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Report to the Committee on Transportation and Infrastructure, House of Representatives

November 2022

CONNECTED VEHICLES

Additional DOT Information Could Help Stakeholders Manage Spectrum Availability Challenges and New Rules

Accessible Version

GAO-23-105069

GAO Highlights

Highlights of GAO-23-105069, a report to the Committee on Transportation and Infrastructure, House of Representatives

November 2022

CONNECTED VEHICLES

Additional DOT Information Could Help Stakeholders Manage Spectrum Availability Challenges and New Rules

Why GAO Did This Study

DOT estimates that automobile crashes caused 42,915 fatalities in 2021, the highest number for any year since 2006. According to DOT, CV technologies that enable radio communication among vehicles and roadway infrastructure could significantly reduce crashes while also improving traffic efficiency. In 1999, FCC allocated spectrum in the 5.9 GHz spectrum band for CV technologies but then, in 2020, repurposed some spectrum to increase access for Wi Fi and other unlicensed wireless users. DOT and transportation stakeholders have voiced concerns that the reduced spectrum could prevent CV technologies from achieving their intended safety and other benefits.

GAO was asked to examine the status of CV technologies and relevant federal efforts. This report discusses (1) DOT's efforts to facilitate the deployment of connected vehicle technologies and (2) how DOT is addressing challenges to the further deployment of connected vehicle technologies. GAO reviewed documents, interviewed agency officials including from DOT and FCC, and interviewed a non-generalizable sample of 40 stakeholders. Our sample included 23 transportation stakeholders and seven wireless industry stakeholders.

What GAO Recommends

GAO recommends that DOT share additional information about its strategy to support the future deployment of connected vehicle technologies under the new spectrum rules.

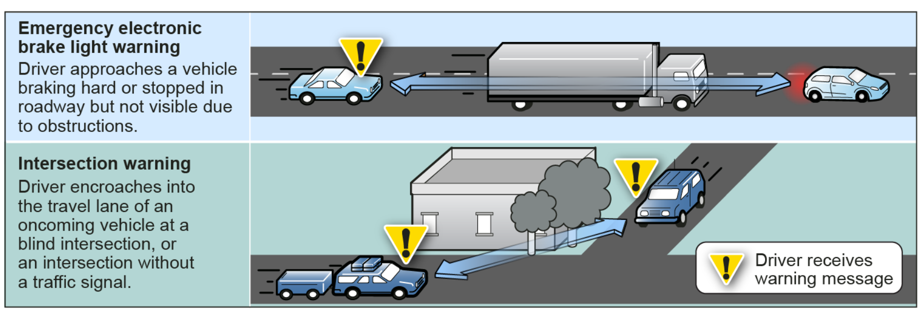
DOT agreed with this recommendation.

View GAO-23-105069. For more information, contact Andrew Von Ah at (202) 512-2834 or VonAhA@gao.go.

What GAO Found

Since 1999, the U.S. Department of Transportation (DOT) has pursued efforts to advance the deployment of connected vehicle (CV) technologies, which enable data to be exchanged among vehicles, infrastructure and road users' personal devices. A driver could receive, for example, a warning about a vehicle that is braking hard on the road ahead but not visible to the driver (see figure below for examples of CV warning messages). According to DOT, these technologies could significantly reduce crashes and improve traffic efficiency. To create a CV environment requires several components, including vehicles and transportation infrastructure equipped with devices to exchange messages. A CV environment also requires radio spectrum (the medium for exchanging messages), and a shared communication protocol or "common language" so messages can be reliably and quickly exchanged. Two communication protocols are available, the original protocol used for CV technologies and a newer protocol. DOT has provided over $800 million in related federal research grants. As of September 2022, transportation agencies in 38 states held licenses to use CV technologies from the Federal Communications Commission (FCC), the agency responsible for regulating, allocating, and assigning non-federal spectrum. Some transportation agencies have deployed CV technologies on roadside infrastructure, but few automakers have produced vehicles equipped for exchanging safety messages.

Examples of Connected Vehicle Warning Messages



Source: GAO analysis of Department of Transportation (DOT) information. | GAO-23-105069

In 2020, FCC changed the communication protocol for and repurposed 60 percent of the spectrum previously allocated to CV technologies to be used for Wi Fi and other wireless users. DOT is taking steps to respond to these spectrum changes, including assessing whether CV technologies that use the new communications protocol can provide safety benefits under the new spectrum rules. DOT has shared some information about its strategy for facilitating the further deployment of CV technologies. However, most of the transportation stakeholders GAO interviewed (18 of 23) said that more information about DOT's strategy to facilitate the deployment of CV technologies could be helpful. By sharing more information with stakeholders, such as the estimated timeframes for key steps to advance CV technologies that use the new communication protocol and achieve nationwide deployment, DOT can help to reduce stakeholders' uncertainty and help them plan their own actions related to investing in CV technologies.

