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According to FHWA's draft guidance on V2I deployment, funds are available for the purchase and installation of V2I technologies under various Federal-aid highway programs.[61] In addition, costs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, *Costs 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.

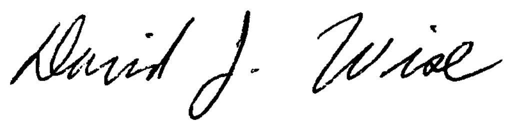
As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. We will send copies of this report to the Secretary of

[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.

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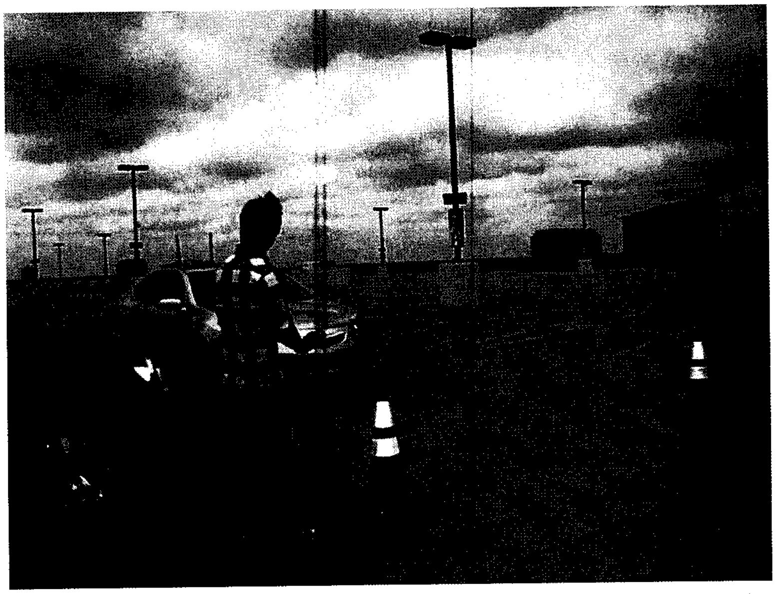
Appendix V. Kami Buchholz, *Honda Works to Prevent Vehicle-to-Pedestrian Accidents*, SAE INTERNATIONAL (Sept. 30, 2013).

Honda works to prevent vehicle-to-pedestrian accidents

30-Sep-2013 04:23 EDT



A pedestrian receives audible and visual alerts via a DSRC-enabled cell phone during Honda's demonstration of vehicle-to-pedestrian safety technologies.

A distracted pedestrian approaches an intersection as a car traveling 35 mph (56 km/h) heads toward the crosswalk. But instead of a vehicle-to-pedestrian (V2P) collision, the pedestrian's dedicated short range communications (DSRC)-enabled smartphone blasts a repeating, high-volume beep and sends a visual alert to the cell phone screen.

An audible warning and a visual "brake" message via the vehicle's head-up display and navigation screen alert the driver to a possible collision.

The above scenario unfolded as an Acura TL equipped with DSRC wireless technology (in the 5.9-GHz band) detected the pedestrian, who was carrying a DSRC-enabled smartphone during a recent safety demonstration for media.

"We're still in the research stage with this project, so these are experimental units. But this V2P demonstration is an indication of where we see the future of safety going," Jim R. Keller, Honda R&D America's Senior Manager and Chief Engineer for Automobile Technology Research, told SAE Magazines as several V2P scenarios unfolded on a rooftop parking lot in Detroit.

A proprietary smartphone application, GPS data, and algorithms are used to determine the location and direction of both the pedestrian and the vehicle, the speed of the approaching vehicle, as well as the likelihood that the walker is in a distracted state (i.e., texting or talking on the cellphone) and a V2P collision is possible.

Honda and Qualcomm independently developed the technologies for the V2P demonstration with Honda handling vehicle aspects and Qualcomm working on phone-related aspects.

According to Chris Borroni-Bird, Vice President of Strategic Development for San Diego, CA-headquartered Qualcomm Inc., "The research on V2P has, so far, focused on the feasibility of using existing phone hardware to enable the functionality. Moving forward, some key challenges will be to enhance the algorithms to reduce false positives and to integrate DSRC with other sensors—camera, radar—on the vehicle-side."

