Executive Summary | National Connected Vehicle Field Infrastructure Footprint Analysis: Final Report

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 vehicle-to-vehicle (V2V) communications in light vehicles for connected vehicle safety applications 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 for 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 percent (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 percent 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

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

Source: USDOT/AASHTO 2014

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 DRSC 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

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

Source: USDOT/AASHTO 2014

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

<table>
<thead>
<tr>
<th>Level of Deployment</th>
<th>20% Signalized + Unsignalized/ITS-Equipped Sites</th>
<th>50% Signalized + Unsignalized/ITS-Equipped Sites</th>
<th>80% Signalized + Unsignalized/ITS-Equipped Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signalized Locations</td>
<td>62,200</td>
<td>155,500</td>
<td>248,800</td>
</tr>
<tr>
<td>Unsignalized/ITS-Equipped Locations</td>
<td>25,000</td>
<td>25,000</td>
<td>25,000</td>
</tr>
<tr>
<td>Total</td>
<td>87,200</td>
<td>180,500</td>
<td>273,800</td>
</tr>
</tbody>
</table>

Source: USDOT/AASHTO 2014

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 40 plus 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 (some of these milestones are illustrative)

Deployment of a connected vehicle field infrastructure is anticipated to 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. Connected Vehicle Infrastructure Deployment Milestones**

*Source: USDOT/AASHTO 2014*

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.
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 that would be supported through a USDOT 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 the "Cloud" data storage and retrieval and integration of connected vehicle technologies with existing traditional and ITS infrastructure.

AASHTO will begin a stronger effort toward implementation by greatly expanding the awareness within the AASHTO Committee structure, by taking advantage of NCHRP funding to address essential issue identified by a group of State DOT Directors through a NCHRP five year research Road Map.

**More Information**

For further information on the Connected Vehicle program, the *Footprint Analysis*, or getting involved in the AASHTO Connected Vehicle Deployment Coalition, contact James L. Wright, P.E., at jwright@aashto.org.