTPRINT ANALYSIS

M:\12\12131.00 - Connected Vehicle General Concept for Deployment\Engineering\CAD\Sheets\Concept 7 - Freight Parking.dwg<Concept 6>Michael Houston 8/14/2013 6:03 PM

Figure 19 - Smart Roadside Freight Corridor Deployment Concept – Parking (Source: USDOT/AASHTO 2014)

DOT Operations and Maintenance

Current State

A Department of Transportation's maintenance and operations divisions oversee the day-to-day needs of maintaining and operating their jurisdictional roadway network. These divisions typically focus specifically on the transportation network's roadway conditions, drainage, roadside and vegetation, bridge and urban tunnels, road weather conditions, and traffic control. Of these functions, roadway conditions, weather, and traffic control tend to have the highest activity service level targets in a DOT's accountability processes.

Maintenance and operations divisions require timely and accurate data to evaluate the condition of its roadways in order to provide the roadway user with a safe means of travel. Weather conditions greatly impact the roadway condition and users of the roadway. To monitor weather conditions, DOTs have installed Road Weather Information Systems (RWIS) that enable proactive winter maintenance practices and better-informed weather related travel decisions. RWIS includes an Environmental Sensor Station (ESS), a communication system for data backhaul, and a central system to manage and store this data. Atmospheric data (e.g. visibility, wind speed/direction), pavement data (e.g. temperature, condition), and water level data are typically collected by RWIS. Environmental data can also be collected from vehicle-based sensors on private vehicles or from specialized sensors that could be installed on snow plows by public agencies. With this data, maintenance control centers can allocate their fleet to desired locations while traffic management centers can alert roadway users via roadway warning systems (e.g. dynamic message signs), websites (e.g. traveler information map), and over land-line (e.g. 511).

Along with roadway conditions, work zone closures have a significant impact on the level of service of a roadway network. Full road closures, partial road closures, and lane closures all facilitate the completion of roadway construction projects. DOT maintenance and operations division as well as private construction contractors apply strategic plans that incorporate advanced warning notification which act as an effective way to manage safety and disruption to traffic along a roadway network.

Concept Description

The concept for the DOT operations and maintenance focuses on providing roadway condition and work zone data to regional maintenance engineers and managers, maintenance personnel, the regional traffic management center personnel, and users of the roadway. Agency fleet vehicles would be equipped with connected vehicle mobile elements to transmit probe data that would include location, speed, heading, and vehicle-specific data such as air and pavement temperatures, snow plow position and spreader rates. The vehicle position data would supplement probe data that could be acquired from private vehicles, and the operational data could be used to feed decision support systems. Other related applications could gather information from and provide information about roadway and traffic conditions in work zones, or use accelerometry from the vehicle to monitor pavement defects.

DSRC Concept

Agency vehicles would be configured with DSRC OBEs with access to the vehicle data bus and any supplementary vehicle sensors or devices. The connected vehicle field equipment for DOT maintenance and operations setting would consist of a DSRC RSU for use by DOT maintenance and operations divisions as well as private construction contractors. Probe data would be cached on the vehicle until it could be transmitted to an RSU. The illustration in Figure 20 shows one example of DSRC communications at a DOT operations and maintenance facility that monitors roadway weather information.

Cellular Concept

Agency vehicles equipped with cellular data (for example, LTE) modems would send information to a server at periodic intervals (e.g., every 100 meters or three seconds) as they travel along the roadway. The message would include the current location, speed, and direction of travel as well as any vehicle operational data (plow position, accelerometry, etc.) that might be applicable to the vehicle and its sensors.

Field Infrastructure

The field infrastructure for DOT maintenance and operations using DSRC will consist of connected vehicle equipment permanently or temporarily installed at locations to best serve the maintenance personnel and work zone construction crews. These locations may include the regional maintenance facility, temporary construction staging sites, major interchanges, and spot locations, construction zones, or areas that may require special maintenance attention. For permanent installations, the equipment typically would be mounted to an existing elevated structure such as a sign gantry, light/camera pole, or overpass. To the greatest extent possible, field infrastructure requirements for this setting should be accomplished through use of infrastructure deployed for other connected vehicle applications.

In order to provide the greatest range for a permanent DSRC deployment and minimize obstruction to line of sight, the equipment will most likely be installed at the highest possible mounting height on the existing structure while meeting FCC requirements.

When identifying permanent installation locations, utilizing existing communication infrastructure will play an important role in reducing installation costs. The connected vehicle field equipment will ideally share communication inside an existing Intelligent Transportation System (ITS) cabinet that is equipped with an Ethernet switch and a backhaul communication connection to the facility control center. Power would be supplied by the existing ITS cabinet (or service cabinet), solar, or nearby electrical service drop.

For temporary settings, such as for short term purposes (e.g. pot hole repair, guard rail repair) and moving operations (e.g. striping, paving), a trailer equipped with a 25 foot pole and cabinet could be utilized, subject to FCC licensing for DSRC operations in that particular location. Placement of the mobile unit should occur on the roadside in the clear zone to avoid a possible collision with construction and roadway vehicles.

Backhaul Communications

The recommended backhaul communications for DOT maintenance and operations setting would consist of an existing backhaul that is owned and maintained by the DOT or leased specifically for the DOT's operational purposes. Backhaul communications for DOT O&M functions could be implemented in a variety of ways depending on the applications being supported; these are discussed in the Common Considerations section.

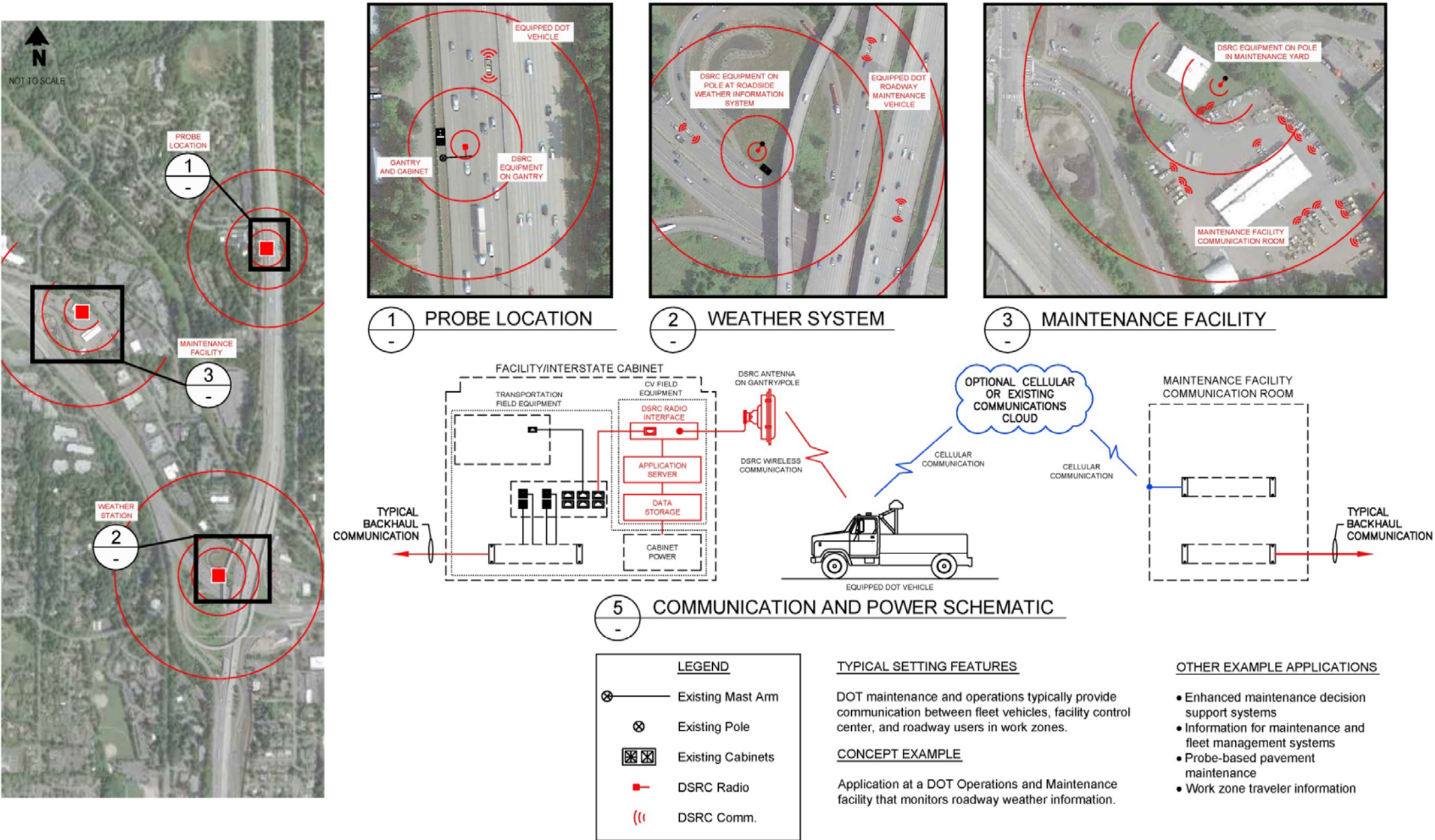
Management Centers and Information Services

Within the connected vehicle system, connected vehicle equipment deployment for the DOT maintenance and operations setting will typically provide real-time communication between fleet vehicles and the facility control center and also work zones and roadway users. Weather information such as snow and ice conditions will be communicated from RWIS back to the control center and relayed to connected vehicle field equipment at regional maintenance facilities and roadside installations. Connected vehicle mobile elements on fleet vehicles will receive this information and respond accordingly. Conversely, fleet vehicles and even general users of the road can provide probe data (e.g., pot-hole detection, weather conditions, pavement traction) that can be sent back to the facility control center. The server system at the control center will gather and archive the data for future use. Potential control applications include DOT maintenance systems, DOT dispatch systems, and interfacing to a traffic management system.