Honda engineers are also using DSRC technology to avert potential vehicle-to-motorcycle (V2M) collisions, including instances when the motorcycle is obstructed from a vehicle driver's view. The system, which is being researched and tested in cooperation with the University of Michigan Transportation Research Institute, provides audible and visual alerts to the vehicle driver.

One of the underlying research issues, according to Keller, is how alerts are communicated to a driver.

"The human-machine interface is going to be key to all of this, whether the potential incidents involve a motorcycle, another vehicle, or a pedestrian. How you communicate information in a non-distracting manner but still give the right information at the right time so that action can be taken is critical," Keller said.

Driver-distraction research is crucial to putting all the pieces together.

Researchers are using information gleaned from driver simulation lab studies in Japan and the U.S. The newest facility, which opened in October 2012 at The Ohio State University, features three different stations with the primary simulation lab featuring a 2010 Honda Accord buck mounted to a six-axis platform.

As the driver views a highway and its surroundings via a 260° screen, three eye-tracking cameras enable researchers to see where the driver's eyes are focused and for how long. Researchers impose various distractions, such as having the driver talk on a cell phone as well as having the driver text from a cell phone.

Steven Feit, Senior Manager and Chief Engineer for Infotainment Technology at Honda R&D Americas, noted that The Ohio State University lab researchers include cognitive scientists and psychologists.

"By having our engineers do joint research with these individuals, we're getting additional perspectives and that really helps us understand the visual, auditory, cognitive, and psychomotor issues associated with distracted driving," Feit said in an SAE Magazines interview.

According to Art St. Cyr, Vice President of Auto Operations, American Honda Motor Co., Inc., the automaker's commitment to safety is fundamental to its corporate philosophy. "Our approach to safety is shaped by our view that as a manufacturer of different types and sizes of motor vehicles, we have a responsibility to share the road," he said.

Author: Kami Buchholz

Sector: Automotive

Topic: Human Factors and Ergonomics Electrical, Electronics and Avionics Safety

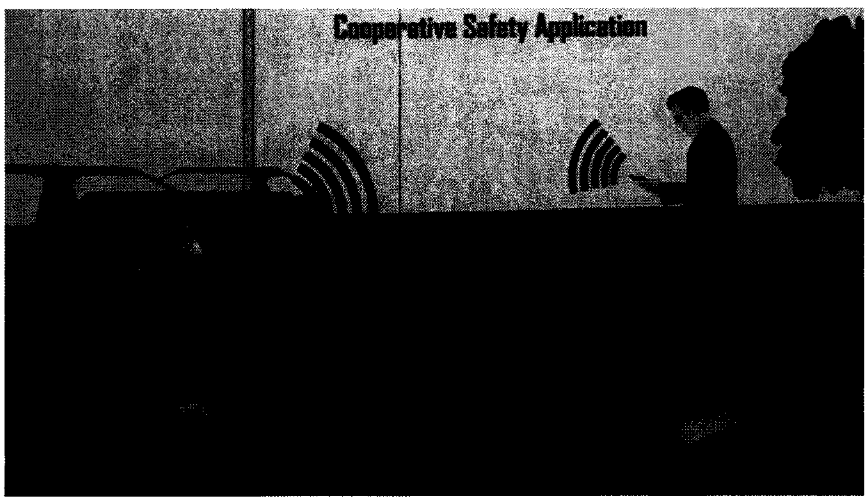
Mentions: Honda

Appendix VI. Andrew Handley, *How Honda's V2V and V2P Technology Uses Smartphones to Save Lives*, QUARTSOFT .COM (Sept. 26, 2013).

How Honda's V2V And V2P Technology Uses Smartphones to Save Lives?

Thursday, September 26, 2013

Editor's Note: *We are excited about so many new possibilities for smartphone owners emerging every day. The members of our Mobile Design & Development Department feel so proud each time they create another useful smartphone app. We are sure they'll be even more proud when they learn how big companies like Honda are starting to use smartphones to protect human lives and reduce car accidents. That's why our editors decided to publish another interesting article on new developments in the world of mobile technology.*



Connectivity is growing by leaps and bounds, and now, Honda has announced vehicle-to-vehicle communication (V2V) technology that allows cars to sense an approaching vehicle and provide timely warnings to other drivers. Similar technology also promises to facilitate safety on the roads and sidewalks by offering vehicle-to-pedestrian communication (V2P) and vehicle-to-motorcycle (V2M) based on the same principle. The approach is founded on Wi-Fi direct that is much like the wireless networks that most people are familiar with at home, school and work.

