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Report to Congressional Requesters

September 2015

INTELLIGENT TRANSPORTATION SYSTEMS

Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist

GAO-15-775

GAO Highlights

Highlights of GAO-15-775, a report to congressional requesters

Why GAO Did This Study

Over the past two decades, automobile crash-related fatality and injury rates have declined over 34 and 40 percent respectively, due in part to improvements in automobile safety. To further improve traffic safety and provide other transportation benefits, DOT is promoting the development of V2I technologies. Among other things, V2I technologies would allow roadside devices and vehicles to communicate and alert drivers of potential safety issues, such as if they are about to run a red light. GAO was asked to review V2I deployment.

This report addresses: (1) the status of V2I technologies; (2) challenges that could affect the deployment of V2I technologies, and DOT efforts to address these challenges; and (3) what is known about the potential benefits and costs of V2I technologies.

GAO reviewed documentation on V2I from DOT, automobile manufacturers, industry associations, and state and local agencies. In addition, GAO interviewed DOT, Federal Communication Commission (FCC), and National Telecommunications Information Administration (NTIA) officials. GAO also conducted structured interviews with 21 experts from a variety of subject areas related to V2I. The experts were chosen based on recommendations from the National Academy of Sciences and other factors.

DOT, NTIA, and the FCC reviewed a draft of this report. DOT and NTIA provided technical comments, which were incorporated as appropriate. FCC did not provide comments.

View GAO-15-775. For more information, contact David Wise at (202) 512-2834 or wised@gao.gov.

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Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist

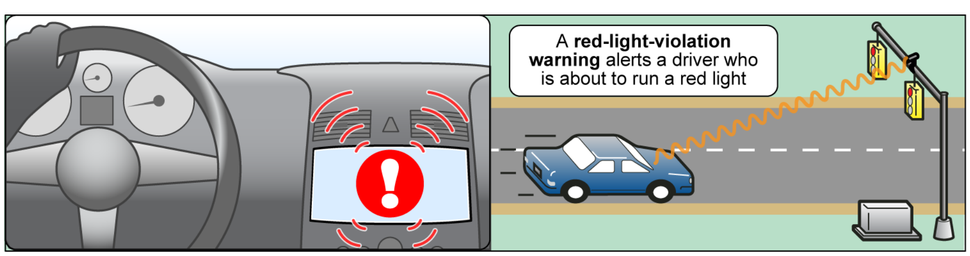
What GAO Found

Vehicle-to-infrastructure (V2I) technologies allow roadside devices to communicate with vehicles and warn drivers of safety issues; however, these technologies are still developing. According to the Department of Transportation (DOT), extensive deployment may occur over the next few decades. DOT, state, and local-transportation agencies; researchers; and private-sector stakeholders are developing and testing V2I technologies through test beds and pilot deployments. Over the next 5 years, DOT plans to provide up to $100 million through its Connected Vehicle pilot program for projects that will deploy V2I technologies in real-world settings. DOT and other stakeholders have also provided guidance to help state and local agencies pursue V2I deployments, since it will be up to these agencies to voluntarily deploy V2I technologies.

According to experts and industry stakeholders GAO interviewed, there are a variety of challenges that may affect the deployment of V2I technologies including: (1) ensuring that possible sharing with other wireless users of the radio-frequency spectrum used by V2I communications will not adversely affect V2I technologies' performance; (2) addressing states and local agencies' lack of resources to deploy and maintain V2I technologies; (3) developing technical standards to ensure interoperability; (4) developing and managing data security and addressing public perceptions related to privacy; (5) ensuring that drivers respond appropriately to V2I warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I. DOT is collaborating with the automotive industry and state transportation officials, among others, to identify potential solutions to these challenges.

The full extent of V2I technologies' benefits and costs is unclear because test deployments have been limited thus far; however, DOT has supported initial research into the potential benefits and costs. Experts GAO spoke to and research GAO reviewed indicate that V2I technologies could provide safety, mobility, environmental, and operational benefits, for example by: (1) alerting drivers to potential dangers, (2) allowing agencies to monitor and address congestion, and (3) providing driving and route advice. V2I costs will include the initial non-recurring costs to deploy the infrastructure and the recurring costs to operate and maintain the infrastructure. While some organizations have estimated the potential average costs for V2I deployments, actual costs will depend on a variety of factors, including where the technology is installed, and how much additional infrastructure is needed to support the V2I equipment.

Figure 1: Example of a Vehicle-to-Infrastructure Application



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

Contents

Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ANPRM	Advanced Notice of Proposed Rulemaking
CAMP	Crash Avoidance Metrics Partners, LLC
CO-Pilot	Cost Overview for Planning Ideas and Logical Organization Tool
DOT	U.S. Department of Transportation
DSRC	dedicated short-range communications
GHz	gigahertz
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
IEEE	Institute of Electrical and Electronics Engineers
ITS	intelligent transportation system
ITS America	Intelligent Transportation Society of America
ITS-JPO	Intelligent Transportation Systems-Joint Program Office
MHz	megahertz
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTIA	National Telecommunications and Information Administration
RSE	roadside equipment
RSU	roadside unit
SAE	Society for Automotive Engineers International
SCMS	Security Credential Management System
SPaT	Signal Phase and Timing
TMC	traffic management center
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VICS	Vehicle Information and Communication System (Japan)

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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September 15, 2015

The Honorable Barbara Comstock
Chairwoman
The Honorable Daniel Lipinski
Ranking Member
Subcommittee on Research and Technology
Committee on Science, Space, and Technology
House of Representatives

The Honorable Larry Bucshon
House of Representatives

Over the past two decades, automobile crash-related fatality and injury rates have declined nearly 34 percent and 40 percent, respectively, due in part to automobile safety features like safety belts and airbags.[1] The U.S. Department of Transportation (DOT) is working to further improve traffic safety through its connected vehicle research program, which aims to develop innovative technologies that enable vehicles, road infrastructure, and personal communications devices to wirelessly communicate and warn drivers and pedestrians of potential accidents. For example, DOT is collaborating with the automobile industry, academic institutions, technology firms, and state and local agencies to develop vehicle-to-infrastructure (V2I) technologies that allow vehicles to "communicate" with road infrastructure (such as traffic signals) through the wireless exchange of data. These technologies can enable the development of V2I software applications[2] that could, among other things: warn drivers of upcoming road conditions, such as work zones, or that they are approaching a curve at an unsafe speed; adjust traffic signal lights to provide priority to emergency vehicles or to address congestion; advise drivers about upcoming traffic and alternative routes; and provide driving advice to minimize stop-and-go driving.[3] For example, in 2011,

[1]Department of Transportation (DOT) National Highway Traffic Safety Administration (NHTSA), *Traffic Safety Facts 2013*, DOT HS 812 139 (Washington, DC).

[2]A variety of software applications are being developed that would use V2I technologies to provide different types of information to drivers.

[3]These are just a few examples of V2I applications: DOT has defined over 40 potential applications that would serve a wide range of functions.

Japan implemented V2I through the deployment of the ITS Spot system. ITS Spot uses roadside equipment to collect and share data with vehicles in order to provide three basic services to drivers: dynamic route guidance, safe driving support, and electronic toll collection. Japan's extensive V2I network includes roughly 55,000 pieces of V2I equipment on local roads and 1,600 pieces of V2I equipment on its approximately 11,000 kilometers of expressways. Similarly, the Netherlands, Germany, and Austria are working to develop a European smart corridor that will provide drivers information on road work and upcoming traffic, among other things. Since V2I technologies are still in development in the United States and rely on the exchange of information between vehicles and infrastructure, developing and deploying V2I will require the collaboration of a number of stakeholders, particularly state and local agencies, as well as auto manufacturers.

In light of research showing the potential for V2I technologies to reduce traffic accidents and fatalities, as well as questions raised regarding potential technological and policy challenges, you asked us to review issues related to V2I technologies. We examined: (1) the status of V2I technologies; (2) the challenges, if any, that could affect the deployment of V2I technologies, and DOT efforts to address these challenges; and (3) what is known about the potential benefits and costs of V2I technologies. To address these issues, we reviewed documentation relevant to the V2I technology research efforts of DOT, state and local governments, and the automobile industry, including DOT's *2015 Federal Highway Administration (FHWA) V2I Draft Deployment Guidance and Products*[4] and the American Association of State Highway and Transportation Officials' (AASHTO) *National Connected Vehicle Field Infrastructure Footprint Analysis*. We interviewed officials from DOT's Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems-Joint Program Office (ITS-JPO), FHWA, National Highway Traffic Safety Administration (NHTSA), and the Volpe National Transportation Systems Center about these efforts. In addition to DOT and its agencies, we also interviewed an additional 12 stakeholders that were involved in V2I efforts, such as associations representing state transportation agencies and engineers.[5] We interviewed officials at all

[4]DOT*, 2015 FHWA Vehicle to Infrastructure Deployment Guidance and Products* (Draft), version 9 (September 9, 2014).

[5]We primarily selected stakeholders based on recommendations from DOT and industry associations.

seven V2I test beds located in Virginia, Michigan, Florida, Arizona, California, and New York.[6] We conducted site visits to three of the seven test beds—the Safety Pilot in Ann Arbor, Michigan, and the test beds in Southeast Michigan and Northern Virginia. We selected the three site visit locations based on which had the most advanced technology according to DOT and state officials. We used our interviews with stakeholders to help us understand the issues, and developed a structured set of questions for interviews with 21 experts, nine of whom were identified by the National Academy of Sciences. We selected an additional 12 experts based on the following factors: (1) their personal involvement in the deployment of V2I technologies; (2) recommendations from federal agencies and industry associations; and, (3) experts' involvement in a professional affiliation such as a V2I consortium or group dedicated to these technologies, or expertise on a specific challenge affecting V2I (e.g., privacy). The 21 experts we selected included domestic automobile manufacturers, V2I equipment suppliers, state and local government officials, privacy experts, global industry organizations responsible for developing technology standards, and academic researchers with relevant expertise. During these interviews we asked, among other things, for experts' views on the state of development and deployment of V2I technologies (including DOT's role in this process), the potential benefits of V2I technologies, and their potential costs.[7] In our report, we use the term "experts" to refer to the 21 selected individuals we interviewed using a structured set of questions; we use the term "stakeholders" to refer to those individuals we spoke with, but that were not interviewed using the structured set of questions. The viewpoints gathered through our expert interviews represent the viewpoints of these specific individuals and cannot be generalized to a broader population.

We also interviewed officials from the Federal Communications Commission (FCC) and National Telecommunications and Information Administration (NTIA) within the Department of Commerce regarding challenges related to the potential for spectrum sharing with V2I technologies. Finally, we conducted a site visit to Japan because of its years of experience with deployment and maintenance of its national V2I

[6]There are two test beds in Michigan, the Safety Pilot in Ann Arbor, Michigan, and one in Southeast Michigan, in Oakland County.

[7]In conducting our structured interviews, we used a standardized interview guide to ensure that we asked all of the experts the same questions.

system.[8] During our site visit, we interviewed Japanese government officials responsible for V2I and auto manufacturers on topics similar to those discussed with U.S. experts, including V2I deployment efforts, benefits, costs, and challenges. Information about Japan's V2I efforts provides an illustrative example from which to draw information on the potential benefits, costs, and challenges of deploying V2I technologies in the United States. Further details about our scope and methodology can be found in appendix I.

We conducted this performance audit from July 2014 to September 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

DOT is working with the automobile industry, state and local transportation agencies, researchers, private sector stakeholders, and others to lead and fund research on connected vehicle technologies to enable safe wireless communications among vehicles, infrastructure, and travelers' personal communications devices.[9] Connected vehicle technologies include vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies:

- V2V technologies transmit data between vehicles to enable applications that can warn drivers about potential collisions.

[8]In the 1990s, Japan introduced its Vehicle Information and Communication System (VICS), which provides real-time road traffic information to drivers via a VICS-equipped navigation device. In 2011, Japan implemented V2I with its deployment of ITS Spot. In 2010, DOT and Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) signed a memorandum of cooperation to promote bilateral collaboration in the field of ITS.

[9]This effort is part of DOT's Intelligent Transportation Systems Program (ITS). ITS technologies consist of a range of communications, electronics, and computer technologies, such as systems that collect real-time traffic data and transmit information to the public via means such as dynamic message signs, ramp meters to improve the flow of traffic on freeways, and synchronized traffic signals that are adjusted in response to traffic conditions. From fiscal years 2003 through 2014, DOT provided about $570 million in funding for connected vehicle technologies. Funding for these efforts ranged from a low of $17 million in 2008 to a high of $84 million in 2011. These figures are not adjusted for inflation.

Specifically, V2V-equipped cars would emit data on their speed, position, heading, acceleration, size, brake status, and other data (referred to as the "basic safety message") 10 times per second to the on-board equipment of surrounding vehicles, which would interpret the data and provide warnings to the driver as needed. For example, drivers may receive a forward collision warning when their vehicle is close to colliding with the vehicle in front of them. V2V technologies have a greater range of detection than existing sensor-based crash avoidance technologies available in some new vehicles.[10] NHTSA is pursuing actions to require that vehicle manufacturers install the underlying V2V technologies that would enable V2V applications in new passenger cars and light truck vehicles, and requested comment on this issue in an August 2014 Advanced Notice of Proposed Rulemaking.[11] We reported on V2V technologies in November 2013.[12] Thus, we are not focusing on these technologies in this report.