Applicability

Applications that may be supported by a connected vehicle equipment deployment in the DOT operations and maintenance setting include, but are not limited to:

- Enhanced Maintenance Decision Support System
- Information for Maintenance and Fleet Management Systems
- Probe-based Pavement Maintenance
- Work Zone Traveler Information



DOT Operations and Maintenance Deployment Concept

NATIONAL CONNECTED VEHICLE FIELD INFRASTRUCTURE FOOTPRINT ANALYSIS

M:\12\12131.00 - Connected Vehicle General Concept for Deployment\Engineering\CAD\Sheets\Concept 8 - DOT Operations and Maintenance.dwg<Concept 8>Michael Houston 8/14/2013 6:05 PM

NOT FOR
CONSTRUCTION

AASHTO
THE VOICE OF TRANSPORTATION

CONCEPT
8

Figure 20 - DOT Operations and Maintenance Deployment Concept (Source: USDOT/AASHTO 2014)

Fee Payment

Current State

User fees are an integral part in supporting transportation systems by means of collecting revenue to fund transportation projects, recuperate funds from a past project, as well as sustain maintenance and operations costs for roadway infrastructure. In the United States, user fees have been collected through traditional means such as toll booths and have been evolving towards electronic tolling collection (ETC) systems for improved operational efficiencies. ETC systems benefit from added efficiencies as vehicles typically do not stop while assessed a fee through tag readers and RFID technology. Roadway facilities that are commonly tolled include bridges, tunnels, express facilities (High Occupancy Tolling or HOT), freeway systems, and ferry systems. ETC systems typically require interaction with back-end systems to process monetary transactions, license plate database interrogation, and cooperation with enforcement agencies. With the added complexities of autonomously collecting a user fee, electronic tolling systems often require a substantial amount of added equipment to provide vehicle detection, pricing information dissemination, payment processing, enforcement, and auditing capabilities.

Toll facilities adopt pricing structures that are sometimes dependent on time-of-day and relative benefit to neighboring roadway facilities. Often times, user fees are also assessed as a flat-rate pricing structure. With ETC systems, the main form of public interaction is disseminating pricing information whether it is through dynamic message signs, traveler information resources, or other means. All other functions are processed by central system equipment.

Concept Description

The connected vehicle setting for a fee payment application using DSRC communications would generally involve deploying connected vehicle field equipment at facility entry and egress points with the primary objective of providing the driver, via a connected vehicle mobile element, with information regarding an upcoming fee payment facility, account balance, alternate non-tolled parallel routes, and any fees associated with using the system. In this context, the system would provide tolling presence detection similar to typical 915 MHz-based toll transponders, with additional bi-directional exchange of supporting account and traveler information. Although out of scope for this discussion, the DSRC-based system could conceptually, with appropriate transactional safeguards, provide access to a payment transaction system.

Field Infrastructure

Field infrastructure that is available for mounting connected vehicle field equipment in a user fee setting includes sign or equipment gantries, bridge and tunnel structures, and ferry docks. Mountings will be elevated to avoid tampering and provide optimal line of sight and range. Preferred DSRC antenna mounting locations include locations in close proximity to roadside toll equipment where a communication source and power is readily available. While existing user fee collection technologies typically require one reader per lane, DSRC can use one radio that can cover an entire road.

Backhaul Communications

The preferred backhaul communications for a connected vehicle user fee system would consist of an existing network that is owned and maintained by the toll operator. The connected vehicle field equipment would communicate over the same backhaul network to a central management center where the payment can be processed. A high bandwidth network is recommended to provide capacity for potential sharing among connected vehicle applications. Most toll facilities in an urban setting would likely have backhaul communications to support the toll network. In a remote setting, a cellular form of communication may be required to support backhaul communication requirements.

For new deployments, backhaul communications at fee payment installations could be implemented in a variety of ways depending on the applications being supported. These options are discussed in the Common Considerations section.

Management Centers and Information Services

Regular and frequent communication with a central tolling system is critical for the operation of the user fee application. Depending on the user fee system utilized, the central system may be interrogated on a regular interval to obtain vehicle identification data, process payments, and update rate schedules. Two-way real-time communication is required between the management center and the connected vehicle field equipment to support the user fee application. Depending on the established user fee policies, other examples of communication requirements may include real-time toll facility usage to adjust pricing schemes and assessment of user fees based on distance travelled in a toll system.

Additionally, a national center-to-center communication may be required to universally process user fees for vehicles that travel out-of-state. Data that is shared between the state agencies will include vehicle/driver data and fee assessments. User fee back-end systems are typically state-specific and not interchangeable between states. A connected vehicle concept could unify different systems together to create a common platform for user fee assessment.

Applicability

Applications that may be supported by a connected vehicle equipment deployment in the user fee setting include, but are not limited to:

- Approach Lane Use Management
- Automated Toll/User Fee Collection and Administration
- Congestion Pricing
- High-occupancy Toll Lanes

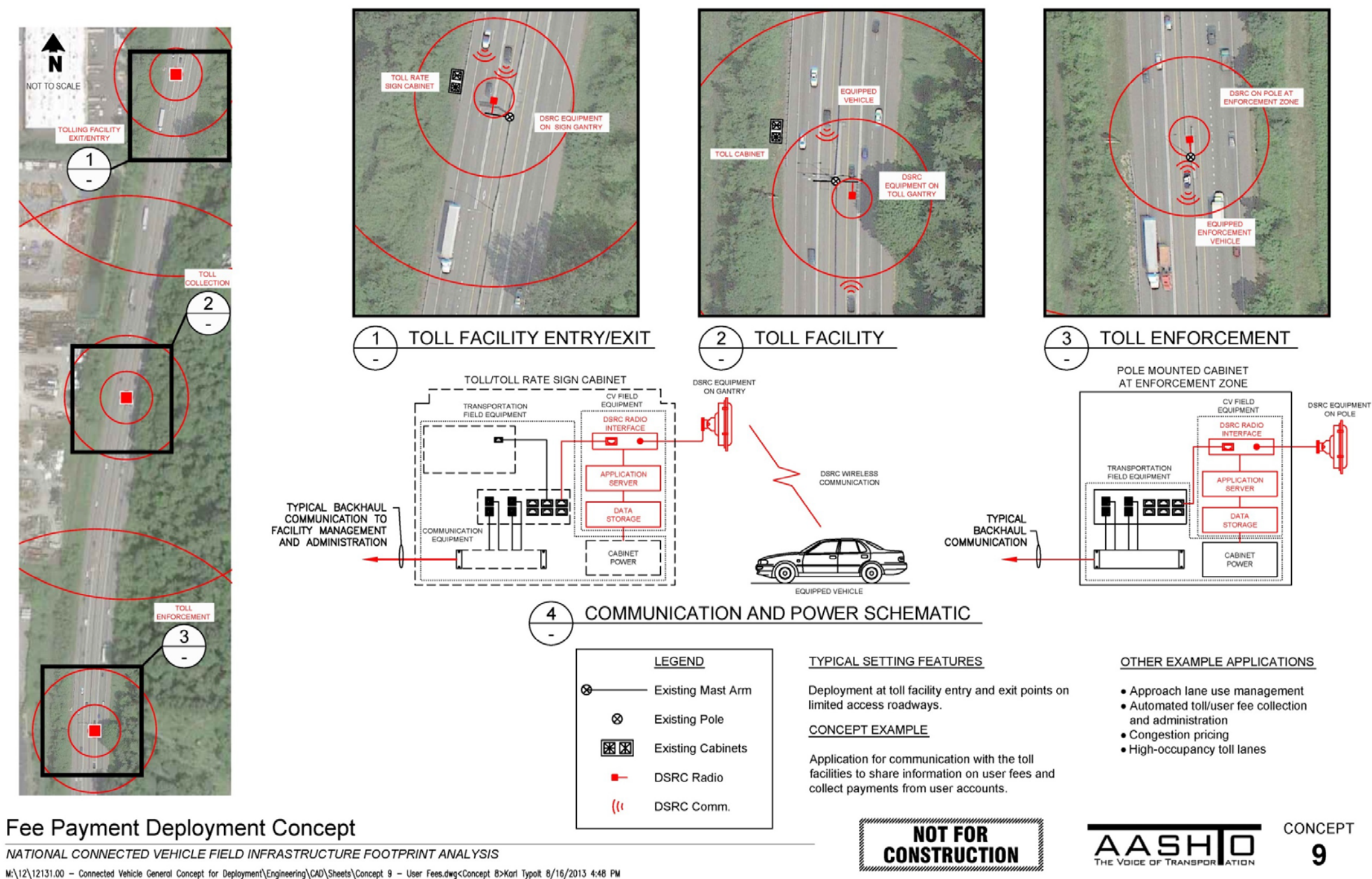


Figure 21 - Fee Payment Deployment Concept (Source: USDOT/AASHTO 2014)

Appendix C. Considerations Common to All Deployment Concepts

Connected Vehicle System Architectures

The connected vehicle system architecture is, at a high level, a system for exchanging data bi-directionally between transportation system field equipment, mobile users, vehicle systems, and transportation system center users. Transportation Field Equipment is typically located at or near the roadway, and may include traffic signal controllers, access controls, or ITS field equipment such as dynamic message signs (DMS), count or vehicle detection (speed) stations, highway advisory radio (HAR) stations, surveillance stations (CCTV), and other related equipment. Vehicle Systems include sensors and various types of user interfaces such as displays, audio interfaces and such. Mobile Users interact directly with the transportation field equipment through the normal use of the transportation system—driving on a roadway, observing a traffic signal—and (if they are in a vehicle) interact with the vehicle systems through the vehicle's user interface equipment. A Mobile User's primary interests are to get through the transportation system safely and efficiently. Transportation Information System Users are any other users that may need information about the roadway or transportation system state or about vehicles on the roadway. These users are typically responsible for managing and maintaining the roads, or may be other users with an interest in information about the transportation system, such as users planning trips. This overall system is illustrated in the figure below.