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Abbreviations

3GPP	Third Generation Partnership Project
C-V2X	Cellular-Vehicle to Everything
CV	Connected Vehicle
CAMP	Crash Avoidance Metrics Partners
DSRC	Dedicated Short Range Communications
DOT	Department of Transportation
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
IEEE	Institute of Electrical and Electronics Engineers
ITS	Intelligent Transportation Systems
NHTSA	National Highway Traffic Safety Administration
NTIA	National Telecommunications and Information Administration
SAE	Society of Automotive Engineers
U-NII	Unlicensed National Information Infrastructure

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November 22, 2022

The Honorable Peter A. DeFazio
Chairman
The Honorable Sam Graves
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

The U.S. Department of Transportation (DOT) estimated that over 42,915 fatalities resulted from automobile crashes in 2021, the highest number for any year since 2005. DOT and transportation industry stakeholders have argued that connected vehicle (CV) safety technologies could significantly reduce crashes while providing other benefits such as improved mobility and traffic efficiency. CV technologies enable the exchange of safety messages among vehicles and the roadway infrastructure. For example, CV technologies could alert a driver about a vehicle that is braking hard on the road ahead but not visible to the driver. According to DOT, CV technologies could help avert about 80 percent of all crashes where the driver is not impaired, potentially saving many lives.[1]

The deployment of CV technologies relies on, among other things, the availability of spectrum to enable communications among vehicles and the roadway infrastructure.[2] In 1999, the Federal Communications Commission (FCC) allocated 75 megahertz of spectrum in the 5.850-5.925 GHz (5.9 GHz) spectrum band for the use of Intelligent

[1] The focus of this report is connected vehicle (CV) technologies that use the 5.9 GHz band of spectrum. In our definition, CV technologies aim to enable the exchange of basic safety messages among vehicles, road infrastructure, and road users. Specifically, CV technologies include Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), as well as Vehicle-to-Pedestrian and other road users' devices. Collectively, these are sometimes called Vehicle-to-Everything (or V2X) technologies. In a broader context, "connected vehicles" refers to any vehicles connected to external networks, such as navigation systems or systems for hands-free phone use. This broader definition of connected vehicles would include CV technologies that use the 5.9 GHz spectrum band but would also include other vehicle safety technologies such as collision avoidance systems that do not use this spectrum to function.

[2] Radio spectrum is the part of the electromagnetic spectrum ranging from 1 Hz to 3000 GHz. Electromagnetic waves in this frequency range, called radio waves, have become widely used in modern technology, particularly in telecommunication.

Transportation Systems (ITS), including CV technologies.[3] As we reported in 2015, DOT and industry stakeholders had piloted CV technologies and developed a path for achieving nationwide deployment by 2040 based on this spectrum allocation.[4] However, in November 2020 FCC repurposed 60 percent of the 5.9 GHz spectrum band it had reserved for ITS technologies for increasing spectrum access for users of Wi Fi and other unlicensed wireless devices, which have grown to demand more spectrum in recent years. In response, DOT and transportation industry stakeholders have voiced concerns about how the loss of this spectrum might affect the further advancement of CV technologies, and stakeholders filed suit challenging FCC's decision.[5] Some stakeholders have stated that the spectrum loss could prevent CV technologies from providing their foreseen safety, mobility, and other benefits.

In light of these circumstances, you asked that we examine issues related to the status of CV technologies and relevant federal efforts. This report addresses: (1) efforts DOT has taken to facilitate the deployment of connected vehicle technologies in the United States, and the deployment status of these technologies; and (2) key challenges identified by stakeholders to the further deployment of connected vehicle technologies, and how DOT is addressing these challenges.

To describe the status of CV technologies and DOT's main efforts to facilitate implementation of technologies, we reviewed literature about CV technologies and their deployment status, and federal agency documents on related efforts, including DOT plans and budget documents. We also interviewed federal agency officials about the agencies' respective efforts that relate to or intersect with CV technologies, including officials at DOT,

[3] According to the ITS Joint Program Office's 2020 – 2025 Strategic Plan, DOT defines ITS as a system of technologies and operational advancements that, when combined and managed, improve the capabilities of the overall transportation system. Besides CV technologies, other examples of ITS include dynamic message boards and metered ramps for entering highways.