V2V Enhancing Driver Safety

Operating on the principles of Dedicated Short Range Communication (DSRC), V2V is a system in which signals are transmitted from one object to another, and the technology helps to show where the different cars, motorcycles or pedestrians are located in relationship to one another. In V2V, car dashboards are outfitted with a display that alerts drivers of the danger that is present. The system is currently being tested by the United States Department of Transportation (DOT) on roads in and around the Ann Arbor, Michigan area. As part of the test to determine whether the new technology can actually help to save lives on the highways, eight different vehicles along with several motorcycles have all been outfitted with transmitting and receiving technology.

Information that is gleaned during the testing is expected to impact whether the latest safety features will soon be mandatory in all vehicles.

V2P: Protecting Pedestrians

Pedestrians also have a chance to benefit from the latest Wi-Fi direct technology, and anyone with a smartphone will soon be able to receive alerts about the dangers of nearby vehicles on the road. Because the system relies on communication that is much like traditional WiFi, smartphones can easily transmit signals to nearby vehicles that are outfitted with the same technology. The DSRC operates on a 5.9 GHz band, and the Honda system uses motion sensors and a phone's GPS to determine the exact location of both parties and the chance of an accident occurring. Alerts will readily appear on a pedestrian's phone with assistance from an app that is especially designed for the purpose. Industry experts predict that the latest technology will simply merge into most car's existing infotainment systems.

The V2V system has a range that is more than 200 yards, and in distinction with regular Wi-Fi, the DRSC connects individual devices with each other without relying on a central access point. Traditional Wi-Fi takes up to eight seconds for a connection to be established because devices must first communicate with a wireless access point. In the V2V technology, two devices can join in less than a second, and this can help to provide the timely alerts that may be able to prevent accidents and save lives. The fast-connecting feature ensures that drivers and pedestrians can always know where others are, and it helps to reduce the chances of a collision.

Driving in Connected Cars

In addition to promising a safer way for pedestrians, vehicles and motorcycles to interact, the new technology also offers a wide variety of benefits to drivers. Experts predict that by installing Wi-Fi in cars, operators will have more access to content and can ensure that their vehicle is fully wired to communicate with their home network, other drivers and even pedestrians. Music, addresses and other entertainment files can also be transferred from a vehicle or pedestrian smartphone to a home or business network, and this can also ensure that passengers have access to movies or books while traveling. While the technology may not be available to everyone for another five years, it may provide an outstanding way to reduce the more than 4,000 fatal accidents that occurred in 2010 alone.

By Andrew Handley

Andrew Handley is a ƒ
at ProctorHonda.com.

Tags: smartphones, mot

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Appendix VII. John Kenney et al ., *A response to the re-channelization proposal* , doc. IEEE 802.11-14/1101r1 (Sept. 5, 2014).

A response to the re-channelization proposal

Authors: **Date:** September 5, 2014

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Preface

The DSRC community:

- Remains committed to a good faith investigation into the question of if and how unlicensed devices can share DSRC spectrum without harmful interference, including eventual testing
- Has engaged positively with the Wi-Fi community in the Tiger Team and other venues, including delivering tutorials, supplying test data, giving feedback, and providing information about harmful interference, channel models, test beds, and DSRC bands outside the US.
- Has indicated that the CCA-based sharing concept (11-13-0994/r0) has potential, and has suggested it be fully developed

Conclusion

For the reasons cited here, the authors of this submission:

- **consider the proposal in 11-13-1276/r1 and 11-14-0819/r0 inconsistent with the DSRC mission for which the FCC allocated the 5.9 GHz band**
- **conclude that the proposal is not viable as a U-NII sharing technology that will protect DSRC services**
- **encourage the Tiger Team to focus resources on developing a proposal that has the potential to protect DSRC services and garner broad-based stakeholder support**

Outline

- Incorrect premise: Critical DSRC traffic fits in 2 channels
- Incorrect premise: Proposal requires no new research or testing
- False equivalence between U-NII and DSRC interference
- Proposal calls for degraded DSRC performance
- Proposal is inconsistent with FCC NPRM
- Proposal offers no in-band protection
- Proposal is Wi-Fi specific
- Proposal is US-specific
- Proposal stifles DSRC innovation

Critical DSRC Traffic

Some DSRC facts that are sometimes *misunderstood*:

