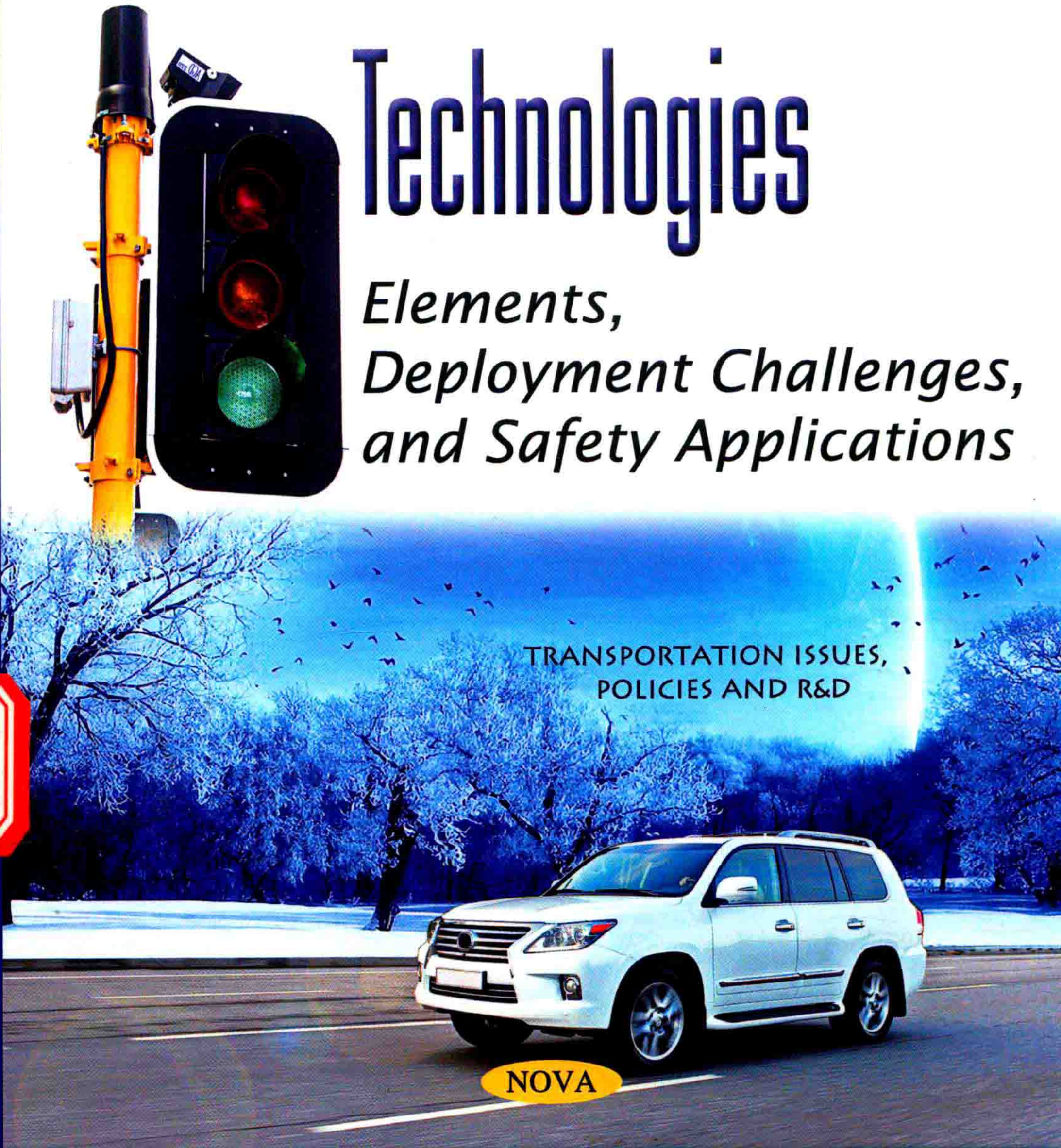
Albert Buchanan
Editor

Vehicle-to-Infrastructure Technologies

Elements, Deployment Challenges, and Safety Applications



TRANSPORTATION ISSUES, POLICIES AND R&D

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VEHICLE-TO-INFRASTRUCTURE TECHNOLOGIES

ELEMENTS, DEPLOYMENT CHALLENGES, AND SAFETY APPLICATIONS

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PREFACE

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, the Department of Transportation (DOT) is promoting the development of vehicle-to-infrastructure (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 book addresses the status of V2I technologies; challenges that could affect the deployment of V2I technologies, and DOT efforts to address these challenges; and what is known about the potential benefits and costs of V2I technologies.