[4] See *Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist,* GAO-15-775 (Washington, D.C.: Sept 2015).

[5] During the course of the work, the D.C. Circuit Court of Appeals denied the petition to review FCC's order. *Intelligent Transportation Society of America v. FCC*, No. 21-1130 (D.C. Cir. Aug. 12, 2022).

FCC, and in the National Telecommunications and Information Administration (NTIA) within the Department of Commerce.

To inform both of our reporting objectives, we selected a total of 40 stakeholders to obtain a wide variety of perspectives, including stakeholders that had been involved in deploying CV technologies, such as representatives of automakers, auto parts suppliers, industry associations, standards bodies, and state and local transportation agencies.[6] We also selected stakeholders from the wireless industry to gather views on issues related to the use of the 5.9 GHz band, including industry associations and wireless internet service providers. We used semi-structured interviews to gather stakeholders' thoughts on issues related to CV deployment and the 5.9 GHz spectrum band, and then asked stakeholders to respond to a structured questionnaire. To help assess the deployment status of CV technologies, we reviewed documents about efforts to pilot the technologies by state and local transportation agencies in five locations.

To describe key challenges to further CV deployment, and to evaluate how DOT is addressing such challenges, we asked federal agency officials and selected stakeholders about the key challenges to the full deployment of CV technologies and potential ways to address these challenges. Given that the lawsuit regarding FCC's 2020 repurposing of the 5.9 GHz spectrum band was ongoing at the time we conducted our review, this report primarily focuses on efforts by DOT to facilitate deployment of CV technologies and to address associated challenges. In assessing DOT's efforts to address challenges, we compared the agency's efforts to the Standards for Internal Control in the Federal Government, which, among other things, call for federal agencies to identify, analyze, and respond to risks that could affect the agencies' defined objectives, and to externally communicate relevant information to

[6] Specifically, we selected 23 transportation industry stakeholders, seven stakeholders in the wireless industry, and 10 others with expertise, such as researchers and foreign government officials involved in implementing CV technologies abroad. For more details on our methodologies, including a list of interviewed stakeholders, see appendix I.

achieve plans related to such defined objectives.[7] See appendix I for a detailed description of our objectives, scope, and methodology, including a list of interviewees.

We conducted this performance audit from March 2021 to November 2022 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

Connected Vehicle (CV) Technologies

CV technologies use short-range radio signals to support wireless communication among vehicles, transportation infrastructure such as traffic signals, and pedestrians or other road users. CV technologies include Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian communications and devices. According to DOT and transportation stakeholders, CV communications are emerging technologies that have the potential to improve roadway safety and optimize traffic flow, among other benefits. For example, CV technologies aim to promote safety by helping drivers to perceive or "see" vehicles and other objects outside their lines of sight, such as in drivers' blind spots or around corners. This can reduce the risk of collisions by alerting drivers about the presence of other cars or hazards beyond the driver's view.[8] With regard to traffic flow, these technologies could for example, give