- Vehicle-to-infrastructure (V2I) technologies transmit data between vehicles and the road infrastructure to enable a variety of safety, mobility, and environmental applications. V2I applications are designed to avoid or mitigate vehicle crashes, particularly those crash scenarios not addressed by V2V alone, as well as provide mobility and environmental benefits. Unlike V2V, DOT is not considering mandating the deployment of V2I technologies.

V2I applications rely on data sent between vehicles and infrastructure to provide alerts and advice to drivers. For example, the Spot Weather Impact Warning application is designed to detect unsafe weather conditions, such as ice or fog, and notify the driver if reduced speed or an alternative route is recommended (see left side of figure 1). DOT is also investigating the development of V2I mobility and environmental applications. For example, the Eco-Approach and Departure at Signalized Intersections application alerts drivers of the most eco-friendly speed for approaching and departing signalized intersections to minimize stop-and-

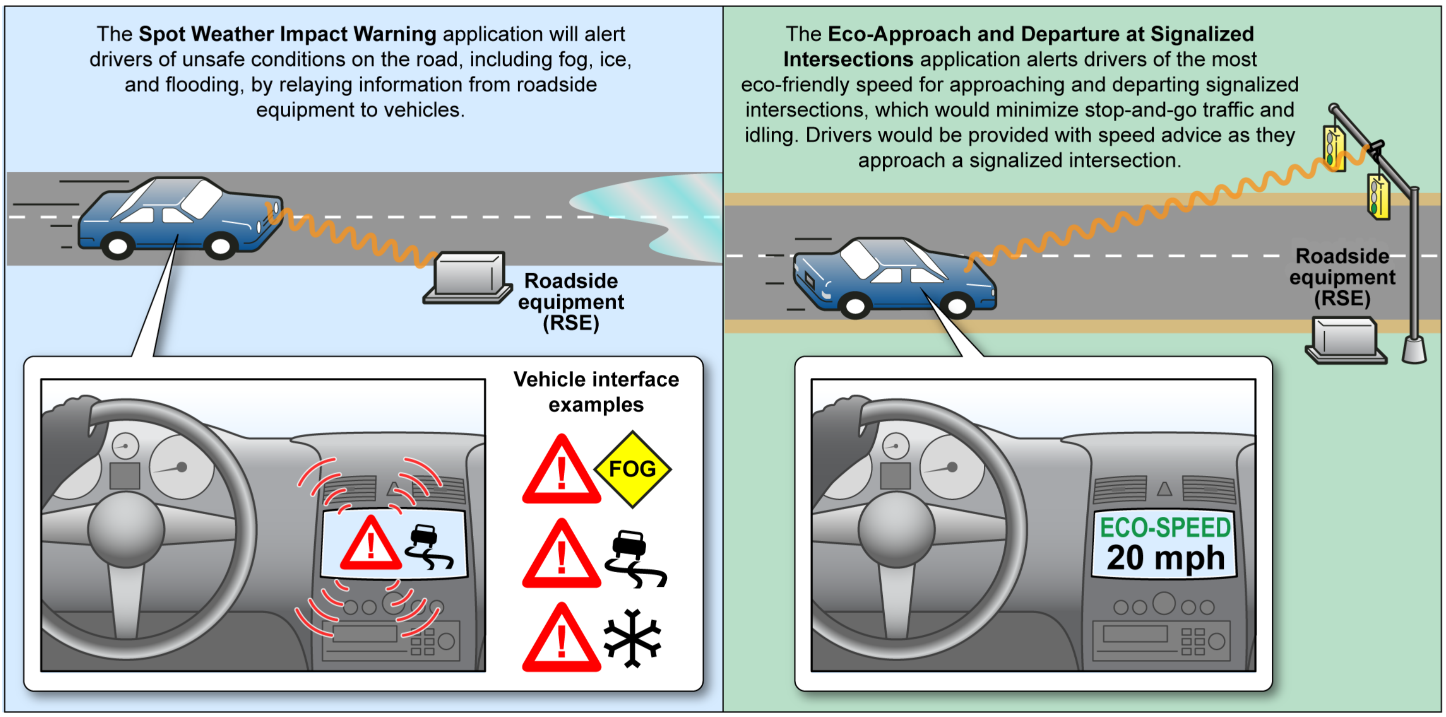
[10]For example, due to the sharing of data between vehicles, V2V technologies are capable of alerting drivers to potential collisions that are not visible to existing sensor-based technologies, such as a stopped vehicle blocked from view or a moving vehicle at a blind intersection. See GAO, *Intelligent Transportation Systems: Vehicle-to-Vehicle Technologies Expected to Offer Safety Benefits, but a Variety of Deployment Challenges Exist*, GAO-14-13 (Washington, D.C.: Nov. 1, 2013).

[11]79 Fed. Reg. 49270 (Aug. 20, 2014).

[12]GAO-14-13.

go traffic and idling (see right side of fig. 1), and eco-lanes, combined with eco-speed harmonization, (demonstrated in the following video) would provide speed limit advice to minimize congestion and maintain consistent speeds among vehicles in dedicated lanes.

Figure 1: Examples of Vehicle-to-Infrastructure Applications



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

DOT is also pursuing the development of V2I mobility applications that are designed to provide traffic signal priority to certain types of vehicles, such as emergency responders or transit vehicles. In addition, other types of V2I mobility applications could capture data from vehicles and infrastructure (for example, data on current traffic volumes and speed) and relay real-time traffic data to transportation system managers and drivers. For example, after receiving data indicating vehicles on a particular roadway were not moving, transportation system managers could adjust traffic signals in response to the conditions, or alert drivers of alternative routes via dynamic message signs located along the roadway. In addition to receiving alerts via message signs, these applications could also allow drivers to receive warnings through on-board systems or personal devices. Japan has pursued this approach through its ITS Spot

V2I initiative, which uses roadside devices located along expressways to simultaneously collect data from vehicles to allow traffic managers to identify congestion, while also providing information to drivers regarding upcoming congestion and alternative routes.[13]

To communicate in a connected vehicle environment, vehicles and infrastructure must be equipped with dedicated short-range communications (DSRC), [14] a wireless technology that enables vehicles and infrastructure to transmit and receive messages over a range of about 300 meters (nearly 1,000 feet).[15] As previously noted, V2V-equipped cars emit data on their speed, position, heading, acceleration, size, brake status, and other data (referred to as the “basic safety message”) 10 times per second to the surrounding vehicles and infrastructure. V2I-equipped infrastructure can also transmit data to vehicles, which can be used by on-board applications to issue appropriate warnings to the driver when needed. According to DOT, DSRC is considered critical for safety applications due to its low latency,[16] high reliability, and consistent availability. In addition, DSRC also transmits in a broadcast mode, providing data to all potential users at the same time. Stakeholders and federal agencies have noted that DSRC’s ability to reliably transfer messages between infrastructure and rapidly moving vehicles is an essential component to detecting and preventing potential collisions. DSRC technology uses radiofrequency spectrum to wirelessly send and receive data.[17] The Federal Communications Commission

[13]Along expressways linking cities in Japan, ITS Spots are installed approximately every 10-15 kilometers and on inner-city expressways, ITS Spots are installed every 4 kilometers. An in-vehicle V2I application collects, stores, and uploads (via ITS Spot road infrastructure) an anonymous travel and behavior record of the vehicle, which contains information about the time, position, speed, acceleration, and angle of the vehicle.

[14]According to DOT, DSRC technology is the designated communications technology for communications-based active safety-systems research.

[15]DSRC is used for safety-critical applications that cannot tolerate interruption; however, DOT has noted that other technologies (such as cellular or satellite, among others) may be used for non-safety-critical applications.

[16]Latency refers to the relative response time in communications between the originating and the responding application components (onboard unit and/or roadside unit and/or back office services) needed for the application to be effective.

[17]Radio-frequency spectrum is a natural resource that is used to provide an array of wireless communications services critical to the U.S. economy and a variety of government functions.

(FCC), which manages spectrum for nonfederal users, including commercial, private, and state and local government users, allocated 75 megahertz (MHz) of spectrum—the 5.850 to 5.925 gigahertz (GHz) band (5.9 GHz band)[18]—for the primary purpose of improving transportation safety and adopted basic technical rules for DSRC operations.[19] However, in response to increased demands for spectrum,[20] FCC has requested comment on allowing other devices to “share” the 5.9 GHz band with DSRC technologies.[21]

V2I equipment may vary depending on the location and the type of application being used, although in general, V2I components in the connected vehicle environment include an array of roadside equipment (RSE) that transmits and receives messages with vehicles for the purpose of supporting V2I applications (see figure 2). For example, a V2I-equipped intersection would include:

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[18]In the United States, responsibility for spectrum management is divided between two agencies: FCC and the Department of Commerce’s National Telecommunications and Information Administration (NTIA). FCC manages spectrum use for nonfederal users, including commercial, private, and state and local government users and NTIA manages spectrum for federal government users and acts for the President with respect to spectrum management issues. Historically, concern about interference or crowding among users has been a driving force in the management of spectrum. In order to minimize interference, FCC and NTIA have allocated particular bands of spectrum for specific uses, and provided users with a license or authorization to use a specific portion of spectrum. According to NTIA, the FCC will issue the licenses for the non-federal DSRC systems. DOT’s spectrum use is authorized by NTIA. 75 Fed. Reg. 38387 (July 1, 2010).

[19]Amendment of Parts 2 and 90 of the Commission’s Rules to Allocate the 5.850-5925 GHz Band to the Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Services, Report and Order, 14 FCC Rcd 18221 (1999)(*FCC 99-305*).

[20]As new spectrum-dependent technologies and services are brought to market and government users develop new mission needs, the demand for spectrum continues to increase and additional capacity will be needed to accommodate future growth that cannot be addressed through more efficient use of wireless technologies. One driver of the increased demand for spectrum has been the significant growth in commercial wireless broadband services, smart phones, and tablet computers. See GAO, *Spectrum Management: FCC’s Licensing Approach in the 11, 18, and 23 Gigahertz Bands Currently Supports Spectrum Availability and Efficiency*, GAO-13-78R (Washington, D.C.: November 20, 2012).

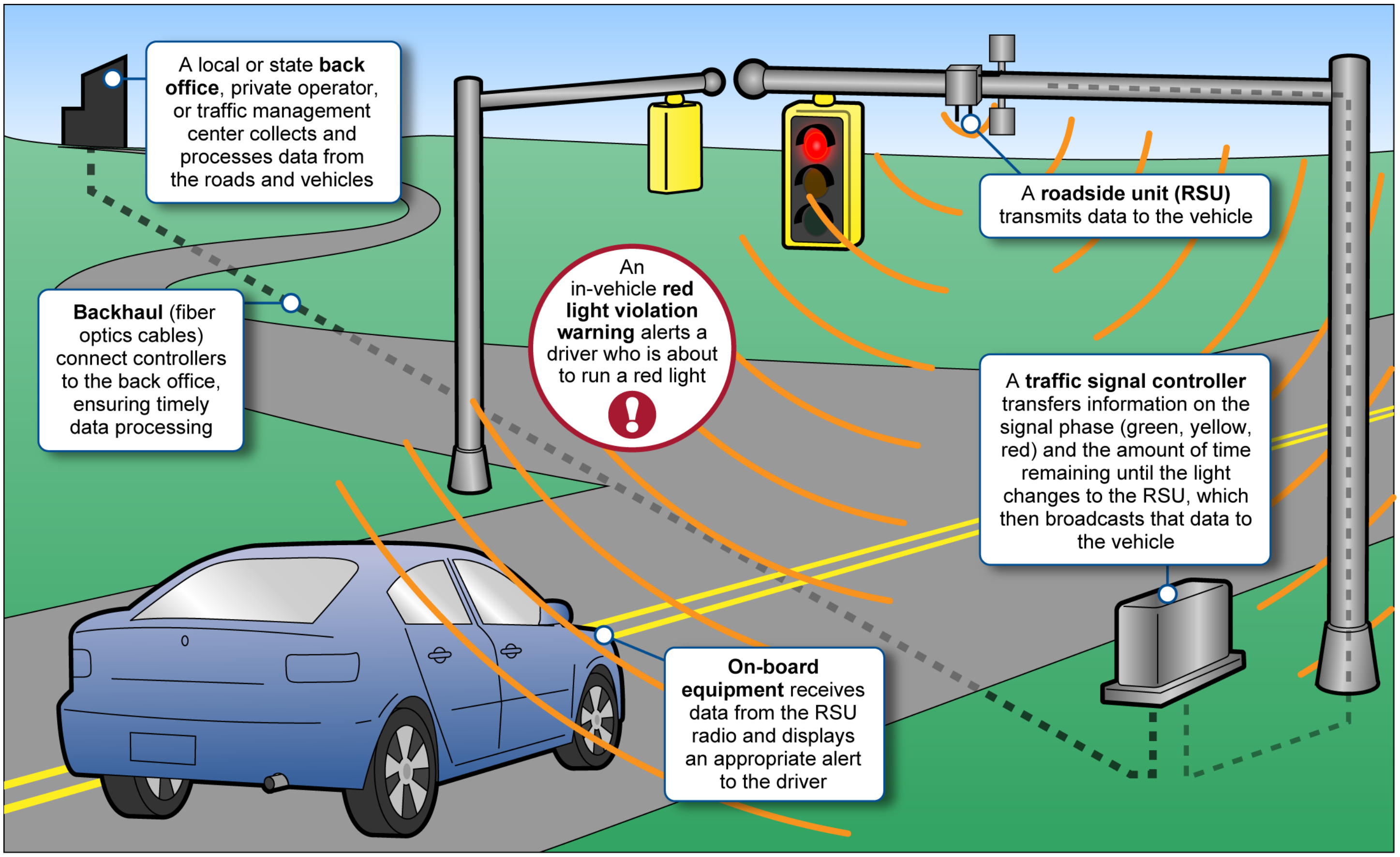
[21]In the Matter of Revision of Part 15 of the Commission’s Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, *28 FCC Rcd 1769, (2014).* The operator on an unlicensed device must accept whatever interference is received from the DSRC devices and must correct whatever interference is caused to DSRC devices. 47 C.F.R. § 15.5.