Fact 1: Every channel is a service channel, except Ch. 178

There are no "non-safety" channels

Channel No.	Frequency range (MHz)	Max. EIRP [1] (dBm)	Channel use
170	5850–5855		Reserved.
172	5855–5865	33	Service Channel. [2]
174	5865–5875	33	Service Channel.
175	5865–5885	23	Service Channel. [3]
176	5875–5885	33	Service Channel.
178	5885–5895	33/44.8	Control Channel.
180	5895–5905	23	Service Channel.
181	5895–5915	23	Service Channel. [3]
182	5905–5915	23	Service Channel.
184	5915–5925	33/40	Service Channel. [4]

CFR47 90.377: Note channels 172 and 184 are service channels with special designations

Critical DSRC Traffic

Fact 2: Every channel will likely carry critical traffic

- **While Ch. 172, 178, and 184 have restrictions, the other channels do not.**
- **They can all be expected to carry critical traffic. Some will carry non-critical traffic as well.**
- **Specific QoS (including latency, priority, range) will vary by application. Each channel can be expected to carry traffic with low loss and low latency requirements.**

Critical DSRC Traffic

Fact 3: Many DSRC applications impact safety

Most will use channels other than Ch. 172 or 184. Examples:

- Pre-crash mitigation
- Work Zone Warning
- Cooperative Adaptive Cruise Control
- Automated driving
- Platooning
- Security: Certificate renewal
- Pedestrian Safety
- Disabled vehicle alert
- Cooperative merge
- Dynamic Routing of Emergency Vehicles
- Queue Warning
- Incident zone
- Dangerous road conditions
- Bicycle Safety
- Curve speed warning
- Tracked vehicle safety
- Security: CRL distribution
- Left-turn assist
- Stop-sign assist
- Excess speed advisory
- R.E.S.C.U.M.E.
- Evacuation
- Automated Advanced Crash Notification
- Other I2V safety ...

Note: this is not a comprehensive list

Critical DSRC Traffic

Fact 4: Many DSRC applications have real-time requirements

Even among those that are not strictly safety apps. Examples:

- Open road tolling
- Commercial vehicle in-motion inspection
- Mileage based user fee
- Speed harmonization
- Transit signal priority
- Connected Eco-driving
- Commercial services

- **Due to high mobility of DSRC stations, service delivery presumptively has low latency requirements**
- **IEEE 802.11p supports low latency requirements**

Critical DSRC Traffic

Illustrative DSRC Application-Channel Usage Map

5.850 5.855 5.865 5.875 5.885 5.895 5.905 5915 5.925

Guard Band	172 SCH	174 SCH	176 SCH	178 Control Channel	180 SCH	182 SCH	184 SCH
	Exclusively for vehicle-to-vehicle safety communications for accident avoidance and mitigation, and safety of life and property applications	Curve speed warning, Queue warning, Left turn assist, stop sign assist, Intersection violation, Disabled vehicle	Automated driving, Distribution of remote sensor data, Platoon control, Cooperative adaptive cruise control, Coop. merge		Pre-crash mitigation, Vulnerable road user safety, Advanced crash notification, CRL, Real-time comm. services	Work zone, Incident zone, Tolling, Speed advisory, Commercial inspection, Dangerous road conditions, GPS corrections	Exclusively for high-power, longer-distance communications to be used for public safety apps involving safety of life & property, including road intersection collision mitigation

This is illustrative. Actual channel used will vary with time and location for many applications. A given application may be offered on more than one channel.

Critical DSRC Traffic: Conclusion

- **The re-channelization proposal calls for all safety-critical traffic to move to the upper 2 or 3 channels of band.**
- **Compressing 7 channels of critical traffic into 2 or 3 creates excess packet loss and latency, degrading application performance.**
- **The re-channelization proposal is inevitably associated with harmful interference to safety-critical communication.**

DSRC Rulemaking Requires Stability

- **"NHTSA will then begin working on a regulatory proposal that would require V2V devices in new vehicles in a future year"**
  – US DOT Sec. Foxx, Feb. 3, 2014
- **"Communication technology for safety applications must be secure, low latency, mature, stable, and work at highway speeds."**
  – US DOT *Principles for a Connected Vehicle,* April 8, 2012
- **US DOT decision follows:**
  - 100s of millions of dollars invested by industry and government
  - More than a decade of productive research
  - Development of a suite of stable, harmonized international standards
  - Large scale Safety Pilot Model Deployment field trial

  all producing the requisite technical maturity and stability
- **Early deployments assume current DSRC channelization (see 11-14-0728/r0)**