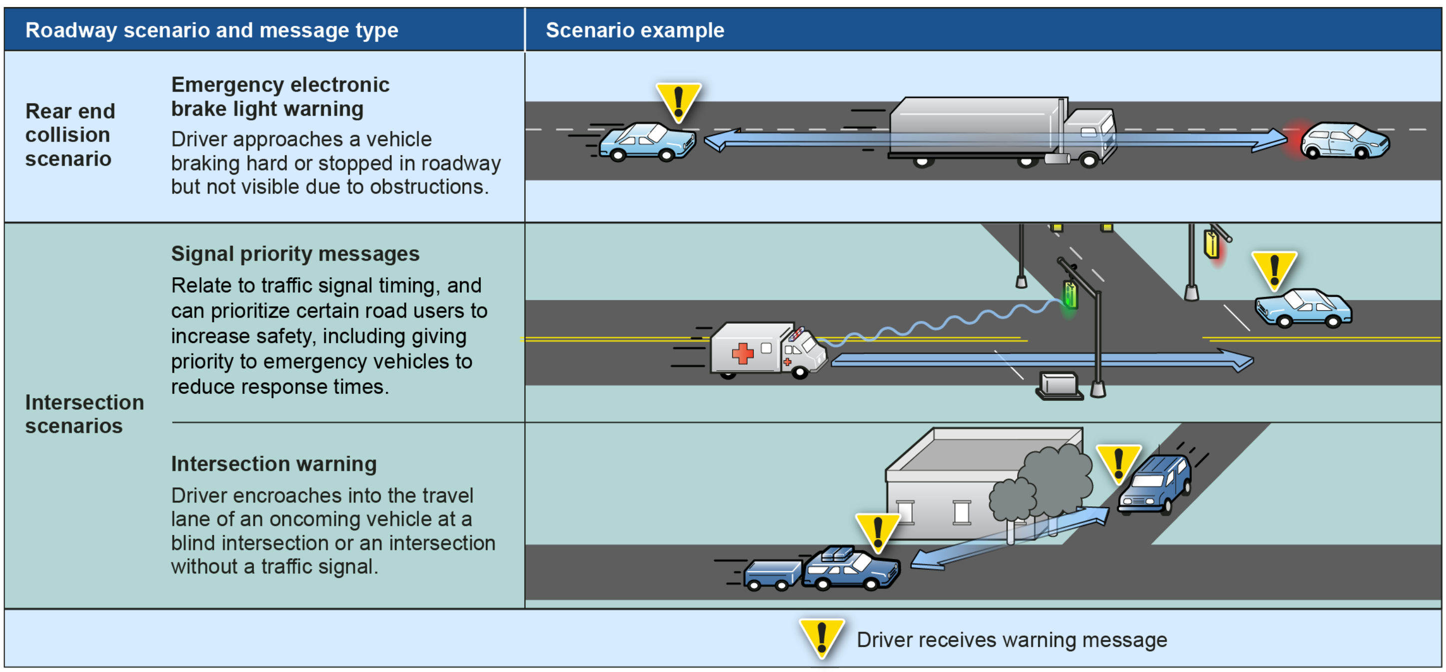
[7] Specifically, these standards state that federal agencies can more effectively respond to risks that relate to the agencies' defined objectives by: (1) identifying risks in the environment that could influence whether objectives are realized, and (2) developing plans for responding to identified changes that could impact the agency's internal controls. These standards also state that agencies should communicate information with those whose participation will be essential for accomplishing the agencies' defined objectives. See GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: September, 2014);

[8] According to DOT officials, CV technologies can alert about hazards within approximately 300 meters, a range at which the driver or automated vehicle can act with enough time to prevent or lessen the effect of a crash.

public transportation vehicles such as buses priority at traffic signals to enable them to operate on schedule and reduce congestion.

In an ideal “connected vehicle environment,” equipped vehicles can communicate with other vehicles, infrastructure, and road users. To function effectively for safety-critical applications, the transmission and receipt of safety messages among equipped vehicles and infrastructure must occur at high speed, and the message data must be processed with minimal delay, also known as low latency. The use of dedicated radio spectrum can help ensure that messages are exchanged instantly between equipped vehicles, infrastructure and other users. See figure 1 for examples of CV messages and associated roadway scenarios.

Figure 1: Examples of Connected Vehicle Messages



Source: GAO analysis of Department of Transportation (DOT) information. | GAO-23-105069

Notes: Messages are sent between equipped vehicles and infrastructure using specific radio spectrum.

Some connected vehicle (CV) applications are similar to other non-CV applications commercially available in some vehicles. Vehicle on-board sensors can replicate the function of some CV applications. However, on-board sensors cannot detect objects outside the driver or vehicle’s line of sight in the way that CV communications can.

An interoperable CV environment consists of several components:

1. **Vehicles equipped with on-board units.** Through these units, equipped vehicles can send and receive messages with other vehicles, infrastructure, or mobile devices. These units emit so-called "basic safety" messages, such as the equipped vehicles' speed, position, acceleration, and brake status.[9]

2. **Transportation infrastructure equipped with roadside units.** This includes traffic signals and other infrastructure with units for sending and receiving messages. Smart infrastructure sends messages to local vehicles to, for example, provide information to drivers about road surface conditions or the time remaining in a green traffic signal.

3. **Reliable communications networks or links, which use radio spectrum.** To ensure that CV messages are reliably transmitted and received in real time, radio spectrum is used to exchange messages between devices.[10] Such message exchanges are vulnerable to harmful interference if, for instance, "out of band" emissions seriously degrade, obstruct, or repeatedly interrupt the radio service, causing interference that impedes the flow of messages in the CV environment.[11]

4. **A shared communication protocol.** This protocol provides a "common language" for exchanging information. In this context, the communication protocol defines the performance requirements that vehicle on-board and roadside units should meet to ensure messages can be reliably and quickly sent and received. Currently, two communication protocols are available for CV technologies:

    a. Dedicated Short Range Communications (DSRC), the original protocol for CV communications, operates using a

[9] In combination, this data forms the Basic Safety Message.