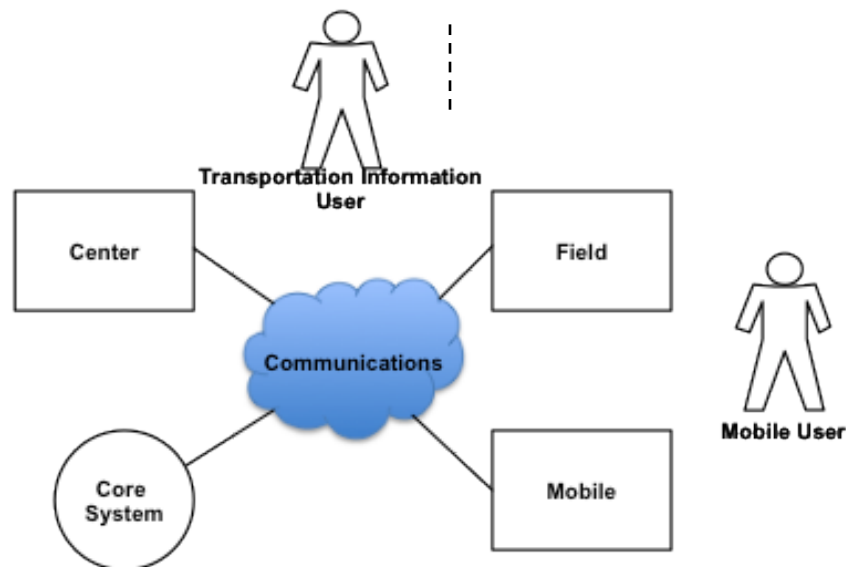


Figure 22 - Top Level View of Connected Vehicle System (Source: USDOT/AASHTO 2014)

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

This system is the same as the overall system described in the Core System architecture and the Connected Vehicle Reference Implementation Architecture (CVRIA) documentation, although here it is focused on the “Mobile”, Field” and “Center” elements of that architecture since these are the parts that actually carry out the steps of connected vehicle applications.

While it is included here for completeness, the Core System does not play a role in the applications discussed in this report. The Core System ConOps does not describe the applications treated in this report, and the Core System Requirements (SYRS) apply to elements within the core system (in support of the Core System functions described in the ConOps), but these do not apply to the Mobile, Field and Center elements described here since these elements are “outside” the Core System boundary.

It is important to note that the connected vehicle system sits within the existing transportation system. Thus the mobile, field and center elements of the system shown above actually include elements that are part of the connected vehicle system and elements that lie outside the connected vehicle system. Vehicles (mobile), traffic signal controllers and signals (field), and traffic management centers (center) exist today without the connected vehicle system. As the connected vehicle system emerges, it will thus include new elements for each of these component areas. A key aspect of the system deployment will be the implementation of the interfaces between these new connected vehicle elements and the existing elements in the transportation system. Figure 23 below outlines this distinction, and illustrates the various internal elements of the connected vehicle system.

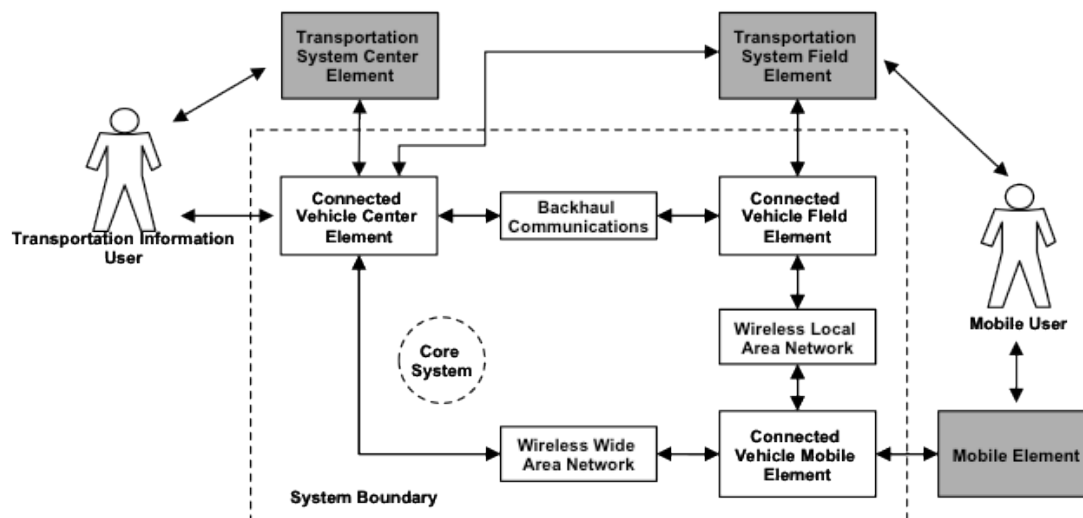


Figure 23 - Connected Vehicle System Diagram (Source: USDOT/AASHTO 2014)

To support this separation between existing elements and their connected vehicle counterparts, diagram has adopted some slightly refined terminology. For example, in a DSRC-based system, the Connected Vehicle Field Element is also known as an RSU (Roadside Unit) and the Connected Vehicle Mobile Element is known as the OBU (On-Board Unit). In general, the Connected Vehicle Mobile Element is located in a vehicle, and “connected vehicles” may therefore refer to a Connected Vehicle Mobile Element even if the mobile element were a user’s smartphone. There will always be a wireless connection to a mobile element.

As shown in the diagram above, the mobile element of the connected vehicle system may communicate with the field element using a wireless local area network (WLAN). The WLAN is so named because it supports communications over limited range in the area local to the field element. In most currently-envisioned implementations of the Connected Vehicle System, the WLAN element is implemented using DSRC. However many studies have examined other ways of implementing this element (for example, Wi-Fi, Bluetooth or LTE Direct), so it is referred to here by its more generic term. Through this connection the mobile element can receive information from the field element. This information may originate at a center element (e.g. a traffic management center) and be provided to the field element over the backhaul link, or it may originate from transportation field equipment co-located with the connected vehicle field equipment (for example, a signal controller providing signal information to a roadside DSRC unit). The mobile element may also provide data to the center element via the field elements (again over the backhaul link), or it may also exchange data (bi-directionally) directly with the center element using a wireless wide area network (WWAN) such as cellular/LTE network. The WWAN is so named because it facilitates communication over a long range, so the mobile element can communicate with the remotely located center element(s) over a large geographic region. Other technologies for implementing the WWAN element include satellite and WiMAX, although generally cellular/LTE is the dominant approach.

This system diagram above is general and technology-agnostic, but it also represents the two primary current connected vehicle approaches: local two-way communication using DSRC, and remote two-way communication using cellular/LTE. Other communication paths may be possible, but from a technical perspective these two approaches are representative and further discussion is generally limited to these concepts (see “Communications Elements” below for further discussion).

Connected Vehicle Data Needs and Standards

Connected vehicle data needs include data needed by connected vehicles from other nearby connected vehicles (V2V data), data needed by the center elements from connected vehicles (V2I data), and data needed by connected vehicles from the roadway (strictly speaking, I2V data, but commonly referred to as V2I data). “V2I” is used in this report for both directions of communication except where this direction is important to understanding the system (e.g., Table 25 below).

V2V data generally consists of kinematic data from nearby vehicles that will enable a receiving vehicle to understand the current state of the transmitting vehicle and to project its trajectory a few seconds into the future so as to assess potential conflicts.

V2I data includes data describing road and traffic conditions observed by the vehicle along sections of road traveled at some earlier time. These data are sent from a vehicle to an RSU using the local wireless link and are generally passed from the RSU to the center element over the backhaul communications link. These data may also be provided directly to the center element by the vehicle using the wide area link (e.g., via cellular). V2I data may also include V2V messages that may be received by an RSU (where the connected vehicle is transmitting V2V data in the vicinity of an RSU).

V2I data also includes data generally associated with the roadway on which the vehicle is or will likely be traveling. This data may be transmitted locally from RSUs to vehicles in the local vicinity of the RSU (i.e., in range of the wireless local link) or may be transmitted to the vehicle directly by the center element using the wide area wireless link. Some of this data may originate locally from transportation

field equipment co-located with the RSU (for example, traffic signal data), and some may be provided to the RSU through its backhaul link by the center element. It is also important to note that data provided to the vehicle may be relevant at the *current location* or at a *potential future location* of the vehicle. For example, it is not necessary to deliver curve speed warning information to the vehicle at or near the curve in question. Since curve speed information is relatively static over time, it can be delivered at a remote location (for example, where it is convenient to locate an RSU) and then activated when/if the vehicle reaches the curve.⁶² Information that has a higher time criticality must be delivered when the vehicle is closer to the location to which the information relates. Traffic signal timing information, for example, generally needs to be delivered when the vehicle is relatively close to the intersection.

The data communications between vehicles and infrastructure are sent as discrete messages. These messages are typically structured as pre-defined sets of data corresponding to particular parameters. These sets may be fixed in size (i.e., a fixed number of data bits) or they may be variable in size, in which case they are preceded by an indication of the length of the subsequent data set. For current connected vehicle applications, the SAE J2735 standard defines messages for many of these types of information. These are listed in Table 25 below in relation to the type of communication (V2V, V2I or I2V) to which they relate.

Table 25 - Representative SAE J2735 Messages and Communication Modes (Source: USDOT/AASHTO 2014)

	V2V	V2I	I2V*
Basic Safety Message Part 1	✓	✓	
Basic Safety Message Part 2	✓	✓	
Emergency Vehicle Alert	✓		
Common Safety Request	✓		
Probe Vehicle Data		✓	
Signal Request Message		✓	
Roadside Alert			✓
Traveler Information			✓
Map Data			✓
Probe Data Management			✓
Signal Phase and Timing			✓
Signal State Message			✓
NMEA Corrections			✓
RTCM Corrections			✓

* I2V here is commonly referred to as V2I data. It is denoted I2V here to illustrate the direction of transmission

⁶² This model presupposes that an application capable of caching and using the curve speed warning data at the appropriate location is deployed in the vehicle.