- Roadside units (RSU)—a device that operates from a fixed position and transmits data to vehicles. This typically refers to a DSRC radio,[22] which is used for safety-critical applications that cannot tolerate interruption, although DOT has noted that other technologies may be used for non-safety-critical applications.
- A traffic signal controller that generates the Signal Phase and Timing (SPaT) message, which includes the signal phase (green, yellow, and red) and the minimum and maximum allowable time remaining for the phase for each approach lane to an intersection. The controller transfers that information to the RSU, which broadcasts the message to vehicles.
- A local or state back office, private operator, or traffic management center that collects and processes aggregated data from the roads and vehicles. As previously noted, these traffic management centers may use aggregated data that is collected from vehicles (speed, location, and trajectory) and stripped of identifying information to gain insights into congestion and road conditions as well.[23]
- Communications links (such as fiber optic cables or wireless technologies) between roadside equipment and the local or state back office, private operator, or traffic management center. This is typically referred to as the "backhaul network."
- Support functions, such as underlying technologies and processes to ensure that the data being transmitted are secure.

[22]When referring to the DSRC radio alone, the term roadside unit (RSU) is used.

[23]Currently, state and local traffic-management centers gather and process traffic data, such as information on accidents and congestion, and take steps to respond to conditions, such as notifying emergency personnel, adjusting traffic signals, and providing alerts to drivers via roadway signs.

Figure 2: Example of Vehicle-to-Infrastructure Application Provided through Roadside Equipment



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

V2I Deployment Efforts Are in the Early Stages and Extensive U.S. Deployment May Occur over the Next Few Decades

DOT and Various Stakeholders Are Developing and Testing V2I Technologies through Small Test Deployments

DOT, state and local transportation agencies, academic researchers, and private sector stakeholders are engaged in a number of efforts to develop and test V2I technologies and applications, as well as to develop the technology and systems that enable V2I applications. DOT's V2I work is funded through its connected vehicle research program. DOT's initial connected vehicle research focused on V2I technologies; however, it shifted its focus to V2V technologies because they are projected to produce the majority of connected vehicle safety benefits and they do not require the same level of infrastructure investment as V2I technologies. After conducting much of the research needed to inform its advanced notice of proposed rulemaking to require that vehicle manufacturers install V2V technologies in new passenger cars and light truck vehicles, DOT is now shifting its focus back to V2I technologies, and some of the technical work needed to develop V2V applications has also informed the development of V2I.[24] A number of DOT agencies are involved with the development and deployment of V2I technologies.[25] In addition, private companies have received contracts from DOT to develop the underlying concept of operations and technologies to support V2I applications, and auto manufacturers are collaborating with DOT in its efforts to develop

[24]79 Fed. Reg. 49270 (Aug. 20, 2014).

[25]DOT's ITS-JPO is responsible for research execution and initial technology transfer activities, such as field testing. FHWA is coordinating with the states and developing the materials to support V2I deployment, such as guides, tools, and best practices—and is working to ensure that deployed services are geographically interoperable and that deployed services are developed in accordance with federal regulations. The Volpe National Transportation Systems Center provides technical support to ITS-JPO and FHWA, and conducts some laboratory testing for V2I technologies, as well as estimating safety benefits of connected vehicle technologies.

and pilot certain V2I applications and the underlying technologies to support them. State and local transportation agencies, which will ultimately be deploying V2I technologies on their roads, have also pursued efforts to test V2I technologies in real-world settings. However, to date, only small research deployments (such as those described below) have occurred to test V2I technologies:

- **The Safety Pilot Model Deployment:** DOT partnered with the University of Michigan Transportation Research Institute to collect data to help estimate the effectiveness of connected vehicle technologies and their benefits in real-world situations. The pilot was conducted in Ann Arbor, Michigan, from August 2012 to February 2014, and included roughly 2,800 V2V-equipped cars, trucks, and buses, as well as roadside V2I equipment placed at 21 intersections, three curve-warning areas, and five freeway sites. While the primary focus was on V2V technologies, the pilot also evaluated V2I technology, such as Signal Phase and Timing (SPaT) technologies. DOT officials stated that it would be releasing six reports with findings from the Safety Pilot in mid to late 2015, although these reports will primarily focus on V2V applications. As of July 2015, DOT has released one report that included an evaluation of how transit bus drivers responded to V2V and V2I warnings, and of how well the test applications performed in providing accurate warnings.[26] The two V2I applications included were a curve speed warning and a warning that alerts the bus driver if pedestrians are in the intended path of the bus when it is turning at an intersection.
- **Connected Vehicle Pooled Fund Study:** A group of state transportation agencies, with support from the FHWA, established the Connected Vehicle Pooled Fund Study.[27] The study aims to aid

[26]The report concluded that the transit safety applications have the potential to improve driver behavior and increase driver safety, but that improvements were needed to increase the accuracy of the warnings provided by the transit safety applications. For example, the report noted that the curve speed warning was provided early enough for the driver to take action only 57 percent of the time. U.S. Department of Transportation's Federal Highway Administration, *Independent Evaluation of the Transit Retrofit Package Safety Applications,* FHWA-JPO-14-175 (Washington, D.C.: February 2015).

[27]The primary members of the Connected Vehicle Pooled Fund Study include FHWA and transportation representatives from Virginia, California, Florida, Michigan, Minnesota, Maricopa County (Arizona), New Jersey, New York, Pennsylvania, Texas, Utah, Washington, and Wisconsin. Virginia serves as the lead state, with support from the University of Virginia.

transportation agencies in justifying and promoting the large scale deployment of a connected vehicle environment and applications through modeling, development, engineering, and planning activities. To achieve this goal, the study funds projects that facilitate the field demonstration, deployment, and evaluation of connected vehicle infrastructure and applications. For example, the University of Arizona and the University of California at Berkeley are collaborating on a project to develop and test an intelligent traffic-signal system that could, among other things, provide traffic signal priority for emergency and transit vehicles, and allow pedestrians to request for more time to cross the street.

- **Crash Avoidance Metrics Partners, LLC (CAMP):** CAMP—a partnership of auto manufacturers that works to accelerate the development and implementation of crash avoidance countermeasures—established a V2I Consortium that focuses on addressing the technical issues related to V2I. In 2013, DOT awarded a cooperative agreement to CAMP, with a total potential federal share of $45 million, to develop and test V2I safety, mobility, and environmental applications, as well as the underlying technology needed to support the applications, such as security and GPS-positioning technologies. According to an FHWA official, CAMP's current efforts include developing, testing, and validating up to five V2I safety applications, as well as a prototype for Cooperative Adaptive Cruise Control, an application that uses V2V and V2I technology to automatically maintain the speed of and space between vehicles. In addition to CAMP, automakers have established the Vehicle Infrastructure Integration Consortium, which coordinates with DOT on connected vehicle policy issues, such as interoperability of V2I technologies.
- **Test Beds**: DOT, state and local agencies, and universities have established connected vehicle test beds. Test beds provide environments (with equipped vehicles and V2I roadside equipment) that allow stakeholders to create, test, and refine connected vehicle technologies and applications. This includes DOT's Southeast Michigan Test Bed, which has been in operation since 2007 to provide a real-world setting for developers to test V2I and V2V concepts, applications, technology, and security systems. In addition, state agencies and universities have established their own test beds. For example, the University Transportation Center in Virginia, in collaboration with the Virginia Department of Transportation, established the Northern Virginia Test Bed to develop and test V2I applications, some of which target specific problems—like congestion—along the I-66 corridor. DOT offers guidance on how

research efforts can become DOT-affiliated test beds, with the goal of enabling test beds to share design information and lessons learned, as well as to create a common technical platform. According to DOT, there are over 70 affiliated test bed members. The deployment of connected vehicle infrastructure to date has been conducted in test beds in locations such as Arizona, California, Florida, Michigan, New York, and Virginia.[28] Additionally, officials from some of these test beds told us they may apply to the Connected Vehicle Pilot Deployment Program later this year (see below).

- **The Connected Vehicle Pilot Deployment Program:** Over the next 5 years, DOT plans to provide up to $100 million in funding for a number of pilot projects that are to design and deploy connected vehicle environments (comprised of various V2I and V2V technologies and applications) to address specific local needs related to safety, mobility, and the environment. As envisioned, there are to be multiple pilot sites with each site having different needs, purposes, and applications.[29] The program solicitation notes that successful elements of the pilot deployments are expected to become permanent operational fixtures in the real-world setting (rather than limited to particular testing facilities), with the goal of creating a foundation for expanded and enhanced connected vehicle deployments. FHWA solicited applications for the pilot program from January through March 2015. According to DOT, the initial set of pilot deployments (Wave 1 award) is expected to begin in Fall 2015, with a second set (Wave 2 award) scheduled to begin in 2017. Pilot deployments are expected to conclude in September 2020.

[28] In addition, the University of Michigan's Mobility Transformation Center is launching a test facility to research automated vehicle technologies, including V2I.

[29] DOT has provided examples of the types of V2I applications that can be included in the pilot projects, and has noted that the applications used will be influenced by what local need the project is trying to address. For example, a pilot project may be located in a rural area with extreme weather and may include applications that improve access to weather-related warnings and that improve safety at highway crossings. Another project may be located in an urban area with poor air quality and thus include applications that address congestion, pedestrian safety, and vehicular emissions in the downtown area.

DOT and Stakeholders Are Collaborating and Developing V2I Guidance for State and Local Agencies

DOT and other stakeholders have worked to provide guidance to help state and local agencies pursue V2I deployments, since it will be up to state and local transportation agencies to voluntarily deploy V2I technologies.[30] In September 2014, FHWA issued and requested comment on draft V2I deployment guidance intended to help transportation agencies make appropriate V2I investment and implementation decisions. For example, the guidance includes information on planning deployments, federal funding that can be used for V2I equipment and operations, technical requirements for equipment and systems, and applicable regulations, among other things. FHWA is updating the guidance and creating complementary guides, best practices, and toolkits, and officials told us they expect the revised guidance to be released by September 2015.[31] In addition, the American Association of State Highway and Transportation Officials (AASHTO),[32] in collaboration with a number of other groups, developed the *National Connected Vehicle Field Infrastructure Footprint Analysis*.[33] This report provides a variety of information and guidance for state and local agencies interested in V2I implementation, including a description of benefits; various state/local based scenarios for V2I deployments; underlying infrastructure and communications needs; timelines and activities for deployment; estimated costs and workforce requirements; and an identification of challenges that need to be addressed. AASHTO, with support the Institute of Transportation Engineers[34] and the Intelligent

[30]As previously noted, unlike V2V, DOT is not considering mandating the deployment of V2I.

[31]For example, some of the tools FHWA is developing include a V2I Benefit Cost Analysis Tool; *V2I Planning Guide*; *Guide to V2I Cyber-Security*; *Guide to Licensing DSRC Roadside Units*; *Guide to V2I Communication Technology Selection*; V2I Message Lexicon (a list of allowable standard messages and formats for transmitted information for in-vehicle use); *Guide to Initial Deployments*; and Warrants for Deployment (a set of criteria which can be used to define the relative need for and appropriateness of a particular V2I application).

[32]AASHTO is a nonprofit association that serves as a liaison between state departments of transportation and the federal government.

[33]American Association of State Highway and Transportation Officials, *National Connected Vehicle Field Infrastructure Footprint Analysis* FHWA-JPO-14-125 (Washington, D.C.: June 2014).

[34]The Institute of Transportation Engineers is an international educational and scientific association of transportation professionals who are responsible for meeting mobility and safety needs.

Transportation Society of America,[35] is also leading a V2I Deployment Coalition. The Coalition has several proposed objectives: support implementation of FHWA V2I deployment guidance; establish connected vehicle deployment strategies, and support standards development. According to information from the coalition and DOT, the V2I Deployment Coalition will be supported by technical teams drawn from DOT, trade associations, transportation system owners/operators, and auto manufacturers.