[10] For many CV use cases, a communications link may be needed for sending messages between equipped devices and a network such as at a local traffic management center. For example, if a state or local transportation agency operates a traffic signal that gives priority to transit buses, a backhaul network could be used to send data from the traffic signal to the local traffic management center (such as the numbers of equipped buses per day that have requested a longer green light from the signal). The transportation agency could use such collected data to, for example, make changes to improve performance such as the percentage of buses operating on schedule.

[11] For example, CV safety messages may not be immediately exchanged among connected vehicles, infrastructure, and other devices if harmful interference, such as from transmissions in adjacent spectrum bands, could cause the vehicle messages to be obstructed and not received in time to prevent an impending crash.

standard related to the family of standards that supports Wi Fi communications.[12] DSRC is designed to enable the transmission of messages over a short range of about 300 to 500 meters (about 1,000 to 1,600 feet).

b. Cellular-Vehicle to Everything (C-V2X), a more recent protocol that emerged in 2017.[13] C-V2X is based on the mobile broadband standard that supports the operation of cellular networks. Similar to DSRC, C-V2X can facilitate the direct exchange of messages between equipped devices. In 2020, FCC changed the communication protocol from the DSRC protocol to C-V2X.[14] CV safety messages exchanged using either protocol require the use of radio spectrum. These two protocols are not interoperable, so any CV environment would need to use one or the other.[15] For details about the DSRC and C-V2X protocols, see appendix III.

According to DOT, optimal system-wide safety and efficiency benefits from CV technologies would be realized by equipping at least 80 percent of traffic signals and 90 percent of passenger vehicles with devices for sending and receiving CV safety messages. However, transportation agencies have reported benefits from partial deployments of CV technologies, such as in pilot projects where only some of the cars on the local roadways were equipped to receive safety messages but drivers in non-equipped vehicles also benefitted, such as from improved information about the road conditions.

[12] Wi Fi communications adhere to the Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards.

[13] The C-V2X protocol is an umbrella term for cellular-based radio communication protocols at different stages of development and device availability. 4G Cellular Long-Term Evolution V2X is the only C-V2X protocol with devices available on the market. C-V2X protocols in development or envisioned for the future include 5G New Radio V2X and V2X-Vehicle-to-Network (V2N).

[14] FCC stated that C-V2X could potentially allow ITS to achieve more rapid development, deployment, and greater pace of advancement.

[15] For example, a CV message sent by a DSRC-equipped vehicle’s on-board unit would be readable for other DSRC units but not be readable for units that use the C-V2X protocol.

Key Federal Roles and Actions Related to the 5.9 GHz Spectrum

FCC. FCC is the federal agency responsible for regulating, allocating, and assigning spectrum for nonfederal use. In 1999, FCC allocated 75 MHz of spectrum in the 5.9 GHz band for DSRC-based technologies, which were the original CV technologies.[16] As spectrum is finite, FCC regularly assesses the demand for this resource and undertakes formal proceedings in cases where it determines that changes are needed.[17] In making changes, FCC seeks to ensure that its decisions are in the public interest and that the allocation of spectrum for some uses does not result in interference for other uses.