The messages defined in the current SAE J2735 standard partially meet the application needs, but there are issues beyond the scope of this analysis that are yet to be addressed.

A significant opportunity presented by the connected vehicle system is to obtain data from mobile (vehicle-based) sensors that would otherwise be provided by infrastructure sensors that are limited in coverage. A single infrastructure communications point can then gather information on what is happening at multiple points along miles of roadway, albeit with some delay. This provides a very cost effective means of creating a general situational awareness of the transportation system status. Some of the messages above, in particular the Probe Vehicle Data message, are intended for this purpose.

The J2735 standard provides a technical description of the potential messages and the data they may contain, but does not guarantee that data elements will actually be available or that messages would be delivered. The Basic Safety Message (BSM) Part 1 is currently the only message widely agreed to be transmitted. A more complete data needs discussion necessarily extends beyond what *can* be transmitted to what *will* be transmitted, but this is largely a policy issue outside the scope of this document. Nonetheless, many of the applications described in this document require data beyond the BSM Part 1, and the availability of those applications is linked to availability of data.

The collection of probe data poses significant privacy issues, especially where a mandate is considered. For data collected using wide area communications, the carrier knows who is sending the data, and so the data must be reliably separated from its source. In the case of local area communications, the data must be stored on the vehicle until the vehicle reaches a suitable RSU, and it must then be encrypted during transmission so that an eavesdropper cannot link the transferred data to a physically observed vehicle.

A potential solution to the privacy concern would be to enlist a third-party who does not know where the data is coming from (either via wide area or local area communications) to process the data packets. The carrier (WAN or LAN) may know the origin of packets, but cannot open the contents. Since this third-party would have access to the data, it is likely they could build a successful business model and help to finance the overall deployment, but many policy issues surround this concept.

Mobile Element Components

Embedded Vehicle Terminals

A typical embedded vehicle terminal is shown below in Figure 24. This implementation includes an interface that enables the collection of a variety of vehicle data that can then be sent over the local or wide area links. Depending on the implementation, this interface may be a bi-directional gateway allowing authorized input of data to the vehicle, or it may be a one-way data reporting gateway.⁶³

⁶³Note: Portions of this section were originally developed by this author, and delivered to the US DOT under contract numbers DTFH61-04-D-00002 and DTFH61-11-D-00019.

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

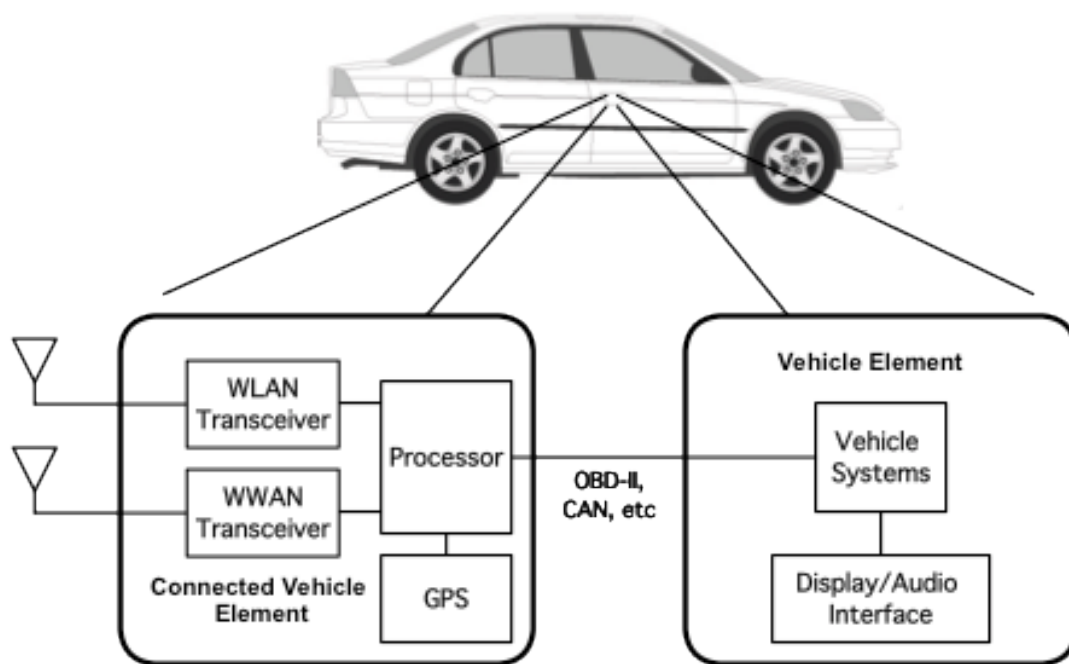


Figure 24 - Embedded Connected Vehicle Terminal Example (Source: USDOT/AASHTO 2014)

The connected vehicle element is typically supported by a host processor that runs various connected vehicle applications and includes a location capability such as GPS. In general an embedded system will be implemented such that the connected vehicle functions are integral with other vehicle elements. They are shown here as separate to preserve the connected vehicle system boundary. In general, embedded vehicle implementations will be exclusively controlled by the vehicle OEM.

Aftermarket Vehicle Terminals

Aftermarket vehicle terminals are similar to embedded terminals except that they depend on post-production installation in the vehicle, and will typically include a dedicated user interface. Depending on the origin of the terminal, the vehicle interface may include extensive vehicle data (for example if the aftermarket device is OEM approved) or it may be limited to data available through the vehicle's on-board diagnostics (OBD-II) connector. Systems without access to OEM data are likely to be limited in functionality due to the lack of access to sensors generally available within a vehicle. A typical aftermarket implementation is illustrated in Figure 25.

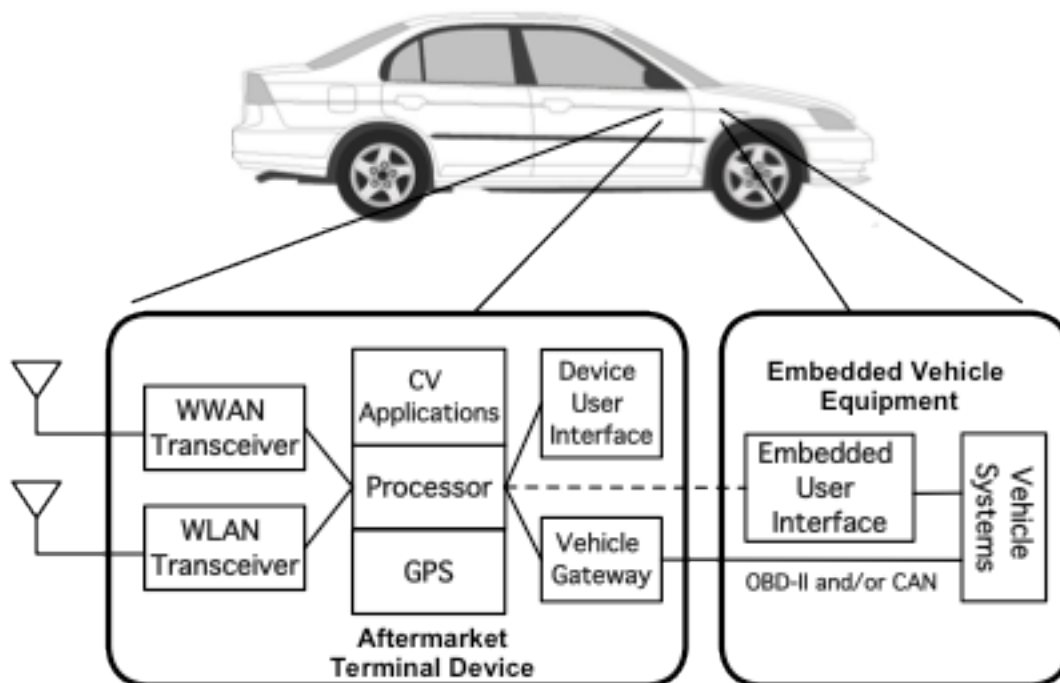


Figure 25 - Aftermarket Connected Vehicle Terminal Example (Source: USDOT/AASHTO 2014)

In addition to variations in the vehicle interface, it is expected that some advanced implementations may also take advantage of specialized user interface technologies such as MirrorLink® or other systems that allow third party devices to access a user interface provided by the manufacturer embedded in the vehicle (shown notionally as a dashed line in the figure). This approach is attractive since it assures a high quality user interface that complies with OEM safety objectives but does not depend on the long vehicle product development cycle, so it can support a changing variety of aftermarket terminal implementations. However, these systems have not yet been proven in the marketplace.

Portable Consumer Electronic Terminals

Portable or “nomadic” connected vehicle terminals are likely to be based on smartphones. The devices, shown in Figure 26 below, may connect to vehicle systems through a gateway using Bluetooth®, MirrorLink® or other serial protocols. Like aftermarket devices, they may use a dedicated device user interface, or may use a user interface embedded in the vehicle. Consumer electronic (CE) “connected vehicle” devices may also be used by pedestrians, wheelchairs, cyclists, motor cyclists, and other non-motor vehicle users. It is also likely that many CE based devices, especially initially, will not support a connected vehicle WLAN connection (i.e. DSRC). These devices will generally use a cellular data connection, and may support Wi-Fi, but these links will only provide access to and transactions with a connected vehicle center element, not connected to vehicle field equipment. It is possible that over time these devices may also support direct local connections to connected vehicle field equipment using DSRC, although no consumer electronics manufacturers have announced any such products.