Extensive Deployment of V2I Technologies May Occur over the Next Few Decades

While early pilot-project deployment of V2I technologies is occurring, V2I technologies are not likely to be extensively deployed in the United States for the next few decades. According to DOT, V2I technologies will likely be slowly deployed in the United States over a 20-year period as existing infrastructure systems are replaced or upgraded. DOT has developed a connected vehicle path to deployment that includes steps such as releasing the final version of FHWA's V2I deployment guidance for state and local transportation agencies (September 2015),[36] and awarding and evaluating the Connected Vehicle Pilot Deployment Program projects in two phases, with the first phase of awards occurring in September 2015 and evaluation occurring in 2019, and the second phase of awards occurring in September 2017 and evaluation occurring in 2021. In addition, DOT officials noted that V2I will capitalize on V2V, and its deployment will lag behind the V2V rulemaking. NHTSA will issue a final rule specifying whether and when manufacturers will be required to install V2V technologies in new passenger cars and light trucks.[37] In addition, FCC has not made a decision about whether spectrum used by DSRC can be shared with unlicensed devices, which could affect the time frames for V2I deployment. Even after V2I technologies and applications have been developed and evaluated through activities such as the pilot

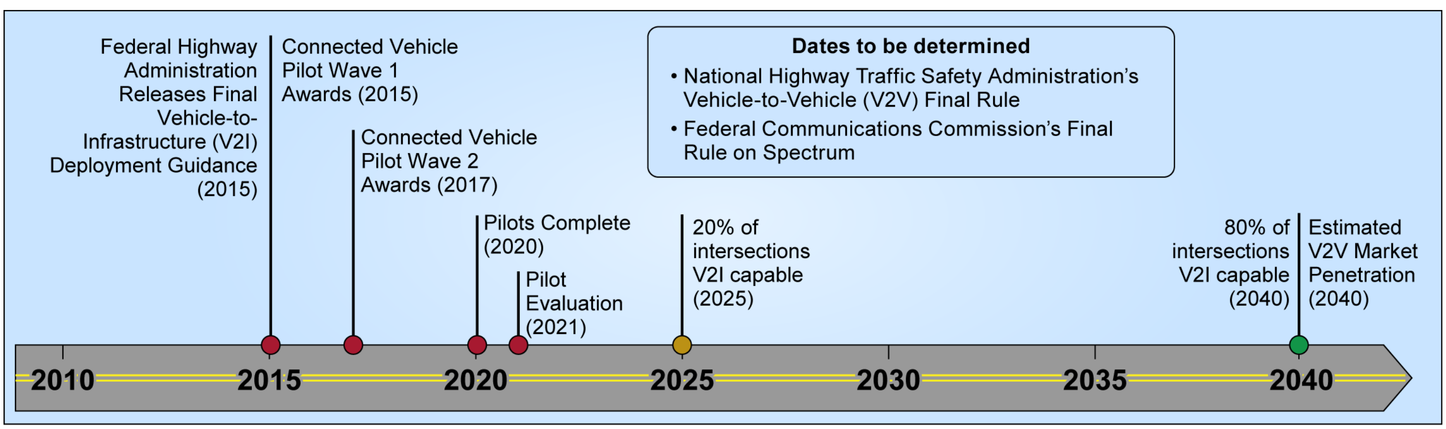
[35]The Intelligent Transportation Society of America (ITS America) is a national organization dedicated to advancing the research, development, and deployment of Intelligent Transportation Systems (ITS) to improve the nation's surface transportation system. Founded in 1991, ITS America's membership includes more than 450 public agencies, private sector companies, and academic and research institutions.

[36]DOT officials noted that this will be the final version of initial guidance, and that FHWA intends to update this guidance over time.

[37]Equipping cars with V2V technologies should allow them to receive V2I messages from roadside infrastructure; however, it is possible that stand-alone, after-market safety devices could be purchased to equip existing vehicles.

program, it will take time for state and local transportation agencies to deploy the infrastructure needed to provide V2I messages, and for drivers to purchase vehicles or equipment that can receive V2I messages. AASHTO estimated that 20 percent of signalized intersections will be V2I-capable by 2025, and 80 percent of signalized intersections would be V2I-capable by 2040. Similarly, AASHTO estimated that 90 percent of light vehicles would be V2V-equipped by 2040. However, DOT officials noted that environmental and mobility benefits can occur even without widespread market penetration and that other research has indicated certain intersections may be targeted for deployment. Similarly, in its *National Connected Vehicle Field Infrastructure Footprint Analysis*, AASHTO noted that early deployment of V2I technologies will likely occur at the highest-volume signalized intersections, which could potentially address 50 percent of intersection crashes.[38] See figure 3 for a list of planned events and milestones related to DOT's path to deployment of connected vehicle technologies.

Figure 3: DOT's Planned Connected Vehicle Path to Deployment, 2010-2040



Source: GAO analysis of Department of Transportation documents. | GAO-15-775

[38]AASHTO cited research from the March 2009 Noblis report, *Footprint Analysis for IntelliDrive^{SM} V2V Applications, Intersection Safety Applications, and Tolled Facilities,* which found that twenty percent of intersections in the three largest metro areas accounted for 50 percent of the collisions. However, the study does not directly address but only infers the safety benefits of V2I-enabling signalized intersections.

A Variety of Challenges, Including Potential Spectrum Sharing, May Affect the Deployment of V2I

According to experts and industry stakeholders we interviewed, there are a variety of challenges that may affect the deployment of V2I technologies including: (1) ensuring that possible sharing with other wireless users of the radiofrequency spectrum used by V2I communications will not adversely affect V2I technologies' performance; (2) addressing states' lack of resources to deploy and maintain V2I technologies; (3) developing technical standards to ensure interoperability between devices and infrastructure; (4) developing and managing a data security system and addressing public perceptions related to privacy; (5) ensuring that drivers respond appropriately to V2I warnings; and (6) addressing the uncertainties related to potential liability issues posed by V2I. DOT is collaborating with the automotive industry and state transportation officials, among others, to identify potential solutions to these challenges.

Potential Spectrum Sharing

As previously noted, V2I technologies depend on radiofrequency spectrum, which is a limited resource in high demand due in part to the increase in mobile broadband use. To address this issue, the current and past administrations, Congress, FCC, and others have proposed a variety of policy, economic, and technological solutions to support the growing needs of businesses and consumers for fixed and mobile broadband communications by providing access to additional spectrum.[39] One proposed solution, introduced in response to requirements in the Middle Class Tax Relief and Job Creation Act of 2012,[40] would allow unlicensed devices[41] to share the 5.9 GHz band radiofrequency spectrum that had been previously set aside for the use of DSRC-based ITS applications

[39]In a previous GAO report, we found that that the scarcity of spectrum in the United States is to some extent a result of the manner in which this resource has been allocated, managed, and used, rather than because of a physical scarcity of the resource. GAO, *Spectrum Management: Incentives, Opportunities, and Testing Needed to Enhance Spectrum*, GAO-13-7 (Washington, D.C.: November 2012).

[40]Pub. L. No. 112-96, §6406, 126 Stat. 156, 231.

[41]Traditional unlicensed equipment consists of low powered devices that operate in a limited geographic range, such as garage door openers and devices that offer wireless access to the Internet. They include Wi-Fi-enabled local area networks and fixed outdoor broadband transceivers used by wireless Internet service providers to connect devices to broadband networks.

such as V2I and V2V technologies.[42] FCC issued a Notice of Proposed Rulemaking in February 2013 that requested comments on this proposed solution.[43]

DOT officials and 17 out of 21 experts we interviewed considered the proposed spectrum sharing a significant challenge to deploying V2I technologies.[44] DSRC systems support safety applications that require the immediate transfer of data between entities (vehicle, infrastructure, or other platforms). According to DOT officials, delays in the transfer of such data due to harmful interference from unlicensed devices may jeopardize crash avoidance capabilities. Experts cited similar concerns, with one state official saying that if they deploy applications and they do not work due to harmful interference, potential users may not accept V2I. Seven experts we interviewed agreed that further testing was needed to determine if sharing would result in harmful interference to DSRC. In addition, DOT officials noted that changing to a shared 5.9 GHz band could impact current V2I research, which is based on the assumption that DSRC systems will have reliable access to the 5.9 GHz wireless spectrum.

According to Japanese government officials we interviewed, Japan also considered whether to share its dedicated spectrum with unlicensed devices and decided not to allow sharing of the spectrum used for V2I in the 700 MHz band.[45] According to officials we interviewed, Japan's Ministry of Internal Affairs and Communications conducted a study to test interference with V2I technologies and mobile phones to determine the

[42]Spectrum sharing can be defined as the cooperative use of common spectrum that allows disparate missions to be achieved. In this way, multiple users agree to access the same spectrum at different times or locations, as well as negotiate other technical parameters, to avoid adversely interfering with one another. For sharing to occur, users and regulators must negotiate and resolve where (geographic sharing), when (sharing in time), and how (technical parameters) spectrum will be used. GAO-13-7.

[43]In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Notice of Proposed Rulemaking, 28 FCC Rcd 1769 (2013).

[44]Two of 21 experts we interviewed did not provide a response to this question.

[45]In 2001, the Japanese government dedicated the 5.8GHz band to broadcast safety information using DSRC, and in 2011, dedicated the 700 MHz (760 MHz) band to support V2I technologies.

impact on reliability and latency in delivering safety messages.[46] Based on these tests, the Japanese government decided not to allow sharing of the spectrum band used for V2I, because sharing could lead to delays or harmful interference with V2I messages. Japanese auto manufacturers we interviewed in Japan supported the decision of the Japanese government to keep the 700 MHz band dedicated to transportation safety uses. According to officials, if latency problems affect the receipt of safety messages, this could degrade the public's trust, consequently slowing down acceptance of the V2I system in Japan.

Since the Notice of Proposed Rulemaking was announced, various organizations have begun efforts to evaluate potential spectrum sharing in the 5.9 GHz band and some have expressed concerns. For example, harmful interference from unlicensed devices sharing the same band could affect the speed at which a V2I message is delivered to a driver. NTIA, which has conducted a study on the subject, identified risks associated with allowing unlicensed devices to operate in the 5.9 GHz band, and concluded that further work was needed to determine whether and how the risks identified can be mitigated. DOT also plans to evaluate the potential for unlicensed device interference with DSRC as discussed below.[47]

Given the pending FCC rulemaking decision, DOT, technology firms, and car manufacturers have taken an active role pursuing solutions to spectrum sharing. Specifically, DOT's fiscal year 2016 budget request included funds for technical analysis to determine whether DSRC can co-exist with the operation of unlicensed wireless services in the same radiofrequency band without undermining safety applications.[48] According to DOT officials, since industry has not yet developed an unlicensed device capable of sharing the spectrum, the agency does not have a specific date for completion of this testing at this time. DOT officials

[46]In this case, latency refers to the relative response time in communications between the originating and the responding application components (onboard unit, roadside unit, or back office services) needed for the application to be effective.

[47]See Department of Commerce, NTIA. *Evaluation of the 5350-5470 MHz and 5850-5925 MHz Bands Pursuant to Section 6406(b) of the Middle Class Tax Relief and Job Creation Act of 2012* (Washington, D.C.: January 2013).

[48]DOT, *Fiscal Year 2016 Office of Secretary Congressional Budget Justification* (Washington, D.C.: February 2015).

noted, however, that they would work with NTIA in any spectrum-related matter to inform FCC of its testing results.[49] According to FCC officials we spoke with, FCC is currently collecting comments and data from government agencies, industry, and other interested parties and will use this information to inform their decision. For example, since 2013, representatives from Toyota, Denso, CSR Technology, and other firms worked together as part of the Institute of Electrical and Electronics Engineers (IEEE) DSRC Tiger Team[50] to evaluate potential options and technologies that would allow unlicensed devices to use the 5.9 GHz band without causing harmful interference to licensed devices. However, the representatives did not reach an agreement on a unified spectrum-sharing approach. Another ongoing effort from Cisco Systems, the Alliance of Automobile Manufacturers, and the Association of Global Automakers is preparing to test whether unlicensed devices using the "listen, detect and avoid"[51] protocol would be able to share spectrum without causing harmful interference to incumbent DSRC operations.[52] As of September 2015, FCC has not announced a date by which it will make a decision.

Lack of State and Local Resources to Develop and Maintain V2I Systems

Because the deployment of V2I technologies will not be mandatory, the decision to invest in these technologies will be up to the states and localities that choose to use them as part of their broader traffic-management efforts. However, many states and localities may lack resources for funding both V2I equipment and the personnel to install, operate, and maintain the technologies. In its report on the costs,

[49]NTIA works with FCC via the Policy and Plans Steering Group, as well as the Policy and Plans Steering Group Spectrum Working group, to foster dialogue between agencies. In addition to the Steering Group, DOT has submitted information through NTIA to the FCC as part of the public docket process.

[50]IEEE members are engineers, scientists, and allied professionals whose technical interests are rooted in electrical and computer sciences, engineering, and related disciplines.

[51]The unlicensed devices would be expected to detect and vacate bands that are being used by DSRC operations at that time.