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Editor: Albert Buchanan

Chapter 1

INTELLIGENT TRANSPORTATION SYSTEMS: VEHICLE-TO-INFRASTRUCTURE TECHNOLOGIES EXPECTED TO OFFER BENEFITS, BUT DEPLOYMENT CHALLENGES EXIST*

United States Government Accountability Office

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

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* This is an edited, reformatted and augmented version of a United States Government Accountability Office, Publication No. GAO-15-775, dated September 2015.

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.

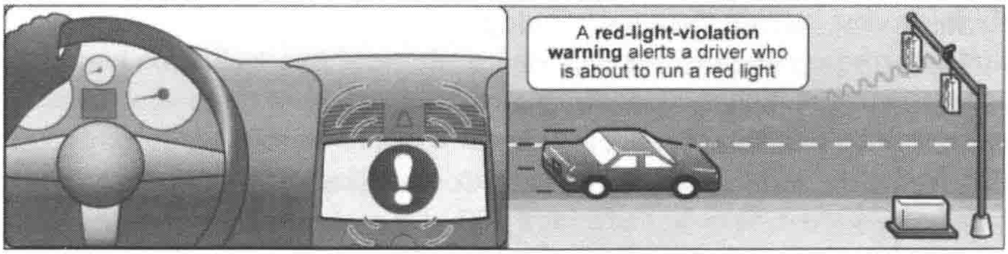
DOT, NTIA, and the FCC reviewed a draft of this report. DOT and NTIA provided technical comments, which were incorporated as appropriate. FCC did not provide comments.

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.



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

Example of a Vehicle-to-Infrastructure Application.

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)

* * *

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, 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 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 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

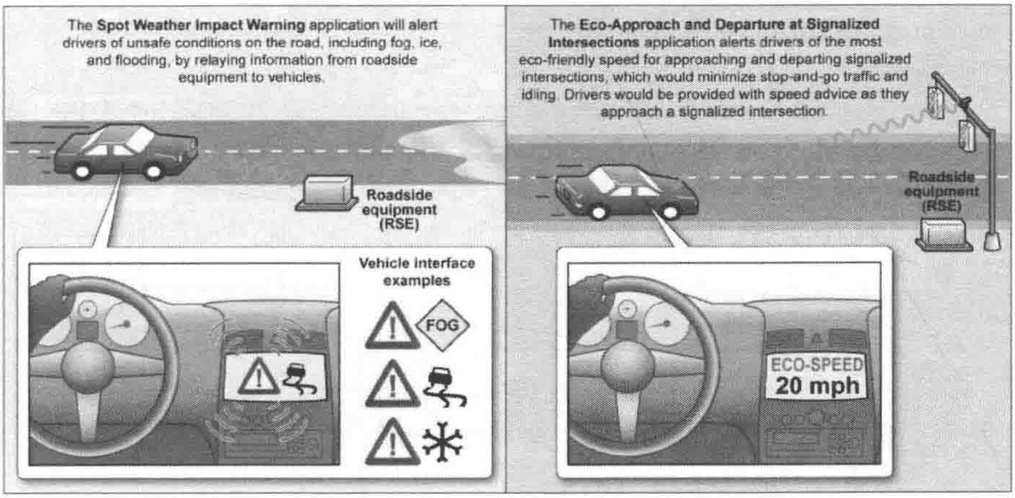
DOT is working with the automobile industry, state and local transportation agencies, researchers, private sector stakeholders, and others to lead and fund research on connected vehicle technologies to enable safe wireless communications among vehicles, infrastructure, and travelers' personal communications 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. 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-go traffic and idling (see right side of fig. 1), and eco-lanes, combined with eco-speed harmonization, would provide speed limit advice to minimize congestion and maintain consistent speeds among vehicles in dedicated lanes.

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]



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

Figure 1. Examples of Vehicle-to-Infrastructure Applications.

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, V2Vequipped 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 (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 V2Iequipped intersection would include:

- 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.