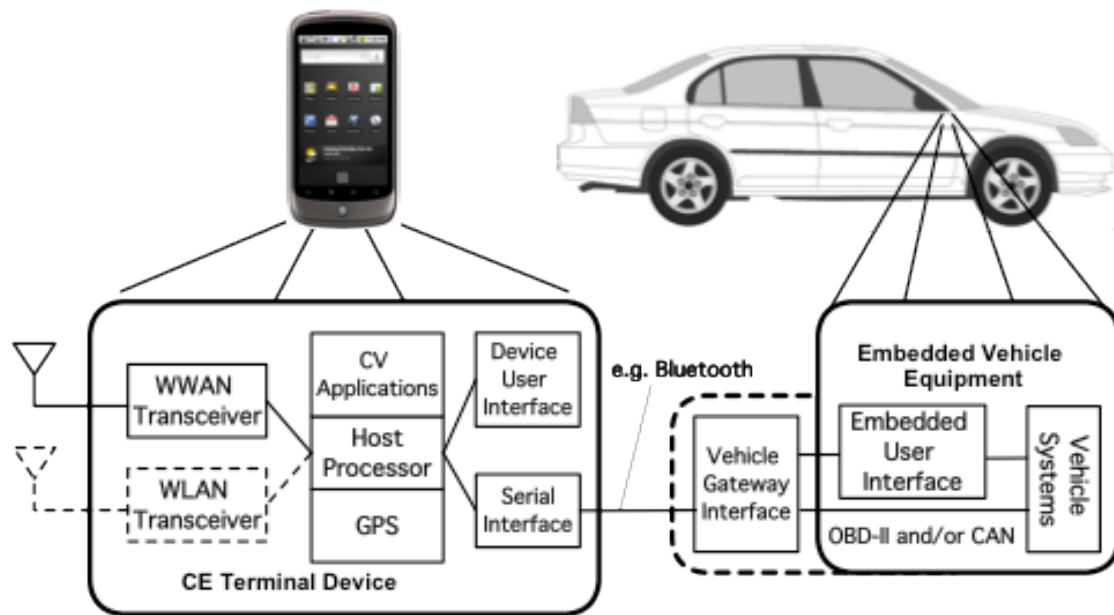


Figure 26 - Consumer Electronic Connected Vehicle Terminal Example (Source: USDOT/AASHTO 2014)

V2I Communications

It is generally assumed in this report that connected vehicle communications between connected vehicle mobile elements and field elements are carried out using DSRC/WAVE technology, and that communications directly between connected vehicle mobile elements and center elements are carried out using cellular/LTE. These are discussed in more detail below. There are other communications systems that could also be used, but generally these are not seen as particularly viable for connected vehicle applications and are outside the scope of this discussion.

DSRC WAVE Communications

DSRC is a form of 802.11 (Wi-Fi) that does not involve any association process between the terminals and the base station. (DSRC systems are *not* interoperable with other Wi-Fi systems, but they are based on most of the same underlying standards). It operates in a frequency band between 5.85 GHz and 5.925 GHz. Unlike Wi-Fi, in which the operating channel is selected at the time of association, DSRC also allows terminals to dynamically switch between channels, so the entire allocated frequency band can be used by any mobile terminal. The other two key differences between DSRC and Wi-Fi are in the upper layers of the protocol. For DSRC this is known as the Wireless Access in Vehicular Environments (WAVE) protocol. WAVE identifies two network layer protocols, the WAVE Short Message Protocol (WSMP) and IPv6, which are discussed below.

WAVE Short Message Protocol

The WAVE Short Message Protocol (WSMP) provides a simple means for sending a short (single packet) message (WAVE Short Message, or WSM) to other terminals in the local area. It is primarily intended for broadcast communication to any and all terminals in range, and as a result it uses a different type of addressing. Instead of addressing a message to a particular network element (i.e. a network address), WSMP “addresses” messages according to the type of service they are associated with. This enables a receiving terminal to deliver a received message to those applications that are associated with the referenced service. While it is also possible to send a message to a specific terminal (known as unicast), this requires that the target terminal has already sent a broadcast message (so that the transmitting terminal can learn its network address – known as a MAC address). In general, most WSM transmissions are broadcast since they relate to all terminals in the immediate proximity of the transmitter.

The WSM is limited in size because the entire message, including all of the headers and security information, must fit into the specified Maximum Transmission Unit (MTU). While the MTU size can be changed, this requires coordination and/or discovery by the communicating terminals, so typically the default value of 1500 bytes is used.

It is also important to note that WSMP is primarily a “local” protocol. That is, it is not routable using conventional network protocols, and thus it is intended to serve applications that are local to the transmitting radio.

Internet Protocol (IPv6)

For transactions involving larger amounts of data than can be supported by WSMP, or for transactions where the recipient is not local to the DSRC terminal (e.g. a remote service provider connected to the fixed provider terminal by a backhaul network) the DSRC system supports the well-known Internet Protocol (IP), specifically, the IPv6 protocol. IP transactions are only supported on the undesignated DSRC service channels, and are forbidden in the 802.11p Standard on the control channel. Unlike WSMP, IP enables the sender to send messages that are larger than a single packet. The IP protocol segments the original messages into smaller packets and sends these, and they are then reassembled at the receiving end to recover the original file.

In order to send an IP packet, a terminal must have an IP address. This is easily accomplished for fixed terminals where the IP address is established when the network is formed. For mobile terminals this is not so simple. Because the terminal is mobile, it is not likely to remain in contact with any given access point for very long, and as a result, if it were to have a fixed IP address, the routing information for each access point would be in constant flux, and would generally be hopelessly out of date all the time. In addition it would then be possible to geographically track any terminal by tracking the IP address. It is not practical to use Dynamic Host Configuration Protocol (DHCP) (which is typically used by Wi-Fi hot spots) to assign IP addresses because the vehicles are entering and leaving a given hot spot at a relatively fast rate, and servicing the high volume of DHCP requests would be overwhelming. IPv6 addresses this problem by using a different sort of IP address. In operation the mobile terminal can adopt a portion of the roadside unit’s IP address and thereby create an IP address that is valid while the vehicle is in the radio footprint of the RSU.

Cellular Communications

Cellular systems are widely available and, driven by various consumer devices (smartphones, tablet computers, etc.), the cellular industry has been substantially expanding cellular capacity and coverage over the past 20 years.

The most recent advancement in cellular technology is known as LTE (long term evolution). This technology effectively combines the benefits of Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA) systems in a highly flexible and wideband IP-based system. While LTE is able to deliver very high data rates to fixed users, the highest achievable future LTE (LTE Advanced) data rate for moving users is 100 Mbps. In practice, however, because of user capacity limitations and interference, this is typically substantially lower. Still, LTE is a rapidly evolving technology that is specifically intended to provide high data rates to mobile users. LTE and the various previous versions of the cellular standard have been managed by the 3rd Generation Partnership Project (3GPP) since 1998. The 3GPP specification releases occur about every 2 years or so. Because the standard is so widely used, there is substantial attention paid to backward compatibility, so in most cases new features that extend performance can be used without rendering earlier systems obsolete. The current standard, known commonly as 4G, is expected to evolve as discussed briefly below (e.g. see LTE-Direct).

LTE is an all IP network. The cell areas are generally large, and each terminal is assigned an IP address when it joins the network. A variety of schemes have been developed to enable terminals to maintain IP connectivity with remote servers as they move from cell site to cell site. As a result LTE is very well suited to connecting mobile terminals to remote servers. Contacting mobile terminals over the IP network is somewhat more complex, although mechanisms for this have been developed.

Unlike DSRC, LTE currently makes no provision for one mobile terminal to communicate directly with another nearby mobile terminal or a local data source (e.g., a system that might be connected to an RSU to provide localized data). With LTE all communications currently must go through the cellular system carrier's back haul network (a network that connects the cell site to the carrier's back office systems, and generally, to the Internet) and must include an IP address for a point-to-point connection. An emerging addition to the 3GPP specifications (Release 12) is a system known as LTE-Direct. This system will allow communication directly between LTE terminal devices. It uses a concept known as "Proximity Discovery" that allows LTE terminals to announce the services they have to offer to other terminals in the local area. These announcements can then lead to one terminal providing information to other terminals in the area. The technology has not been widely used as yet, but it may provide an LTE-based mechanism for V2V and V2I communications. In this case, the WLAN of Figure 23 above would be an LTE-Direct link, and the WWAN would be a conventional LTE client terminal-to-cell site link.

Communications Security

The connected vehicle security system is aimed at ensuring three basic objectives: privacy, authenticity and robustness through certification. The basic structure of the security system is designed to provide assurance of the confidentiality of private message traffic, the authenticity of public message traffic, and the anonymity of private generators of public messages.

Privacy

Because the connected vehicle system includes messages relating to location and speed of mobile users, it has been generally agreed that it is necessary to protect the privacy of the mobile user population (to avoid, for example, using the system to enforce traffic laws, and to prevent tracking of the movements of individuals based on their transmitted messages). Privacy is not necessarily needed or desired for public sector users and/or equipment, and generally both public and private field elements do not require anonymous certification since they are stationary.

For private sector mobile users, privacy is addressed in two ways: anonymity and confidentiality. Anonymity is achieved by excluding any sort of identifying information in publicly transmitted messages, and by assuring that there is no publicly available linkage between the user's identity and any of the message content. In addition, when identifying information is passed through the system to trusted service providers (for example to execute a payment transaction, or to request services from a subscriber based service), the system provides mechanisms to encrypt this information so that only the intended recipient can access this information. This process uses conventional encryption techniques.

To assure anonymity, the connected vehicle system uses a special security credentialing process for private users. This process assures that the security credentials themselves do not provide a mechanism for tracking or identifying the users. This system has some shortcomings outside the scope of this analysis that are yet to be addressed.

Authenticity

To provide assurance that received messages are authentic, the connected vehicle system employs a digital signing system based on conventional public key cryptography (PKI) systems. In this approach, each message includes a digital signature and a "certificate." To generate a signature, a digest of the message is generated using some agreed-upon algorithm. This digest is essentially a small subset of the data that forms the message, generated by a hashing algorithm. The resulting digest is then encrypted using the sender's private key. The certificate includes other information relating to the permissions of the sender. For example an RSU certificate might include the authorized location or jurisdiction for the RSU to avoid issues with the RSU being physically moved to a different location. The certificate also includes a digital signature which is provided by a trusted third party, known as a Certificate Authority (CA). This signature allows the receiving party to verify that the certificate is legitimate.