[52]The tests are developmental in nature and designed to demonstrate and measure a Cisco proposal in the presence of DSRC transmitters and to ensure the technology operates as intended. Testing will begin in a laboratory setting and then advance to field tests, with the expectation that the initial round of feasibility testing will be completed by the end of 2015.

benefits, and challenges of V2I deployment by local transportation agencies, the National Cooperative Highway Research Program (NCHRP) noted that many states they interviewed said that their current state budgets are the leanest they have been in years.[53] Furthermore, states are affected because traditional funding sources, such as the Highway Trust Fund, are eroding, and funding is further complicated by the federal government's current financial condition and fiscal outlook.[54] Consequently, there can be less money for state highway programs that support construction, reconstruction, and improvement of highways and bridges on eligible federal-aid highway routes, as well as for other authorized purposes.[55] According to one stakeholder we interviewed, there have been widespread funding cuts for state DOTs, and many state DOTs must first focus on maintaining the infrastructure and equipment they already have before investing in advanced technologies.[56] Ten experts we interviewed, including six experts from state and local transportation agencies, agreed that the lack of state and local resources will be a significant challenge to deploying V2I technologies.[57] According to one report, without additional federal funding, deploying V2I systems would be difficult.[58]

Even if states decide to invest in V2I deployment, states and localities may face difficulties finding the resources necessary to operate and maintain V2I technologies. We have previously found that effectively

[53]The NCHRP is a research organization administered by the Transportation Research Board, and sponsored by members of AASHTO, in cooperation with FHWA. Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

[54]See GAO. *High-Risk Series: An Update*, GAO-15-290 (Washington, D.C; February 2015). GAO maintains a program to focus attention on government operations that it identifies as high risk due to their greater vulnerabilities to fraud, waste, abuse, and mismanagement or the need for transformation to address economy, efficiency, or effectiveness challenges. Funding the nation's surface transportation system has been listed on our high-risk list since 2007.

[55]GAO, *Highway Trust Fund: All States Received More Funding Than They Contributed in Highway Taxes from 2005 to 2009,* GAO-11-918. (Washington. D.C: September 2011).

[56]The stakeholder was from a transportation research organization.

[57]Five of 21 experts we interviewed did not provide a response to this question.

[58]NCHRP, *Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies, 03-101 (Washington, D.C.:* 2013).

using intelligent transportation systems, like V2I, depends on agencies' having the staff and funding resources needed to maintain and operate the technologies.[59] However, a recently released DOT report noted that staffing and information technology resources for maintaining V2I technologies were lacking in most agencies due to low and uncompetitive wage rates and funding constraints at the state and local government levels.[60] Similarly, 12 experts we interviewed stated that states and localities generally lack the resources to hire and train personnel with the technical skills needed to operate and maintain V2I systems.

According to FHWA's draft guidance on V2I deployment, funds are available for the purchase and installation of V2I technologies under various Federal-aid highway programs.[61] In addition, costs that support V2I systems, including maintenance of roadside equipment and related hardware, are eligible in the same way that other Intelligent Transportation System (ITS) equipment and programs are eligible. According to DOT, states have the authority and responsibility to determine the priority for funding V2I systems along with other competing transportation programs.

Japan's V2I systems, which were also voluntarily deployed, were funded in large part by the national government. According to Japan's National Police Agency, half of the costs for traffic signals were provided by the national government. In addition, according to the National Policy Agency, the Japanese government has invested an estimated $97 million (2014 dollars) in research and development for these systems. Two of the Japanese automakers we interviewed attributed the success of the Japanese V2I system in part to the significant government involvement and financial investment. Furthermore, according to a study on international connected vehicle technologies, Japan's nationally deployed

[59]GAO, *Intelligent Transportation Systems: Improved DOT Collaboration and Communication Could Enhance the Use of Technology to Manage Congestion*, GAO-12-308 (Washington, D.C.: Mar. 19, 2012).

[60]DOT, *Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs*, (Ann Arbor, MI: May 30, 2014).

[61]For example, a deployment that supports V2I mobility or environmental applications may be eligible for funds through the Congestion Mitigation and Air Quality (CMAQ) Improvement Program, because these applications may provide the benefits of relieving traffic congestion, enhancing transit bus performance, and improving air quality.

and funded infrastructure devices allowed for industry partners to test and release connected vehicle technologies.[62]

Developing Technical Standards to Ensure Interoperability of V2I Systems

Nineteen of the 21 experts we spoke with reported that establishing technical standards is essential for all connected vehicle programs, including V2I, and will be challenging for a number of reasons.[63] According to DOT, such standards define how systems, products, and components perform, how they can connect, and how they can exchange data to interoperate.[64] DOT further noted that these standards are necessary for connected vehicle technologies to work on different types of vehicles and devices to ensure the integrity and security of their data transmission. As well, current standardization efforts have focused on standardizing the data elements and message sets that are transmitted between vehicles and the infrastructure.[65] Currently, according to DOT officials, DOT and various organizations have worked with the Society for Automotive Engineers (SAE) International to standardize the message sets and associated performance requirements for DSRC (SAE J2735 and J2945), which support a wide variety of V2V and V2I applications.[66] DOT, SAE International, and engineers from auto manufacturers, V2I suppliers, technology firms, and other firms meet to develop high-quality, safe, and cost-effective standards for connected vehicle devices and technologies, according to an expert from a leading industry organization specializing in setting connected vehicle technical standards. This expert also noted that developing consensus around what standards should be instituted could be difficult given the different interests (political,

[62]Center for Automotive Research and the Michigan Department of Transportation, *International Survey of Best Practices in Connected and Automated Vehicle Technologies*, (September 26, 2014).

[63]One of 21 experts we interviewed did not provide a response to this question.

[64]According to DOT, it is important to note that these are not design standards; for example, they do not specify specific products or designs to use.

[65]Before 2007, in the early development phase, DOT worked with National Institute of Standards and Technology on the framework for V2I standards.

[66]SAE International is a global association of more than 138,000 engineers and related technical experts in the aerospace, automotive, and commercial-vehicle industries. SAE International is recognized as the world's largest automotive and aerospace standards-setting body. According to SAE International, these standards are recognized as the foundation for safety, quality, and the effectiveness of products and services across the global mobility-engineering industry.

economic, or industry-related) of the many stakeholders involved in developing and deploying V2I technologies. For example, the expert said that developing effective security standards required for these technologies that are also cost-effective for auto manufacturers and government organizations to implement may be difficult.

Without common standards, V2I technologies may not be interoperable. DOT has noted that consistent, widely applicable standards and protocols are needed to ensure V2I interoperability across devices and applications. However, ensuring interoperability with a standard set of V2I applications in each state may be particularly challenging because unlike V2V, deployment of V2I technologies will remain voluntary. Consequently, states and localities may choose to deploy a variety of different V2I technologies—or no technologies at all—based on what they deem appropriate for their transportation needs. DOT officials we interviewed recognized that a complete national deployment[67] of V2I technologies may never occur, resulting in a patchwork deployment of different applications in localities and states, although these applications will be required to be interoperable with one another. As a result, V2I deployment may be challenged by the following limitations:

- Benefits may not be optimized: Four experts we interviewed said that having a standard set of V2I applications in each state would be beneficial for drivers because a consistent deployment of applications could potentially increase benefits.
- Development of applications may be more limited: AASHTO's National Connected Vehicle Footprint Analysis argues that 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.
- Drivers may not find the system valuable: One expert from a state agency said without a standard set of V2I applications that allows drivers to use V2I applications seamlessly as they travel from state to

[67]According to the AASHTO Footprint Analysis, a mature connected vehicle environment by 2040 will include: (1) 80 percent (250,000) of traffic signal locations will be vehicle-to-infrastructure (V2I)-enabled; (2) up to 25,000 other roadside locations will be V2I-enabled; and (3) accurate, real-time, localized traveler information will be available on 90 percent or more of roadways.

state, travelers may lose confidence in the usefulness of the system and choose not to use it.

DOT and standardization organizations, such as the Society of Automotive Engineers (SAE) International, are working to develop standards to support DSRC and other V2I communications technologies. The data elements and message sets specified in the SAE standards are suitable not only for use with DSRC but also with other communications technologies such as cellular. According to DOT officials, the department is providing funding support, expert participation, and leadership in multiple standards development organizations to promote consensus on the key standards required to support nationally interoperable V2I and V2V technology deployments. Furthermore, the V2I Deployment Coalition—which includes AASHTO, the Institute of Electrical and Electronic Engineers, and the Institute of Transportation Engineers—intends to lead the effort to develop and support publishing of V2I standards, guidelines, and test specifications to support interoperability.[68] To facilitate standardization among potential state users of V2I technologies, FHWA is currently developing deployment guidance as discussed previously. According to DOT, that guidance will include specifications to ensure interoperability and to assist state and local agencies in making appropriate investment and implementation decisions for those agencies that will deploy, operate, and maintain V2I systems.

In addition to developing V2I standards across the United States, five experts we interviewed mentioned the importance of international harmonization for V2I technologies. Auto manufacturer experts recognized the importance of developing standards at both a domestic and international level as cars are manufactured globally. However, this is a challenge because international standardization organizations, including those in Europe and Japan, have different verification and validation processes than the United States, according to an auto manufacturer expert. [69] Furthermore, another expert noted that harmonization of

[68]The Connected Vehicle Reference Implementation Architecture (CVRIA) is an initiative to define a multi-view system architecture to support development of full-scale connected vehicle deployments as well as to identify candidate interfaces for standardization.

[69]Some European nations have begun testing and deploying V2I efforts. For example, as previously noted, the Cooperative ITS Corridor will provide warning to drivers of upcoming roadwork and other obstacles via V2I technologies in three countries: Netherlands, Germany, and Austria.

standards is dependent on the country's or regional government's regulations, and since there are different views on the role of these regulations in Europe, Japan, and the United States, achieving global standards will be complex. According to DOT, the joint standardization of connected vehicle systems (V2V and V2I) is a core objective of European Union-U.S. cooperation on ITS, and U.S.-Japan staff exchanges have been invaluable in building relationships and facilitating technical exchange, thus creating a strong foundation for ongoing collaboration and research. According to DOT officials, even when identical standards are not viable across multiple countries or regions due to technical or legal differences, maximizing similarities can increase the likelihood that common hardware and software can be used in multiple markets, reducing costs and accelerating deployment. According to officials from one Japanese auto manufacturer we interviewed, developing a standard message set for V2I communications in Japan was a long and challenging process that took over 5 years of discussion among auto manufacturers.

Data Security System and Privacy Concerns

According to DOT, for connected vehicle technologies to function safely, security and communications infrastructure need to enable and ensure the trustworthiness of messages between vehicles and infrastructure. The source of each message needs to be trusted and message content needs to be protected from outside interference or attacks on the system's integrity. A DOT study[70] we reviewed and the majority of the experts we interviewed noted that data security challenges exist and cited challenges that range from securing messages delivered to and from vehicle devices and infrastructure to managing security credentials and associated policies for accessing data and the system.[71] Fourteen of 21 experts we interviewed cited securing data as a significant challenge to the deployment of V2I technologies.[72] For example, experts from 5 states and one local agency that operated V2I test beds told us they were uncertain how vehicle and infrastructure data would be stored and secured for a larger deployment of V2I technologies because they have only tested V2I

[70]DOT, *An Approach to Communications Security for a Communications Data Delivery System for V2V/V2I Safety,* FHWA-JPO-11-130 (Washington. D.C: November 2011).

[71]One of 21 experts we interviewed did not provide a response to this question.

[72]This included 6 of 7 experts associated with a test bed, and 8 of 14 experts that were not associated with a test bed.

applications in limited, small-scale deployments.[73] Most of these experts were also unsure whether current data security efforts could be scalable to a larger deployment. According to DOT officials, they are currently researching this area.

DOT and industry have taken steps to develop a security framework for all connected vehicle technologies, including V2I. DOT, along with automakers from CAMP, are testing and developing the Security Credential Management System (SCMS) to ensure the basic safety messages are secure and coming from an authorized device. More than half of the experts we interviewed expressed a variety of concerns about (1) the SCMS system, including whether SCMS can ensure a trusted and secure data exchange and (2) who will ultimately manage the system.[74] To solicit input on these issues DOT launched a Request for Information in October 2014 to obtain feedback in developing the organizational and operating structure for SCMS.[75] In our previous work on V2V,[76] we found that as a part of its research on the security system, DOT had identified three potential models—federal, public-private, and private. We previously found that if a federal model were pursued, according to DOT, the federal government would likely pursue a service contract that would include specific provisions to ensure adequate market access, privacy and security controls, and reporting and continuity of services.[77] We also reported that under a public-private partnership, the security system would be jointly owned and managed by the federal government and private entities. At the time of our prior report, DOT officials stated that its legal authority and resources have led NHTSA to focus primarily on working with stakeholders to develop a viable private model, involving a privately owned and operated security-management provider.

According to DOT officials, the agency is expanding the scope of its planned policy research to enable the Department to play a more active

[73]One university researcher was certain that information could be stored and secured for a larger deployment.

[74]One of 21 experts we interviewed did not provide a response to this question.

[75]The request for information was for V2V; however, SCMS is expected to serve the same purpose for V2I efforts, in terms of managing security credentials.

[76]GAO-14-13.