DSRC Rulemaking Requires Stability

- **The re-channelization proposal raises a host of questions that a DSRC rule-making process would need to contemplate:**
  - Precise allocation of V2V safety messages among Channels 180, 182, and 184?
  - For each allocation choice, what interference would V2V safety communication receive from:
    - Other DSRC communication (co-channel and cross-channel), including messages that otherwise would not be as spectrally close to V2V communication. Of particular concern is interference from very high power public safety communications on Ch. 184.
    - Other primary and secondary users of the band, especially Fixed Satellite Services.
    - Devices operating above 5.925 GHz
    - Raised noise floor from U-NII devices operating up to 5.895 GHz

(Continued next slide)

DSRC Rulemaking Requires Stability

- **Questions for regulators posed by re-channelization (continued):**
  - Implications for other critical services that would also be compressed into these channels?
  - Changes needed in the DSRC standards?
  - Implications for international harmonization of V2V safety?
- **Qualcomm's FCC NPRM 13-22 comments: allowing unlicensed devices to share Ch. 172 "would invalidate previous testing results and necessitate additional rounds of interference studies."** (Sec. I.B.)
- **The proposal's re-channelization of Ch. 172 traffic has the same issues, and will, despite the wishes of the proposers, lead to considerable delay in the rule-making process and deployment of V2V safety.**
- **33,561 traffic fatalities in 2012: We all agree that this proceeding should not delay DSRC deployment.**

Comparing sources of interference

Consider:

- CRF 47 §15.5: "Operation of an intentional, unintentional, or incidental radiator is subject to the conditions that **no** harmful interference is caused ..." *(emphasis added)*
  - CFR 47 §95.1511 "All licensees shall **cooperate** in the selection and use of channels in order to **reduce** interference" *(emphasis added)*
- **The requirement for U-NII devices is strict and absolute**
- **Any implied equivalence between interference standards is flawed**
- **Sharing solutions developed by the Tiger Team should not:**
  - **Expect or depend on cooperation from DSRC devices**
  - **Expect DSRC devices to accept higher interference from licensed devices**
- **The fact that DSRC already operates in challenging environment only heightens need for U-NII to avoid contributing interference**

Comparing sources of interference

The re-channelization proposal places safety-critical DSRC traffic closer to:

- **interfering FSS signals**
- **high power DSRC Public Safety communication (Ch. 184)**

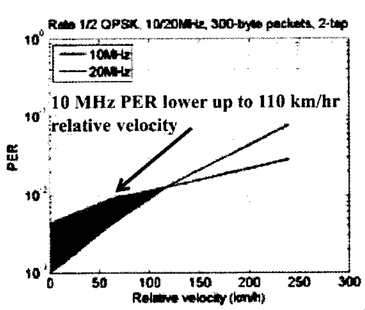
The Tiger Team should consider potential solutions that do not have these weaknesses

- **11-14-0819/r0 states:**
  - "cross-channel interference has always been a problem between existing service channels and high-avail channels; the proposed channelization **does not increase** the interference" [from one DSRC to another] – slide 9 *(emphasis added)*
  - **This is incorrect**
  - Ignores increased interference from high power Ch. 184 into Ch. 180 and Ch. 182
  - Ignores increased interference due to loss of flexibility in assignment of applications to channels, Tx power, spreading V2V on non-adjacent channels, etc.

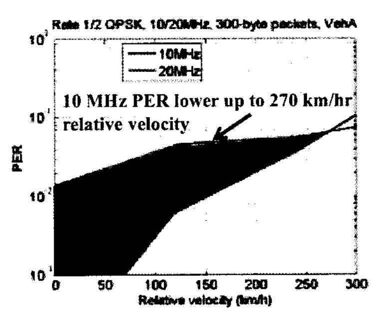
Proposal calls for degraded DSRC performance

- **Already seen:**
  - Packing 7 channels' critical traffic into 2 or 3 degrades performance
  - Placing Basic Safety Messages near High Power Ch. 184 degrades performance
  - Removing flexibility in assignment and operation degrades performance
- **In addition, using 20 MHz channels degrades performance (next slide)**