The signature and the sender's certificate and, if appropriate, the certificate authority signature on the sender's certificate are appended to the message; the sender's certificate includes the sender's public key so that the receiver can decrypt the signature. Once decrypted, the receiver can compare the decrypted signature to the same data generated from the received message (using the same agreed upon algorithm for generating the digest). If the two resulting files match, then the receiver can be assured that the message was sent by the holder of the certificate, the holder of the certificate is endorsed by the certificate authority, and the message was not somehow altered in transit.

This process is the same for both public and private users, except that the certificates used by public users are not necessarily anonymous, so, the certificate and/or the message itself may include information identifying, for example, the organization responsible for generating the message.

Certification

The originator must be certified by the certificate authority to send signed messages. In general the originator is assumed to be the transmitting terminal. For connected vehicle mobile equipment, the originator would be the WLAN or WWAN device; for connected vehicle field equipment, it would be the WLAN device (e.g. RSU); and for connected vehicle center elements it would be the server originating the message. It is generally assumed that backhaul communication between the center elements and the field elements is secured using conventional network security methods, so a message provided by the center element to a field element for transmission would be provided through whatever secure backhaul system the agency had implemented, and the message transmitted over the WLAN (DSRC) link would be signed by the sending device.

There has been a great deal of industry attention applied to the process of certifying private mobile terminal equipment. This is primarily a result of the need for anonymity and the desire to prevent tracking of private mobile terminals through the security credentials. The process for certification of public sector mobile equipment and both public and private field equipment is much simpler since it can be based on conventional PKI certification processes. It is important to point out that field equipment is inherently trackable and non-anonymous (since it is generally licensed, and is located at a known place), so it does not require anonymous certification.

Other Security Elements

The entire security system and its management has been the topic of extensive development effort over the past few years. Currently the threats addressed by the security system focus primarily on false messages and resulting false positive application actions (generally false warnings). Issues associated with the number of certificates used in vehicles, the process of identifying bad actors (misbehavior detection), the process of removing those bad actors and the scope of this sort of problem (i.e. the size of the revocation list) are all key concerns to which interim approaches have been developed.

There are open questions about the ability of the system to withstand attacks and about the threat model that the system is designed to protect against. For example, the current assumptions about the scale of misbehavior and the resulting scale of certificate revocation are either so low as to suggest that the security system may not be all that necessary (i.e. the security system is imposing heavy overhead to avoid a problem that will almost never be seen), or are so large that the current design will be unable to cope with the load (i.e., creating a large number of misbehaving vehicles will cause the security system to fail). In addition the fact that a vehicle terminal has certificates does not by itself assure that the terminal has not been tampered with in some way. Recent studies have indicated that in addition to false messages, attacks where the terminal is injected with malware are feasible. Such an attack could find its way inside the existing security system (so malware messages would be signed and appear legitimate), and could extensively subvert system operations.

Security is a moving target and will likely undergo extensive evolution over time.

Backhaul

The connected vehicle environment includes mobile terminals, field terminals and center terminals. Mobile terminals are typically vehicles, while field terminals, when they are used, are typically radio terminals located along the roadway (typically called “roadside equipment”, or RSU). Center facilities include traffic management centers and other road authority/agency back office facilities, and remote service providers.

Conventional connected vehicle architectures assume that field equipment and center facilities are connected by a communications link. This is typically called a “Backhaul Network”. In these systems the Center can send information to field terminals (e.g. messages to be transmitted by the field terminal) and the field equipment can send information back to the center facility. The information sent back to the center facility may be status information about the field terminal, or it may be local information relating to other field equipment such as signal controllers that are attached to the field terminal. It may also be information received from nearby mobile terminals and forwarded to the center by the field terminal.

Some connected vehicle architectures may not use field equipment. In this case communications between the mobile terminals and the center facilities would be over a wide area network. While this could be considered a backhaul link, for purposes of this project it is not included. Wireless wide area network connections to mobile terminals are discussed elsewhere in this report.

Numerous technologies can be used to provide backhaul communications. Table 26 below describes the available technologies and summarizes their key strengths and limitations for backhaul applications.

Table 26 - Backhaul Technology Overview (Source: USDOT/AASHTO 2014)

Type	Technology	Description	Metrics	Strengths	Limitations
Wide Area	Cellular (LTE)	General purpose IP data oriented wide area wireless system. Generally available from a variety of commercial service providers. LTE is an evolution of the well-known European GSM system that provides increased capacity and data rates. Typical fixed service data rates of about 300 Mbps are available.	Data Rate: 300 Mbps (when stationary) Range:10-20 Km Modem Cost: ~\$500 (industrial) Service Cost: ~\$50/mo* BW Limit: 6 GB/Mo* * Pricing varies; rates shown were obtained 8/29/2013	Widely available and generally low cost Generally high data rates Some limitations with IPv6 Rural availability varies	Data volumes can be limited; excess data volume costs can rise rapidly Data rates and costs may be higher than required Substantial competition for data resources (may drive down stream costs) Requires external antenna
	Cellular (GPRS)	Low end cellular data link. Generally provided, at substantially lower cost than LTE, by the same providers. GPRS is commonly used for M2M data links that do not require significant data rates.	Data Rate: 80 kbps Range:10-20 Km Modem Cost: ~\$300 (industrial) Service Cost: ~\$50/mo* BW Limit: 6 GB/Mo* (25 kbps sustained 6 hours per day) * Pricing varies; rates shown were obtained 8/29/2013	Widely available and generally low cost Generally usable data rates Cannot support IPv6 Rural availability varies	May be being phased out in lieu of higher bandwidth higher priced services Requires external antenna
	WiMAX	WiMAX is a wide area Wi-Fi –like communications technology. It is simpler than cellular/LTE, and has a lower overall user capacity, but it is commonly used for relatively long range wireless backhaul networks. It is	Data Rate: 1-70 Mbps Range:30 Km (at lower data rates) Base Station Cost: ~\$50K Modem Cost: ~\$200 (industrial) Service Cost: Typically none (custom network installation)	Very good performance in terms of range and data rates Costs are determinate; no data volume costs Easily extensible by adding inexpensive client modems	Somewhat high initial system cost Requires external antenna

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

		described by the IEEE 802.16 standard. "Campus area" systems can be easily purchased and set up with minimal collateral complexity. Licenses are required for wide area implementations. Some service providers offer WiMAX commercially, but generally the technology is evolving toward self-contained purchased networks.		Highly reliable Generally limited competition, and limited downstream cost risk	
	Fixed Service Satellite (FSS)	Fixed Satellite Service (FSS) uses Very Small Aperture Satellite (VSAT) terminals to provide high data rate wide area two way communications nearly anywhere that has a clear sky view. This technology is used to deliver satellite television (e.g., DirecTV, DISH, etc.) although it can also be used to provide other types of data communication. When used in a two way system the terminals generally include a 1 meter (i.e. larger than a TV dish antenna) dish antenna. These systems may be useful in remote areas	Data Rate: 5-15 Mbps Coverage: Nationwide Modem Cost: ~\$500 Service Cost: \$40-\$100/mo (<40GB) * HughesNet Gen4 pricing	Very flexible in terms of geographic locations Generally high data rates	VSAT antennas are somewhat large for most physical installations (e.g., at a controller cabinet) May be subject to weather related performance issues May require periodic maintenance (snow/ice removal, etc.)

		where RSUs are too far away to be services by conventional wide area radio links			
	Satellite SDARS	Satellite Digital Audio Radio Service (SDARS) is a system that provides relatively high bandwidth digital data broadcasts over the continental US. The system is broadcast only and cannot support any return channel communications. The primary use of this system is for delivery of CD quality audio (the SiriusXM system). It is also used to deliver targeted telematics data to vehicles, and could be used to deliver message content and operational control messages to remote RSUs.	Data Rate: 44 Kbps (single stream); 4 Mbps (all streams) Coverage: Nationwide Modem Cost: ~\$50 Service Cost: ~\$5-\$10/month	Low cost equipment and service Wide geographic capability (e.g. rural locations)	Downlink only Relatively low data rate Relatively high latency (unsuitable for “real time” alerts) Requires external antenna
Local Area	UWB	Ultra-wideband (UWB) is a short range communication system that uses very short pulses. The result is a very wide spectrum with low signal levels. It is used for short range high data rate communications. The technology has been in development for a long time and it has never	Data Rate: 675 Mbps Range: ~5 meters Modem Cost: unknown No commercially available units identified. Service Cost: Typically none (custom network installation)	High data rate Low power	Limited commercial equipment availability Uncertain regulator environment Unstable standards environment Only suitable for local manual RSU programming using a localized device. Not a true remote backhaul

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

		gained any significant following. It could be used for local communications between an RSU and a handheld or truck mounted system that could link the RSU over a roaming cellular or other link on an intermittent basis.			Requires development of secure system access system to prevent unwanted RSU tampering May require external antenna
	Wi-Fi	Wi-Fi is a relatively short range wireless Ethernet system that provides relatively high data rate point to point communications between terminals. It is defined by a set of standards under IEEE 802.11 which specifies numerous variants of the standard providing a range of ranges and data rates. Typical uses are for providing connectivity between mobile devices (e.g. PCs and consumer devices) and the internet. The system is very popular and is widely available and inexpensive.	Data Rate: ~1- 150 Mbps Range:~20-150 meters Modem Cost: ~\$20-\$50 Service Cost: Typically none (custom network installation)	May exist in RSU by default, zero added cost No backhaul wiring installation	Only suitable for local manual RSU programming using a localized device. Not a true remote backhaul Requires development of secure system access system to prevent unwanted RSU tampering May require external antenna
	DSRC	DSRC is a variant of Wi-Fi. As a result, and since the RSU already supports DSRC, the DSRC link could be used as	Data Rate: ~3-27 Mbps Range:~20-400 meters Modem Cost: ~\$100-\$500 Service Cost: Typically none	Exists in RSU by default, zero added cost No backhaul wiring installation	Only suitable for local manual RSU programming using a localized device. Not a true remote backhaul