[77]GAO-14-13.

leadership role in working with V2V and V2I stakeholders to develop and prototype a private, multi-stakeholder organizational model for a V2V SCMS. Officials said that such a model would ensure organizational transparency, fair representation of stakeholders, and permit the federal government to play an ongoing advisory role. A central component of the Department's planned policy research is the development of policies and procedures that could govern an operational SCMS, including minimum standards to ensure security and appropriately protect consumer privacy. Currently, NHTSA is reviewing comments on the management and organization for SCMS to inform its V2V Notice of Proposed Rulemaking, expected to be submitted for Office of Management and Budget review by the end of 2015. In addition, according to DOT's Connected Vehicle Pilot Deployment Program request for proposals, participating state and local agencies will utilize SCMS as a tool to support deployment security, which will allow states, local agencies, and private sector firms an opportunity to test capabilities in a real-world setting. Ultimately, when asked about the sufficiency of SCMS, almost half of the experts we interviewed (10 of 21) indicated they were confident that a secure system for V2I could be developed.[78]

According to FHWA, a secure system is essential to appropriately protect the privacy of V2I users. Nine of the experts identified privacy as a significant challenge for the deployment of V2I technologies. For example, the public may perceive that their personal information could be exposed or their vehicle could be tracked using connected vehicle technologies.[79] In a connected vehicle environment, various organizations—federal, state, and local agencies; academic organizations; and private sector firms—potentially may have access to data generated by V2I technologies in order to, for example, manage traffic and conduct research. DOT has taken some steps to mitigate security[80] and privacy concerns related to V2V and V2I technologies.

[78]One of 21 experts we interviewed did not provide a response to this question.

[79]One of 21 experts we interviewed did not provide a response to this question.

[80]According to DOT officials, the department plans to complete an assessment of V2I cyber security, and use the results to address the identified vulnerabilities for the V2I program. In addition, DOT will provide the results of this assessment to partners that will need to execute these mitigation measures. Currently, DOT is at the beginning stage of developing cyber-security materials for state and local DOT operating agencies to address the risk of legacy systems connecting to CV systems. DOT officials did not provide us with a completion date for these efforts.

According to DOT officials, the safety message will be broadcast in a very limited range (approximately 300 meters) and will not contain any information that identifies a specific driver, owner or vehicle (through vehicle identification numbers or license plate or registration information). The messages transmitted by DSRC devices (such as roadside units) in support of V2V and V2I technologies also will be signed by security credentials that change on a periodic basis (currently expected to be every 5 minutes) to minimize the risk that a third party could use the messages as a basis for tracking the location or path of a specific individual or vehicle.

Additionally, with respect to V2I technologies, DOT officials, car manufacturers and V2I suppliers plan to incorporate privacy by design into V2I technologies.[81] Under this approach, according to DOT, V2I data will be aggregated, and anonymized. Also NHTSA is currently in the process of conducting a V2V privacy risk assessment and intends to publish a Privacy Impact Assessment in connection with its V2V Notice of Proposed Rulemaking, which is expected to include an analysis of data collected, transmitted, stored, and disclosed by the V2V system components and other entities in relation to privacy concerns. The Department expects the V2V privacy risk research and the Privacy Impact Assessment to influence the development of policies, including security and privacy policies with regard to V2I. Furthermore, according to DOT, its V2I Deployment Coalition also plans to identify privacy and data issues at the state and county level.

According to Japanese officials we interviewed from the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), Japan took a number of steps to address the security and privacy of its V2I system. First, Japan's Intelligent Transportation Systems Technology Enhancement Association is responsible for managing the security of their V2I systems, and developed a system that used encryption to maintain security and ensure privacy. More specifically, each vehicle participating in V2I is assigned a changing, random identification number each time the vehicle started,

[81]According to the Information and Privacy Commissioner of Ontario, Canada, privacy by design is an approach to protecting privacy by embedding it into the design specifications of technologies, business practices, and physical infrastructures. According to DOT, for V2I, this would create a security system technically designed so that it would be very difficult to use the system to track vehicles or individuals, or otherwise discover any personally identifiable information.

thus making it difficult to track the vehicle over time. MLIT officials also noted that data generated from each vehicle is not stored permanently, but rather saved for distinct time frames depending on its use. Further, MLIT officials stated that security is ensured because V2I information is protected, anonymous, non-identifiable, and not shared with outside organizations; rather, it is used solely for public safety purposes. According to the National Police Agency officials, no significant security issue has occurred with V2I technologies as of July 2015.

Human Factors

Because V2I data will initially provide alerts and warning messages to drivers, the ultimate effectiveness of these technologies, especially as it relates to safety, depends on how well drivers respond to the warning messages.[82] In a November 2013 report on V2V technologies, we found that addressing human factors that affect how drivers will respond included (1) minimizing the risk that drivers could become too familiar with or overly reliant upon warnings over time and fail to exercise due diligence in responding to them, (2) assessing the risk that warnings could distract drivers and present new safety issues, and (3) determining what types of warnings will maximize driver response.[83] Seven of the 21 experts we interviewed identified human factors issues as significant to V2I deployment.[84]

To address these concerns, DOT is participating in a number of research efforts to determine the effects of new technologies on driver distraction. To further examine the effects on drivers using V2I applications, NHTSA has a research program in place to develop human factors principles that may be used by automobile manufacturers and suppliers as they design and deploy V2I technology and other driver-vehicle interfaces that provide warnings to drivers.[85] In addition, DOT's ITS-JPO is funding NHTSA and

[82]However, according to DOT officials, automobile manufacturers are also evaluating how to combine data from public infrastructure and on-board sensors in vehicles to affect control functions such as braking, throttling, and potentially steering to mitigate driver inattention or confusion.

[83]GAO-14-13. The term "human factors" refers broadly to how humans' abilities, characteristics, and limitations interact with the design of the equipment they use and the environments in which they function.

[84]Two of 21 experts we interviewed did not provide a response to this question.

[85]DOT officials stated this was an ongoing effort and did not provide us with an estimated completion date.

FHWA research to investigate human factors implications for V2I technologies. Furthermore, according to DOT, the Connected Vehicle Pilot Program will allow additional opportunities to review drivers' reactions to V2I messages using cameras and driver vehicle data on speed, braking, and other metrics.

Liabilities

Eleven of the 21 experts we interviewed identified uncertainty related to potential liability in the event of a collision involving vehicles equipped with V2I technologies as a challenge.[86] In our November 2013 report on V2V, an auto manufacturer expert said that it could be harder to determine whether fault for a collision between vehicles equipped with connected vehicle technologies lies with one of the drivers, an automobile manufacturer, the manufacturer of a device, or another party.

According to DOT officials, it is unlikely that either V2I or V2V technologies will create significant liability exposure for the automotive industry, as DOT expects auto manufacturers will contractually limit their potential liability for integrated V2I and V2V applications and third-party services. However, according to DOT, V2I applications using data received from public infrastructure may create potential new liability risks to various infrastructure owners and operators—state and local governments, railroads, bridge owners, and roadway owners—because such cases often are brought against public or quasi-public entities and not against vehicle manufacturers. According to DOT, this liability will likely be the same as existing liability for traffic signals and variable message signs.

[86] Four of 21 experts we interviewed did not provide a response to this question.

Extent of Benefits and Costs Are Likely to Remain Unclear until Further Deployment of V2I Technology

Experts Identified Potential Safety, Mobility, Operational, and Environmental Benefits to V2I Technologies, but Extent of Benefits Is Not Yet Clear

DOT officials, stakeholders representing state officials and private sector entities, and experts we interviewed stated that the deployment of V2I technologies and applications is expected to result in a variety of benefits to users. Experts identified safety, mobility, operational, and environmental benefits as the potential benefits of V2I.

- Safety: Eleven of 21 experts identified safety as one of the primary benefits of V2I technologies.[87] This included 6 of the 8 state and local agencies we interviewed. According to Japanese officials we interviewed, Japan has realized safety benefits from its deployment of V2I infrastructure. For example, in an effort to prevent rear-end collisions, Japan installed V2I infrastructure that detected and warned motorists of upcoming congestion on an accident-prone curve on an expressway in Tokyo. According to Japanese officials, this combined with other measures such as road marking, led to a 60-percent reduction in rear-end collisions on this curve.
- Mobility: In interviews, 8 of 21 experts identified mobility as one of the primary benefits of V2I, including 6 of the 8 state and local agencies we interviewed.[88] Officials in three states we interviewed noted that they are focusing on V2I applications that have the potential to increase mobility. These applications could allow for transportation system managers to identify and address congestion in real-time, as well as provide traffic signal priority to certain types of vehicles, such as emergency responders or transit. For example, Japanese officials estimated that as the use of electronic tolling rose to nearly 90 percent

[87]Eight of the 21 experts we interviewed did not provide a response to this question.

[88]Eight of the 21 experts we interviewed did not provide a response to this question.

of vehicles on expressways, tollgate congestion was nearly eliminated on certain expressways.[89]

- Operations: In interviews, 7 of 21 experts, including 4 of 8 state and local agencies, identified the potential for V2I applications to provide operational benefits or cost savings.[90] For example, one state agency noted that using data collected from vehicles could allow the transportation managers to more easily monitor pavement conditions and identify potholes (typically a costly and resource-intensive activity). DOT and the National Cooperative Highway Research Program[91] have also noted that the visibility and enhanced data on current traffic and road conditions provided by V2I applications would provide operational benefits to state and local transportation managers. This result, in turn, could provide safety or other benefits to drivers. For example, officials in Japan told us that by using data collected from vehicles through the ITS infrastructure, they were able to identify 160 locations in which drivers were braking suddenly. After investigating the cause, officials took steps to address safety issues at these sites (such as trimming trees that created visual obstructions) and incidents of sudden braking decreased by 70 percent and accidents involving injuries or fatalities decreased 20 percent. In addition, the Japanese government partnered with private industry to collect and analyze vehicle probe data to help the public determine which roads were passable following an earthquake.
- Environment: Of the experts we interviewed, 4 of 21 identified environmental benefits as a primary benefit of V2I technologies, with some noting interconnections among safety, mobility, and environmental benefits.[92] For example, officials from two state agencies we interviewed stated that improving safety and mobility will lead to environmental benefits because there will be less stop-and-go traffic. Indeed, Japanese officials estimated that decreased tollgate

[89]Specifically, Japan estimates that congestion on the Metropolitan Expressway, located in Tokyo, was reduced from 56.2 kilometers/hour/day in 2003 to 2.8 kilometers/hour/day in 2007, with a respective rise in electronic toll usage from 6.1 percent to 73 percent of vehicles.

[90]Eight of the 21 experts we interviewed did not provide a response to this question.

[91]Transportation Research Board National Cooperative Highway Research Program, *Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies*, NCHRP 03-101 (Reston, VA: 2013).

[92]Eight of the 21 experts we interviewed did not provide a response to this question.

congestion reduced CO_2 emissions by approximately 210,000 tons each year.

Although V2I applications are being developed for the purpose of providing safety, mobility, operational, and environmental benefits, the extent to which V2I benefits will be realized is currently unclear because of the limited data available and the limited deployment of V2I technologies. To date, only small research deployments have occurred to test connected vehicle technologies. However, DOT has commissioned or conducted some studies to estimate potential V2I benefits, particularly with respect to safety and the environment.

- NHTSA used existing crash data and estimated that in combination, V2V and V2I could address up to 81 percent of crashes involving unimpaired drivers.[93] Similarly, in 2012, a study commissioned by FHWA used existing crash data and estimated the number, type, and costs of crashes that could be prevented by 12 different V2I applications. This study estimated that the 12 V2I applications would prevent 2.3-million crashes annually (representing 59 percent of single vehicle crashes and 29 percent of multi-vehicle crashes and comprising $202 billion in annual costs).[94]
- With respect to the environment, DOT contracted with Booz Allen Hamilton to develop an initial benefit-cost analysis for its environmental applications, with the goal of informing DOT's future work and prioritization of certain applications.[95] As part of the next phase of this work, Booz Allen Hamilton used models to estimate

[93]U.S. Department of Transportation, National Highway Traffic Safety Administration, *Frequency of Target Crashes for IntelliDrive Safety System,* DOT-HS-811-381 (Washington, D.C.: October 2010).

[94]U.S. Department of Transportation, Federal Highway Administration, *Crash Data Analyses for Vehicle-to-Infrastructure Communications for Safety Applications,* FHWA-HRT-11-040 (McLean, VA: November 2012). This statistic is based on assumptions including full deployment and 100 percent effectiveness of applications.

[95]U.S. Department of Transportation, *AERIS: Applications for the Environment: Real-Time Information Synthesis Identification and Evaluation of Transformative Environmental Applications and Strategies Project, Initial Benefit-Cost Analysis*, (Washington, DC: September 30, 2012).

potential benefits of individual applications, as well as their benefits when used in combination with other applications.[96]

- NCHRP estimated operational and financial benefits that V2I applications may provide to state and local governments, such as reduced costs for crash response and cleanup costs; reduced need for traveler information infrastructure; reduction of infrastructure required to monitor traffic; and lower cost of pavement condition detection.[97] However, one of the study's major conclusions was that the data required to quantify benefits are generally not available.
- DOT is taking some steps to evaluate the benefits of V2I applications. For example, as part of its upcoming Connected Vehicle Pilot Deployment Program, pilot projects are expected to develop a performance-monitoring system, establish performance measures, and collect relevant data. Projects will also receive an independent evaluation of their projects' costs and benefits; user acceptance and satisfaction; and lessons learned.