Proposal calls for degraded DSRC performance: 20 MHz DSRC Channels



Maximum excess delay: 0.5us



Maximum excess delay: 2.5us

From 11-13-1276/r1

- **10 MHz PER is better than 20 MHz PER, especially when weighted with relative velocity probability density**
- **10 MHz has lower noise floor, greater range**
- **10 MHz has better immunity to large outdoor delay spreads**

Proposal calls for degraded DSRC performance: 20 MHz DSRC Channels

- 11-14-0819/r0 states: "20MHz DSRC service-channel operation → would allow for <u>more effective</u> detection of the DSRC signals" *(emphasis added)*
- **This is incorrect.**
- **10 MHz detectors are more sensitive, greater range**
- **10 MHz detectors are commercially available; no new design needed**
  - **Used in all current DSRC chipsets and some Wi-Fi chipsets**
- **The reality is that the proposal seems to suggest 20 MHz DSRC channels primarily for <u>convenience</u> of U-NII device**

Proposal is inconsistent with NPRM

"I think ITS has envisioned that it would have the entire 75 MHz and has been planning for that, so we did not tee up the question of whether we should change the allocation. And, generally with unlicensed it shares on a non-interference basis, so [the Qualcomm proposal] ***<u>would be a completely different direction than was teed up in the Commission's notice.</u>****"* (emphasis added)

- Julius Knapp, US Federal Communications Commission

Hearing of House Energy and Commerce Subcommittee on Communication Technology – Nov. 15, 2013

Proposal is inconsistent with NPRM

*"For the study, NTIA assumed that the FCC's existing U-NII TPC and DFS regulations would be extended to the U-NII-2B and U-NII-4 bands, and that the Federal agencies **will not have to alter their systems or operations to accommodate U-NII devices**."* (emphasis added)

- FCC NPRM 13-22, paragraph 104 (2/20/13), ET Docket 13-49

Proposal is inconsistent with NPRM

"the Qualcomm proposal is inconsistent with the premise of the spectrum sharing concept proposed in the FCC's NPRM"

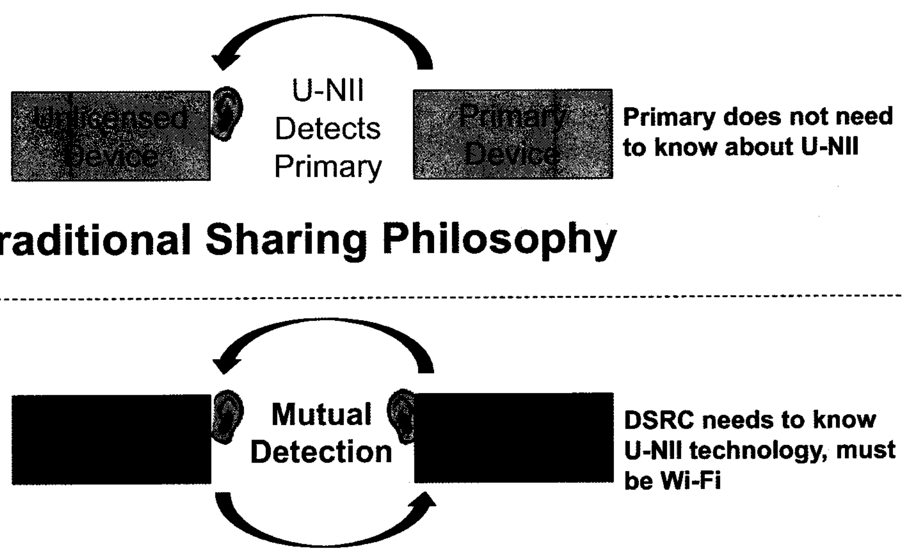
- Jim Arnold, US Dept. of Transportation

IEEE 802.11 Tiger Team meeting 5/30/14

Proposal offers no in-band protection

- CFR47 Part 15 does not recognize channels of unlicensed operation within a band
- CFR47 Part 15 does not impose transmit spectral masks on unlicensed devices
- The proposal allows simultaneous DSRC and unlicensed device operation in the band
  - e.g. 802.11ac on Ch. 177 and DSRC on Ch. 173
- A rule allowing such simultaneous operation could not protect DSRC from harmful interference
- In order to develop a potentially workable rule, the Tiger Team should focus on proposals that vacate the entire band upon detection of DSRC devices

Proposal assumes unlicensed device technology is Wi-Fi



Proposed Philosophy: U-NII must be Wi-Fi