Point-to-Point		described above to link the RSU to a mobile system (handheld or truck mounted) that would then provide a backhaul link to a center facility.	(custom network installation)		Requires development of secure system access system to prevent unwanted RSU tampering May require external antenna
	ZigBee	ZigBee is a low power short range wireless networking system. It is primarily used for smart metering and sensor network applications.	Data Rate: 250 Kbps Range: ~10-100 meters Modem Cost: ~\$50 Service Cost: Typically none (custom network installation)	Low cost, low power	Few commercially available general purpose components (most embedded in other products) Only suitable for local manual RSU programming using a localized device. Not a true remote backhaul Requires development of secure system access system to prevent unwanted RSU tampering May require external antenna
	Fiber	High data rate long distance network that uses light traveling along a glass/plastic fiber. Communications is generally point to point. Numerous different types and capabilities.	Data Rate: > 10 Gbps Range: unlimited with relays Modem Cost: ~\$100 Service Cost: none for custom network installation; or as leased lines with variable cost depending on bandwidth	Very high data rates possible Non-conductive (simplifies installation with other power related equipment)	Expensive to install Difficult to splice Expensive equipment and connectors, etc.
	DSL	Digital Subscriber Line (DSL) is a system for providing relatively high data rate communications over conventional phone lines.	Data Rate: 64 Kbps-8 Mbps Range: ~18K feet (3.4 miles from central station) Modem Cost: ~\$50	Reliable Low cost, low power equipment and service Relatively high data rate	Requires wire-line connection Limited rural availability

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

		This is the technology that many homes and businesses use to access the internet. It is available in most urban areas, but is generally not available in rural locations. The service is offered by most wire-line phone companies.	Service Cost: ~\$60/mo	No antennas Secure	
	Cable TV	Cable TV systems are well known for providing broadband internet access and VoIP phone service, as well as television services. These systems use standard 6 MHz cable TV channels, but because the link is well controlled (since it is over a cable) the systems can use very high order modulation schemes to provide very high digital data rates. In many cable systems one conventional TV channel can carry as many as 10 digital TV channels	Data Rate: Up to about 500 Mbps Range: Limited only by cable provider facilities Modem Cost: ~\$150 Service Cost: ~\$60/mo	Reliable Low cost, low power equipment and service High data rate No antennas Secure	Requires cable connection Cable connections not always available at or near roadside Uncertain rural availability
	Microwave	Microwave systems use a line of sight radio link to provide very high data rates between two fixed points. These systems are available in a variety of configurations and operating in a	Data Rate: Up to about 1000 Mbps Range: Line of sight Equipment Cost: up to-\$18K per link Service Cost: None	High data rate, Low operating cost	Expensive installation Requires licensing May require large exterior antennas

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

		variety of radio bands. The systems are all generally configured to customized applications using off the shelf transmitter, receive modem and antenna components.			
	Power Line Carrier Communications (PLCC)	Power Line Carrier Communications is a system that overlays data communications signals on regular AC power line wires. Technically any system that has AC utility power can be connected for data purposes using PLCC. In practice the system is somewhat limited for applications outside a specific power distribution area since power pole transformers impose communications barriers, and to overcome this requires involvement of the power utility company	Data Rate: Up to about 30 Mbps, typically about 1Kbps Range: Depends on data rate Equipment Cost: unknown Service Cost: unknown	Simplified deployment (RSU installations typically all have AC power) Potentially high data rates	Uncertain feasibility for longer distances Uncertain deployment constraints due to power utility involvement

Mapping Support

The term “map” is used very broadly in relation to connected vehicle applications. Connected vehicle maps are digital descriptions of the physical roadway environment in particular and of the transportation system environment in general. Maps in this context can range from road network descriptions that describe how different road segments connect together, all the way down to detailed geometric descriptions of roadway features such as curves, lanes, intersection limit lines, and other “road furniture”. In general maps use some form of geographic reference point (or points) so that a user application, knowing its current position, can orient itself relative to the road features described in the map. Depending on the function of the application, this orientation may be broad, as in “which road am I on,” narrow as in “which lane am I in,” or detailed, as in “where am I in the lane” or “how far am I from the intersection limit line.” Connected vehicle maps generally have little relation to conventional graphical maps simply because the connected vehicle applications relate their function to the relative position of the mobile unit to the roadway features of interest in strictly quantitative ways.

Road network level maps are widely available from commercial sources. These maps are generally used for routing and navigation, because they provide critical information about which road segments connect to which other road segments. They could also be used in a connected vehicle context for various types of roadway alerts and warnings. These maps generally have an accuracy of about 10 meters, since higher levels of accuracy are not really useful for routing, and few general road hazards require high location accuracy.

Vehicle safety warning and control applications generally require lane level or better maps. This enables them to correlate the vehicle path to hazards or movement states (e.g. signal states) associated with specific lanes, limit line locations and other position specific hazards. Depending on the application, these maps may require an accuracy of less than one meter. Nearly all control based applications will require map data at the higher end of the accuracy scale (i.e. finer resolution). Because of the higher level of resolution, these maps are very sensitive to local changes in the roadway, and since the roadway can change significantly at this scale (e.g. lane closures, construction, re-striping, etc.), they are much more difficult to maintain and validate.

Because they are used commercially in many navigation and internet related applications, road network map generation technology is generally highly refined. Higher level detail mapping is not as well established. Generally these maps require relatively accurate and complete surveys of the region being mapped.

Connected vehicle deployments are likely to require at least two classes of maps. The first are those that are at road level and relatively stable and can be expected to be valid for some time. This class of map can support applications like curve speed warning and be broadcast to a vehicle at a remote location and used by the vehicle some time later when it reaches the curve. The second class of maps is more precise (supporting lane-level and geometry-specific applications) and dynamic (supporting time-dependent features in work zones and reversible lanes). These maps can then support applications that require the higher precision, but they need to be continually validated and cannot be stored indefinitely in a vehicle until use since they are subject to change.

In the simplest instantiation, a map distributed from an RSU would cover the communications area of that RSU. This greatly reduces the problem of building and maintaining the map. However, this greatly reduces the potential benefit of connected vehicle technology since the map would not support remote

applications beyond the range of the RSU. If map coverage does extend beyond the RSU, problems of versioning and configuration control become much more significant, as well as priority of different databases that may represent the same spot, but don't have the inherent authority of being the local source.

Consistency

Consistency of a connected vehicle map has several dimensions: spatial consistency with adjacent and possibly overlapping map regions for the same data (e.g., geometry between two adjacent RSUs); layer consistency among content from different sources, such as a navigation map and a geometric intersection description (GID) for an intersection; and source consistency, if the maps are derived from different master databases (e.g., a TomTom versus a Nokia database). Consistency across sources may be a significant problem since inaccuracies between maps may result in a location specified by latitude and longitude being on one lane (or road!) in one map database and on another lane in a second map.

Siting and Installation

Siting Dependencies for DSRC

DSRC Services operate in a protected frequency band (i.e., 5.850 – 5.925 GHz), which means operators must obtain a license from the FCC in order to legally operate DSRC-based devices. Typically, a FCC license is issued for a specific frequency range in a specific geographic area. This ensures that the license holder is the only operator allowed to deploy devices in the given area, guarding the system against interference. In the case of the RSU, the operating agency must apply for a DSRC license for their territory and each RSU must also be registered with the FCC such that other operators are aware of their existence.⁶⁴

RSUs transmitting at the maximum licensed effective radiated power (ERP) have an antenna height limit of eight (8) meters above the roadway. RSU antennas that must be installed at heights greater than eight meters to meet coverage must operate at reduced ERP. RSU antennas cannot in any circumstance be located more than 15 meters above the roadway.⁶⁵

A wireless spectrum analysis should be performed as part of the communications evaluation to identify relevant wireless communication systems in use in the area. The DSRC spectrum specifically should be evaluated as well as any spectrum intended for wireless backhaul. Specific factors governing the selection of a site and the particulars of the physical installation are:

- The expected applications served, and the traffic flow past the RSU. For example, if it is desired to collect probe data from freeways, then obviously the RSU must be located so that it has good RF coverage of the freeway.
- The environment around the site, especially in relation to the roadways served. For example, hills, buildings, signs, foliage and the roadway geometry all contribute to the overall RF performance. Since DSRC uses high frequency radio waves, these generally work best for

⁶⁴ More information on DSRC Services and the DSRC FCC License application can be found at http://wireless.fcc.gov/services/index.htm?job=licensing&id=dedicated_src.

⁶⁵ FCC regulations from 47 CFR Part 90.377 (10-1-10 Edition).

line-of-sight communications. It is thus important to locate the RSU so that the messages it sends can be received sufficiently far from any hazards that stopping sight distance requirements of the MUTCD can be maintained.

- The impact of weather and seasonal variations in the local environment. For example, exposure to high snow or ice accumulations may have a very negative impact on RF performance. Heavy vegetation that blocks the line of sight in a particular direction may have a substantial seasonal impact on the range of the system in the affected direction.
- The antenna pattern selected also has a large impact on system performance.
- The availability of power and backhaul communications may impact the site selection.
- Physical security to prevent tampering with the equipment.

Traffic density and traffic flow behavior must be considered relative to the primary applications expected to be served by the RSU. In some cases this is obvious; an RSU providing intersection collision warning messages is best located so as to provide a clear line of sight along the approaches to the intersection for which it is providing messages. In other cases the location may be non-obvious. For example, many signage messages may be relatively static, so it might be more efficient to distribute these from “regional” RSUs that cover major traffic cross-points, thereby reaching as many vehicles as possible.