In addition, organizations researching the benefits of V2I have noted that the benefits of V2I deployments may depend on a variety of factors, including the size and location of the deployment, the number of roadside units deployed, the number of vehicles equipped, and the types of applications that are deployed. A study sponsored by the University of Michigan Transportation Research Institute noted that some V2I safety applications require a majority of vehicles to be equipped before reaching optimum effectiveness, in contrast to mobility, road weather, and operations applications, which only require a small percentage of equipped vehicles before realizing benefits.[98] Japanese government officials, as well as representatives from a private company we

[96]According to DOT officials, reports with the results of these models are underway and unpublished; however, they did provide us with copies of the current versions of the reports.

[97]Transportation Research Board National Cooperative Highway Research Program, C*osts and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies*, NCHRP 03-101 (Reston, VA: 2013).

[98]For example, the study cited other studies that found that agencies using probe data from vehicles (for example, data from vehicles that provide insight into traffic or pavement conditions), could collect reliable data with a 5 to 10 percent penetration rate among vehicles. University of Michigan Transportation Research Institute, *Connected Vehicle Infrastructure Deployment Considerations: Lessons Learned from Safety Pilot and Other Connected Vehicle Test Programs*, (Ann Arbor, MI: May 30, 2014).

interviewed in Japan, noted that in some cases, they have found it difficult to quantify benefits. However, DOT and the Ministry of Land, Infrastructure, Transport and Tourism of Japan established an Intelligent Transportation Systems (ITS) Task Force to exchange information and identify the areas for collaborative research to foster the development and deployment of ITS in both the United States and Japan. According to DOT, evaluation tools and methods are high-priority areas for the task force, and DOT has stated that a report detailing the task force's collaborative research on evaluation tools and methods will be published in 2015. In addition, 8 of the 21 experts we interviewed noted that it can be difficult to identify benefits that are solely attributable to V2I, due to the interconnected nature of V2V and V2I technologies.[99] However, some experts we spoke with provided some examples of how connected vehicle benefits could be measured, including: crash avoidance, reduction in fatalities, reduced congestion, and reduced travel times.

The Costs for V2I Are Unclear due to Limited Deployment

The costs for the deployment of a national V2I system are unclear because current cost data for V2I technology are limited due to the small number of test deployments thus far. According to DOT officials, experts, and other industry stakeholders we spoke to, there are two primary resources for estimating V2I deployment costs: AASHTO's *National Connected Vehicle Footprint Analysis* (2014) and National Cooperative Highway Research Program's (NCHRP)[100] *03-101 Costs and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies* (2013).[101] However, the cost estimates in both reports are based on limited available data from small, research test beds. As a result, neither report contains an estimate for the total cost if V2I were to be deployed at

[99]Eight of the 21 experts we interviewed did not provide a response to the question about quantifying V2I benefits apart from V2V benefits.

[100]The NCHRP is a research organization administered by the Transportation Research Board and sponsored by members of AASHTO, in cooperation with FHWA. Individual projects are conducted by contractors with oversight provided by volunteer panels of expert stakeholders.

[101]We use both the NCHRP and the AASHTO reports to provide global statements about potential costs, but we will only be using cost figures from the AASHTO report as it contains the most recent information on potential, average estimates and is being used by DOT for the basis of cost estimation tools.

a national level.[102] Despite these limitations, the cost estimates in these two studies are cited by several experts and industry stakeholders, including DOT.[103] According to DOT, these cost figures may be useful to agencies considering early deployments.

According to AASHTO and NCHRP, costs of V2I deployment will likely be comprised of two types of costs. First, V2I will require *non-recurring* costs—the upfront, initial costs required to deploy the infrastructure. According to AASHTO, there are two primary, non-recurring cost categories associated with V2I deployments:

- *Infrastructure deployment* costs include the costs for planning, acquiring, and installing the V2I roadside equipment. State and local agencies will need to evaluate the costs for planning and design that may include mapping intersections and deciding where to deploy the DSRC radios based on traffic and safety analyses, according to AASHTO. Deployment costs will include the cost of acquiring the equipment, including the roadside unit. AASHTO estimates that the total equipment costs would be \$7,450 per site,[104] with \$3,000 attributed to each roadside unit, on average.[105] However, 4 of the experts we interviewed stated that the cost estimates for the hardware are likely to decrease over time, as the technology matures and the market becomes more competitive. The total average cost for installation of the equipment per site includes the costs of labor and inspection. In addition, deployment costs may include the cost of

[102]During development of the "*National Connected Vehicle Field Infrastructure Footprint Analysis* (FHWA-JPO-14-125)," there was an effort to develop an estimate for the total cost of deploying V2I systems on a national level, using the anticipated deployment costs, locations and timelines. However, according to DOT officials, the uncertainties in the cost elements are so significant that it was not deemed appropriate to generate an estimated cost for deploying V2I systems on a national level.

[103]Nine experts and five stakeholders mentioned one or both of the reports' cost estimates.

[104]"Per site" refers to each specific location where a roadside unit is deployed. For example, a unit could be deployed at an intersection. The "per site" costs would be multiplied by the number of units required by the region.

[105]In a connected vehicle environment, there will also be costs for the on-board equipment. NHTSA conducted an assessment of preliminary V2V costs and estimated that the total cost per vehicle will be approximately \$341 to \$350 in 2020, decreasing to \$209 to \$227 in 2058.

upgrading traffic signal controllers.[106] AASHTO estimates that approximately two thirds of all controllers in the United States will need to be upgraded to support connected vehicle activities.

- *Backhaul costs* refer to the costs for establishing connectivity for communication between roadside units and back offices or traffic management centers (TMCs).[107] As discussed, backhaul includes the fiber optic cables connecting traffic signals to the back office, as well as any sensors or relays that link to or serve these components. According to NCHRP, backhaul will be one of the biggest components of costs. In fact, three state agencies and one supplier we spoke with referred to backhaul as a factor that will affect costs for V2I deployment. Backhaul costs are also uncertain because states vary in the extent to which they have existing backhaul. According to AASHTO, some sites may only require an upgrade to their current backhaul system to support expected bandwidth requirements for connected vehicle communications. However, 40 percent of all traffic signals have either no backhaul or will require new systems, according to AASHTO. The difference in cost between tying into an existing fiber-optic backhaul and installing a new fiber-optic backhaul for the sites is significant, according to DOT. The average national cost to upgrade backhaul to a DSRC roadside site is estimated to vary from $3,000, if a site has sufficient backhaul and will only need an upgrade, to $40,000, if the V2I site requires a completely new backhaul system, according to AASHTO estimates.

The total potential average, non-recurring costs of deploying connected vehicle infrastructure per site, according to DOT and AASHTO, are $51,650 (see table 1).[108]

[106]Traffic signal controllers provide information on the signal phase (green, yellow, or red) and the amount of time remaining until the light changes to the DSRC radio, which then broadcasts the information to the vehicle.

[107]As previously mentioned, backhaul is the closed network communication links between back offices (or TMCs) and field installations (such as traffic signal controllers).

[108]According to DOT officials, these costs are based on limited, research installations, and are not necessarily reflective of planned deployments. Furthermore, as agencies renovate or upgrade existing systems (such as periodic replacement of traffic signal systems), they are already installing components necessary to support V2I deployments, such as fiber optic backhaul for the modern traffic signal controllers.

Table 1: Total Potential Average, Non-Recurring Costs of Connected Vehicle Infrastructure per Site

Cost element	Average cost
Planning and design average costs	$6,650
Equipment average costs	$7,450
Installation average costs	$3,550
Backhaul average costs	$30,800
Signal controller upgrades average costs	$3,200
Total potential average costs per site	**$51,650**

Source: American Association of State Highway and Transportation Officials and DOT, | GAO-15-775
Note: "Per site" refers to each specific location where a roadside unit is deployed.

Second, V2I will also require recurring costs—the costs required to operate and maintain the infrastructure. According to AASHTO, there are several types of recurring costs associated with V2I deployments, including equipment maintenance and replacement, security, and personnel costs. The amount of maintenance needed to keep roadside units running is unclear, according to 3 of the experts we interviewed, because the test bed deployments have generally not operated long enough to warrant maintenance of the equipment. However, NCHRP estimates that routine maintenance costs for roadside units would likely vary from 2 to 5 percent of the original hardware and labor costs. This includes such maintenance as realigning antennas and rebooting hardware. AASHTO also estimates that the device would need replacing every 5 to 10 years. In addition, states and localities may also need to hire new personnel or train existing staff to operate these systems. According to AASHTO, personnel costs will also depend on the size of the deployment as smaller deployments may not need dedicated personnel to complete maintenance, while large deployments may require staff dedicated to system monitoring on site or on call. Furthermore, security costs will be a recurring cost and include the costs of keeping the security credentials of the SCMS up to date and the costs to manage the security system, according to AASHTO. Given that SCMS is still being developed, cost estimates are unknown.[109] One car manufacturer we interviewed explained that because the management of the security system is unknown, it is extremely challenging to estimate future costs. In

[109]In its report, AASHTO assumes a cost of $50 per device to develop a more accurate estimate of the annual operating costs.

addition, one county agency official said security costs could greatly affect the total costs for V2I deployment because the requirements and funding responsibility are not clearly defined. As part of its ANPRM, NHTSA conducted an assessment of preliminary V2V costs, including costs for the SCMS.[110] NHTSA estimated that the SCMS costs per vehicle range from $1 to $6, with an average of $3.14. SCMS costs will increase over time due to the need to support an increasing number of vehicles with the V2V technologies, according to NHTSA.

While AASHTO and NCHRP have estimated the above potential average costs for various components associated with a V2I deployment, 10 of 21 experts stated that it is difficult to determine the actual costs for a V2I deployment in a particular state or locality due to a number of factors.[111]

- First, the scope of the deployment will affect the total costs of a region's V2I deployment, according to NCHRP, because it will determine the amount of equipment needed for the system to function, including the number of roadside units. Previous test bed deployments have varied in size ranging from 1 to 2,680 DSRC roadside units. Further, the number of devices needed will be dependent on how many devices are required to enable the applications. For example, while a curve-speed-warning application may require installing equipment at a specific location, applications that aim to mitigate congestion by advising drivers of the best speed to approach an intersection may need to be installed at several intersections throughout an urban corridor. One state agency said that one factor that could affect costs is how often roadside equipment needs to be replaced in order to enable certain V2I applications. In addition, as previously mentioned, the size of the deployment will contribute to personnel costs.
- Second, the state or locality's deployment environment will affect its deployment costs. One state agency pointed out that everyone's costs will be different because they will be deploying in environments with differing levels of existing infrastructure. For example, as previously noted, the region's existing backhaul infrastructure will determine the extent of the cost for installing or upgrading the region's system,

[110] 79 Fed. Reg. 49270 (Aug.20, 2014).

[111] Seven of the 21 experts we interviewed did not provide a response to this question.

including whether a city or state has fiber optics already installed or signal controllers need upgrading.

- Lastly, the maturity of the technology will also affect cost estimates for equipment such as a DSRC radio. Estimating equipment costs is difficult at this time because the technology is still developing, according to NCHRP. Ten of the 21 experts we interviewed, including all of the state agencies, also mentioned that estimating costs is challenging because the technology is still immature.[112] Furthermore, the reports and 4 experts we interviewed agree that the cost estimates for the hardware are likely to decrease over time, as the technology matures and the market becomes more competitive. [113]

As part of the upcoming Connected Vehicle Pilot Deployment Program, DOT developed the Cost Overview for Planning Ideas and Logical Organization Tool (CO-PILOT). This tool generates high-level cost estimates for 56 V2I applications based on AASHTO's estimations. In addition, according to DOT, the agency will work with AASHTO to develop a life-cycle cost tool that agencies can use to support V2I deployment beyond the Connected Vehicle Pilot Deployment Program. DOT officials also indicated that they plan to update the tool over time as more data are collected from the Connected Vehicle Pilot Deployment Program, and they expect the tool to be available for use by 2016. Also, as previously mentioned, FHWA is developing deployment guidance that will outline potential sources of funding for states and localities, among other things.

Agency Comments

We provided a draft of this product to the Secretary of Transportation, Secretary of Commerce, and the Chairman of the FCC, for review and comment. DOT and Commerce's NTIA both provided comments via email that were technical in nature. We incorporated these comments as appropriate. FCC did not provide comments.

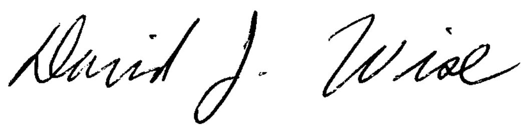
As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. We will send copies of this report to the Secretary of

[112]Seven of the 21 experts we interviewed did not provide a response to this question.

[113]Five of the 21 experts we interviewed did not provide a response to this question.

Transportation, the Chairman of the Federal Communications Commission, and the Administrator of the National Telecommunications and Information Administration and appropriate congressional committees. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or wised@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix III.