One question that frequently arises relative to RSU placement is the issue of overlapping RSU coverage. Overlapping RSUs are generally not an issue in terms of technical performance. The access control schemes used in 802.11 assure that the RSUs will not interfere with each other as long as they are in range of each other (the system uses a scheme where each terminal listens to the channel before sending, and if another terminal is transmitting it waits). Problems may arise if RSUs are located near the limits of the radio range. In these situations each RSU becomes a “hidden terminal” for the other, and since they cannot hear each other they may transmit at the same time. A vehicle located between the two RSUs can hear both of them, and if they transmit at the same time, neither transmission will be intelligible. This may not be a problem if the region of potential interference is not a safety critical area, but the issue must be considered when placing multiple RSUs within about 500 meters of each other.

The other important issue when addressing overlapping RSUs is that they should operate on different service channels. This is not a necessity, since the CSMA scheme will generally assure that the service channel is shared properly. Using separate service channels will however provide substantially more system capacity, may avoid marginal hidden terminal effects, and can avoid the issues of duplicate messages being received by different RSUs.

Installation

Installation of connected vehicle field infrastructure is conceptually no different than installation of other Intelligent Transportation System (ITS) equipment. The same considerations of siting, foundations, mounting points, power, physical accessibility and security, backhaul networks and so forth that have become standardized and accepted in ITS practice will be considerations in connected vehicle infrastructure deployments. Connected vehicle infrastructure models and practices are still in development, however, and will continue to be so until applications have been deployed and operating for several years.

In the interim, guidance for installation of connected vehicle field infrastructure will be based on a combination of experiences.

- Substantial changes in DSRC radio hardware and software have been made over the last few years of development, particularly in anticipation of interoperability testing as part of the Safety Pilot Model Deployment. The equipment manufacturers' guidance on installation of their equipment will continue to evolve and be the best first information on any new units.
- Siting of DSRC radios and antennas may be a new factor to be considered in connected vehicle deployments relative to existing ITS, but is similar to other wireless communications models. Siting considerations are becoming well known and are discussed elsewhere in this document.
- Existing ITS installation practices can be followed for the majority of field infrastructure supporting connected vehicle application deployments. The structural, power, and physical security features are virtually identical between ITS and connected vehicle systems.
- The practice of configuring backhaul networks to support connected vehicle applications is developing rapidly in light of the Safety Pilot Model deployment. This will continue to develop as more diverse connected vehicle applications are deployed into other transportation system networks.
- Practical field experience with connected vehicle system and applications deployment will continue to accumulate as new prototypes and model deployments are brought into the field. The Safety Pilot Model Deployment has significantly scaled up the field deployment of both infrastructure equipment and back office systems relative to prior test beds and demonstrations. Lessons learned and best practices from Safety Pilot will be invaluable guides to future deployments.

Power Considerations

Power Consumption

Power consumption calculations should be made to evaluate the demanded load of equipment utilized in the field. Power requirements will depend upon all of the ancillary equipment that may be considered to be installed in a roadside location. While some network switches or cabinet environment (temperature and humidity) control devices may require a few hundred watts of power each, a typical DSRC device consumes relatively low power. The evaluation of the demanded electrical load is needed to determine if existing field circuits could be utilized or if new sources need to be located.

Power Type Considerations

The type of power used will depend upon the load calculated and the location of available transformed power from the roadside location. For urban settings or in areas where 240/120 VAC utilization voltage is nearby, it is recommended that a permanent power connection is made to the roadside equipment. If 240/120 VAC is not nearby, transformation from higher (480 VAC) other types of distribution voltage may need to be made through the use of a nearby transformer.

If the roadside equipment is in a rural location and the equipment used consumes a relatively low amount of power, it may be more appropriate to use solar power as a permanent power source. The

use of solar power should take into consideration the amount of available sunlight in a given locality for all seasons of use.

Appendix D. List of Acronyms

Acronym	Definition
AACN-RELAY	Advanced Automatic Crash Notification Relay
AASHTO	American Association of State Highway and Transportation Officials
ACTIVE	Alberta Cooperative Transportation Infrastructure & Vehicular Environment
ADA	Americans with Disabilities Act
AERIS	Applications for the Environment: Real-Time Information Synthesis
APTA	American Public Transportation Association
ASD	Aftermarket Safety Device
ATIS	Advanced Traveler Information Systems
ATM	Active Traffic Management
ATMS	Advanced Traffic Management System
AURORA	Automotive Test Bed for Reconfigurable and Optimized Radio Access
AVL	Automatic Vehicle Location
BIFA	Border Information Flow Architecture
BSM	Basic Safety Message
BWT	Border Wait Time
CACC	Cooperative Adaptive Cruise Control
CAD	Computer Aided Dispatch
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CBP	Customs and Border Protection
CBSA	Canadian Border Services Administration
CCTV	Closed-circuit television
CFR	Code of Federal Regulations
CICAS	Cooperative Intersection Collision Avoidance System
COTS	Commercial-off-the-shelf
COV	Commercially Operated Vehicle
CTS	Cooperative Transportation System
CV	Connected Vehicle

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Acronym	Definition
CVII	Commercial Vehicle to Infrastructure Integration
CVISN	Commercial Vehicle Information Systems and Networks
CVI-UTC	Connected Vehicle/Infrastructure University Transportation Center
CVRIA	Connected Vehicle Reference Implementation Architecture
DC	District of Columbia
DMS	Dynamic message sign
DOT	Department of Transportation
DRIC	Detroit River International Crossing
D-RIDE	Dynamic Ridesharing
DSRC	Dedicated Short Range Communications
DUAP	Data Use, Analysis, and Processing
ELT	Executive Leadership Team
ESS	Environmental sensor station
ETC	Electronic toll collection
EVAC	Emergency Communications and Evacuation
F-ATIS	Freight Real-time Traveler Information with Performance Monitoring
FCC	Federal Communications Commission
F-DRG	Dynamic Route Guidance for Freight
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRATIS	Freight Advanced Traveler Information Systems
FSP	Freight Signal Priority
FTA	Federal Transit Administration
GHG	Green-house gas
GHz	Gigahertz
GID	Geometric Intersection Description
HAR	Highway advisory radio
HAZMAT	Hazardous Material
HELP	Heavy Vehicle Electronic License Plate
HOT	High Occupancy Tolling
HPMS	Highway Performance Monitoring System
HRDO	Office of Operations Research and Development, FHWA
IAG	Interagency Group

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Acronym	Definition
IBC	International Border Crossing
IBTTA	International Bridge, Tunnel and Turnpike Association
ICM	Integrated Corridor Management
IDTO	Integrated Dynamic Transit Operations
IEEE	Institute of Electrical and Electronics Engineers
IMO	Integrated Mobile Observations
INC-ZONE	Incident Scene Work Zone Alerts for Drivers and Workers
INFLO	Integrated Network Flow Optimization
IP	Internet Protocol
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
I-SIG	Intelligent Traffic Signal System
ISTEA	Intermodal Surface Transportation Efficiency Act
IT	Information Technology
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITS JPO	Intelligent Transportation Systems Joint Program Office
JPO	Joint Program Office
kWh	Kilowatt-hour
LIE	Long Island Expressway
LTE	Long-term Evolution; a type of 4G cellular network
M-ISIG	Multimodal Intelligent Traffic Signal Systems
MAP-21	Moving Ahead for Progress in the 21st Century Act
MD	Maryland
MDSS	Maintenance Decision Support System
MHz	Megahertz, one million cycles per second
MI	Michigan
MMITSS	Multi-modal Intelligent Traffic Signal System
MN	Minnesota
MPO	Metropolitan Planning Organization
MTP	Metropolitan Transportation Plan
NAFTA	North American Free Trade Agreement
NHS	National Highway System

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Acronym	Definition
NHTSA	National Highway Traffic Safety Administration
NJ	New Jersey
NORPASS	North American Preclearance and Safety System
NV	Nevada
NY	New York
OBU	On-board Equipment
P3	Public Private Partnership
PCB	Professional Capacity Building
POE	Port of Entry
POV	Privately Operated Vehicle
PRD-SIG	Pedestrian Mobility
PFN	Primary Freight Network
PFS	Pooled Fund Study
Q-WARN	Queue Warning
RAMP	Next Generation Ramp Metering System
R.E.S.C.U.M.E.	Response, Emergency Staging and Communications, Uniform Management, and Evacuation
RESP-STG	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
RF	Radio frequency
RFID	Radio frequency identification
RITA	Research and Innovative Technology Administration
RITIS	Regional Integrated Transportation Information System
RSU	Roadside Unit
RTSMIP	Real-Time System Management Information Program
RWIS	Road Weather Information System
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SCMS	Security Credential Management System
SDMS	Safety Data Message Set
SHSP	Strategic Highway Safety Plan
SPaT	Signal Phase and Timing
SPD-HARM	Dynamic Speed Harmonization
SSOM	AASHTO Subcommittee on System Operations and Management
STIP	Statewide Transportation Improvement Plan

U.S. Department of Transportation, Office of the Assistant Secretary for Research and Technology
Intelligent Transportation System Joint Program Office

Acronym	Definition
TBD	To Be Determined
T-CONNECT	[Transit] Connection Protection
T-DISP	Dynamic Transit Operations
TIP	Transportation Improvement Plan
TMC	Transportation (or Traffic) Management Center
TOC	Transportation Operations Center
TSA	Transportation Security Administration
TSP	Transit Signal Priority
TTI	Texas Transportation Institute
UBC	University of British Columbia
UBI	Usage-based Insurance
US	United States
USDOT	United States Department of Transportation
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VA	Virginia
VIIC	Vehicle Infrastructure Integration Consortium
VMS	Variable Message Sign, see DMS
VMT	Vehicle Miles of Travel
VSDM	Vehicle Situation Data Message
W	Watt
WAVE	Wireless Access in Vehicular Environments
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WX-INFO	Real-Time Route Specific Weather Information for Motorized and Non-Motorized Vehicles

U.S. Department of Transportation
ITS Joint Program Office-HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-14-125



U.S. Department of Transportation