David Wise
Director, Physical Infrastructure

Appendix I: Scope and Methodology

To address all of our objectives, we reviewed documentation relevant to vehicle-to-infrastructure (V2I) technology research efforts of the Department of Transportation (DOT), state and local government, and automobile industry, such as DOT's 2015 Federal Highway Administration V2I Draft Deployment Guidance and Products and AASHTO's *National Connected Vehicle Field Infrastructure Footprint Analysis*, as well as documentation on completed and ongoing research. We interviewed officials from DOT's Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems-Joint Program Office (ITS-JPO), Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), and the Volpe National Transportation Systems Center, about these efforts.

For all objectives, we developed a structured set of questions for our interviews with 21 experts who represented domestic automobile manufacturers, V2I device suppliers, state and local government, privacy experts, standardization organizations, and academic researchers with relevant expertise. The identified experts have varying degrees of expertise in the following areas related to V2I technology: the production of passenger vehicles; technology development; technology deployment; data privacy; security; state agency deployment; and legal and policy issues. Our starting point for our expert selection was a list of experts originally created in January 2013 by the National Academy of Sciences for GAO's vehicle-to-vehicle (V2V) report.[1] We used this list for our initial selection because V2V and V2I technologies are both connected vehicle technologies with many similarities, and many V2V stakeholders are also working on V2I.[2] In addition to nine experts we selected from the National Academy of Sciences list, we selected an additional 12 experts based on the following factors:

[1]GAO, *Intelligent Transportation Systems: Vehicle-to Vehicle Technologies Expected to Offer Safety Benefits, but a Variety of Deployment Challenges Exist,* GAO-14-13 (Washington D.C.: November 2013)

[2]Connected vehicle technologies involve vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies. V2V is a system designed to transmit basic safety information between vehicles to facilitate warnings to drivers about potential collisions. V2I is defined as the wireless exchange of safety and operational data between vehicles and roadside infrastructure, intended primarily to avoid or mitigate motor vehicle crashes.

1. their personal involvement in the deployment of V2I technologies;
2. recommendations from federal agencies (DOT, and the Federal Communications Commission (FCC) and associations (such as the American Association of State and Highway Transportation Officials (AASHTO); and
3. experts' involvement in professional affiliations such as a V2I consortium or groups dedicated to these technologies or to a specific challenge affecting V2I (e.g., privacy).

Table 2 lists the experts we selected.

In conducting our structured interviews, we used a standardized interview to ensure that we asked all of the experts the same questions. During these interviews we asked, among other things, for expert views on the state of development and deployment of V2I technologies (including DOT's role in this process), the potential benefits of V2I technologies, and their potential costs. We also asked for each expert's views on a number of defined potential challenges facing the deployment of V2I technologies, and asked the experts to rate the significance of each challenge using a three-point scale (significant challenge, moderate challenge, or slight challenge). We determined this list of potential challenges after initial interviews with DOT, industry associations, and other interest groups knowledgeable about V2I technologies. Prior to conducting the interviews, we tested the structured interview with one association to ensure our questions were worded appropriately. After conducting these structured interviews, we summarized expert responses relevant to each objective. The viewpoints gathered through our expert interviews represent the viewpoints of individuals interviewed and cannot be generalized to a broader population.

Table 2: Subject Matter Experts Interviewed

Experts	Organization
Roger Berg	Denso
Debra Bezzina	University of Michigan Transportation Research Institute
Dorothy Glancy	Santa Clara University School of Law
Michael Shulman	Ford and Crash Avoidance Metrics Partners, LLC
Tom Schaffnit	Vehicle Infrastructure Integration Consortium
Ravi Puvvala	Savari Networks
David Miller	Siemens
Barry Einsig	Cisco
Jack Pokrzywa	SAE International
Siva R.K. Narla	Institute of Transportation Engineers
Scott Geisler	General Motors
Steven Siko	Chrysler
Jules Polonetsky	Future for Privacy Forum
Greg Larson	California Department of Transportation
Richard McDonough	New York State Department of Transportation
Matt Smith	Michigan Department of Transportation
Catherine McGhee	Virginia Department of Transportation
Elizabeth Birriel	Florida Department of Transportation
Charlie Farnham	Texas Department of Transportation
Blaine Leonard	Utah Department of Transportation
Faisal Saleem	Maricopa County Department of Transportation, Arizona

Source: GAO. | GAO-15-775

For the purpose of this review, state and local agency officials were considered experts because of their experience in deploying and testing V2I technologies, and experience working with the required technologies (DSRC equipment and software), decision process (funding and scheduling); personnel requirements and skill sets needed for deployment; operations and maintenance. We specifically included six officials who deployed V2I test beds in their respective states in our pool of expert interviews.

We also included two officials who studied V2I for several years, had taken part in the AASHTO's Connected Vehicle group, and had applied to DOT's prior Connected Vehicles Pilot Program (V2I test bed). We also interviewed additional officials who have contributed to the U.S. efforts to develop and deploy connected vehicle technologies—officials who we refer to as "stakeholders." Specifically, we used these stakeholders to help us understand issues that informed our structured set of questions, but did not administer the structured question set during these stakeholder interviews. We primarily selected stakeholders based on recommendations from DOT and industry associations. However, we also included DOT as a stakeholder in the deployment of V2I technologies because it is leading federal V2I efforts.

We interviewed officials from 17 V2I stakeholder organizations including:

1. DOT, NHTSA
2. DOT, Office of the Assistant Secretary for Research and Technology, ITS-JPO
3. DOT, FHWA
4. DOT, Volpe National Transportation Systems Center
5. DOT, Chief Privacy Officer
6. National Telecommunications and Information Administration (NTIA)
7. FCC
8. AASHTO
9. Intelligent Transportation Society of America (ITS America)
10. Crash Avoidance Metrics Partners, LLC (CAMP)
11. Institute of Electrical and Electronics Engineers (IEEE)
12. National Cooperative Highway Research Program (NCHRP)
13. Leidos, previously known as Science Applications International Corporation (SAIC)
14. Virginia Tech Transportation Institute
15. Virginia Department of Transportation
16. Minnesota Department of Transportation
17. Road Commission for Oakland County, Michigan

To determine the status of development and deployment of V2I technology, we interviewed officials from DOT, including the Office of the Assistant Secretary for Research and Technology, ITS-JPO, FHWA, Volpe National Transportation Systems Center, and the NHTSA. We also interviewed officials at all seven V2I test beds located in Virginia, Michigan, Florida, Arizona, California, and New York.[3] We conducted site visits to three test beds—the Safety Pilot in Ann Arbor, Michigan, and the test beds in Southeast Michigan and Northern Virginia. We selected the three site visit locations based on which had the most advanced technology according to DOT and state officials. At these site visits, we conducted interviews with officials from state and local transportation agencies and academic researchers to collect information on developing and deploying V2I technology. We visited FHWA's Turner Fairbank Highway Research Center in Virginia to understand the agency's connected vehicle research efforts. We reviewed documentation of the efforts of DOT and automobile manufacturers related to vehicle-to-infrastructure (V2I) technologies, such as the 2015 FHWA's V2I *Draft Deployment Guidance and Products* and documentation on completed and ongoing research. We identified materials published in the past 4 years that were related to the terms "vehicle-to-infrastructure" and "V2I" through searches of bibliographic databases, including Transportation Research International Documentation and WorldCat. While a variety of V2I technologies exist for transit and commercial vehicles, for the purpose of this report we limited our scope to passenger vehicles since much of DOT's connected vehicle work is focused on passenger vehicles.

To determine the challenges affecting the deployment of V2I technology and DOT's existing or planned actions to address potential challenges, we reviewed FHWA's V2I draft guidance to assist in planning for future investments and deployment of V2I systems. In addition, we interviewed officials from FCC and NTIA about challenges related to the potential for spectrum sharing in the 5.9 GHz band. We interviewed DOT's Privacy Officer, two privacy experts, and several stakeholders to understand privacy concerns regarding the deployment of V2I technologies.

We collected information on anticipated benefits of these technologies through interviews with officials from DOT, automobile manufacturers, industry associations, and experts identified by National Academy of Sciences and other stakeholders, and through reviews of studies they provided. To specifically address the potential costs associated with V2I

[3]There are two test beds in Michigan, the Safety Pilot in Ann Arbor, Michigan, and in Southeast Michigan, in Oakland County.

technologies, we analyzed two reports, AASHTO's *National Connected Vehicle Field Infrastructure Footprint Analysis* and NCHRP's 03-101, *Cost and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies* report, both of which addressed acquisition, installation, backhaul, operations, and maintenance costs.[4] According to DOT officials and other stakeholders we interviewed, those two reports were the primary sources of information for V2I potential deployment costs estimates and actual costs.[5] We used V2I costs estimates from the *AASHTO Footprint Analysis* to give examples of potential costs for deployment. To further assess the reliability of the cost estimates, in addition to our own review of the two reports, our internal economic stakeholder also independently reviewed both reports, and we subsequently interviewed representatives from AASHTO and NCHRP to verify the scope and methodology of the cost analyses performed in both reports. In addition, we discussed estimated costs and factors that affected costs for V2I investments with experts and stakeholders from federal, local, state government, academia, car manufacturers, industry associations, and V2I suppliers. We determined that the actual cost figures were reliable and suitable for the purpose of our report.

In addition to the above work, we selected Japan for a site visit because of its nationwide deployment and years of experience with deployment and maintenance of V2I technologies. Japan has led efforts in V2I technology development and deployment for over two decades. The country serves as an illustrative example from which to draw information on potential benefits, costs, and challenges of deploying V2I technologies in the United States.[6] During our site visit, we interviewed Japanese government officials and auto manufacturers on similar topics that we discussed with U.S. experts, including V2I deployment efforts, benefits, costs, and challenges.

[4]AASHTO, *AASHTO National Connected Vehicle Field Infrastructure Footprint Analysis,* (Washington, D.C.: June 27, 2014) and National Cooperative Highway Research Program (NCHRP), *Cost and Benefits of Public-Sector Deployment of Vehicle-to-Infrastructure Technologies,* 03-101 (Washington. D.C.: 2013).

[5]However, it should be noted that these reports are limited in their scope because their findings are based on small, connected vehicle infrastructure deployments to date.

[6]Although there are V2I efforts underway in Europe, we focused on Japan due to its 20 years of experience in developing and deploying V2I technologies.

Japanese Government

- Cabinet Secretariat (IT Strategy)
- Cabinet Office (Council for Science and Technology Policy)
- Ministry of Land, Infrastructure, Transport and Tourism (MLIT)
  - Road Bureau
  - Road Transport Bureau
- Ministry of Internal Affairs and Communications (MIC)
- National Police Agency (NPA)
- Ministry of Economy, Trade and Industry (METI)

Car Manufacturers

- Toyota
- Honda
- Nissan

V2I Supplier

- Denso

We conducted this performance audit from July 2014 through September 2015 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Expert Ratings of Potential Challenges Facing Deployment of Vehicle-to-Infrastructure Technologies

As part of our review, we conducted 21 structured interviews with individuals identified by the National Academy of Sciences and based on other factors discussed in our scope and methodology to be experts on vehicle-to-infrastructure (V2I) technologies (see table 2 in app. I for list of experts interviewed). During these interviews we asked, among other things, for each expert’s views on a number of already defined potential challenges facing the deployment of V2I technologies. The ratings provided by the experts for each of the potential challenges discussed are shown in table 3 below. To inform our discussion of the challenges facing the deployment of V2I technologies, we considered these ratings as well as experts’ responses to open-ended questions.

Table 3: Expert Ratings of Potential Challenges Facing Deployment of Vehicle-to-Infrastructure Technologies

Potential Challenges	Significant Challenge	Moderate Challenge	Slight Challenge	Did Not Answer
Spectrum sharing—allowing unlicensed devices to operate in the 5.9 GHz band along with V2I technologies	17	1	1	2
Non-mandatory, voluntary deployment of V2I technologies among states and localities	12	6	1	2
Limitations at the federal level for V2I deployment in terms of funding or providing technical resources to state/local transportation operators	9	2	3	7
Limitations at the state/local level for V2I deployment (for example, funding, personnel, or other areas)	10	6	0	5
Ensuring privacy under a system that involves the sharing of data among vehicles and government infrastructure.	9	5	6	1
Data Security measures are in place to secure the data that is collected at the Test Bed [Question for Test Bed locations only] [a] (Total = 7)	6	1	0	0
Ensuring data security in deploying V2I technologies. [Question for a non-test bed interviews—car manufacturers, associations, and others] [a] (Total = 14)	8	3	2	1
Standardization	7	8	5	1
Human factors in the deployment of V2I technologies	7	10	2	2
Liability issues, in terms of uncertainty related to legal responsibility for vehicle crashes using V2I technology	5	7	5	4

Source: GAO analysis of expert interviews. | GAO-15-775

[a]We asked separate data security questions depending on whether the expert had previously or currently worked on a V2I test bed.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact:

David Wise at (202) 512-2834 or at wised@gao.gov

Staff Acknowledgments:

In addition to the contact named above, Susan Zimmerman, Assistant Director; Nelsie Alcoser; David Hooper; Crystal Huggins; Amber Keyser; Nancy Santucci; Terence Lam; Josh Ormond; Amy Rosewarne; and Elizabeth Wood made key contributions to this report.