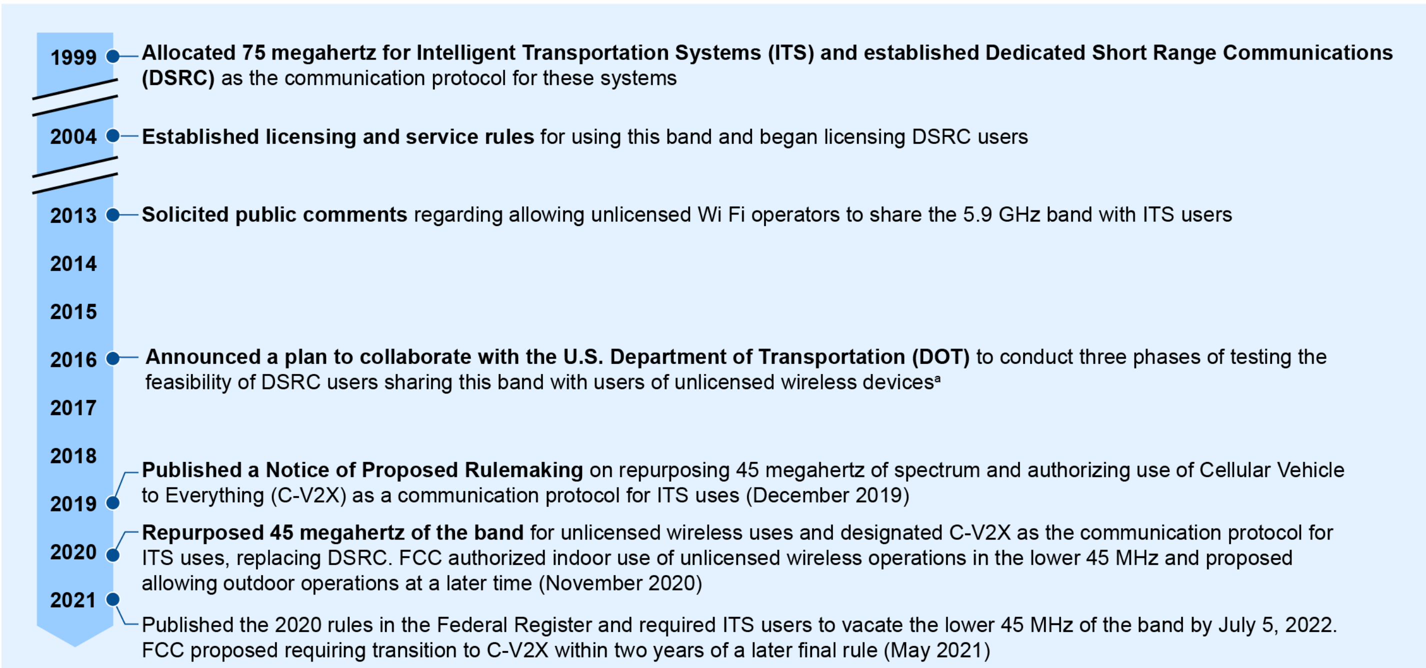
In 2020, FCC repurposed 45 MHz of the 5.9 GHz band for unlicensed uses, such as for Wi Fi and other wireless communications applications, and retained 30 MHz for CV use.[18] See figure 2 for this along with other actions FCC has taken affecting the 5.9 GHz spectrum band since 1999.

[16] The Transportation Equity Act for the 21st Century required FCC to complete "a rulemaking considering the allocation of spectrum for intelligent transportation systems" by January 1, 2000. Pub. L. No. 105-178, § 5206(f), 112 Stat. 107, 457 (1998).

[17] FCC often starts a "rulemaking proceeding" by notifying the public that it is considering adopting or modifying rules on a particular subject and to seek comments that it considers in developing final rules. FCC publishes a Notice of Proposed Rulemaking, which communicates actions that FCC is proposing as part of the proceeding, in the publicly available proceeding record and invites the public to submit comments, studies, and any other supporting documents into that record. See GAO, *Spectrum Management: Agencies Should Strengthen Collaborative Mechanisms and Processes to Address Potential Interference,* GAO-21-474 (Washington. D.C. June 2021).

[18] In its November 2020 order, FCC repurposed the lower 45 MHz of the 5.9 GHz band to allow Unlicensed National Information Infrastructure (U-NII) devices to use this spectrum. According to FCC, U-NII devices provide short-range, high-speed unlicensed wireless connections in the 5 GHz band for, among other applications, Wi-Fi-enabled radio local networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless internet providers. FCC refers to the banded segments available for U-NII devices in the 5 GHz spectrum using numbers; these include 5.15-5.25 GHz (called the U-NII-1 band), 5.725-5.85 GHz (the U-NII-3 band), and 5.85-5.895 (the U-NII-4 band).

Figure 2: Key Federal Communications Commission (FCC) Actions Related to the 5.9 GHz Spectrum Band



Source: GAO analysis of Federal Communications Commission information. | GAO-23-105069

[a] Although FCC announced a plan to conduct three phases of testing, including researching ways to address interference issues, only one phase of the planned joint testing was completed.

DOT. As the lead department overseeing roadway safety, DOT has statutory responsibility for researching, developing, and advancing deployment of Intelligent Transportation Systems and assessing new technologies for traffic safety.[19] DOT has several offices responsible for managing research and developing supporting standards and protocols for the widespread use of Intelligent Transportation Systems, of which CV technologies are a key part. Several DOT offices have roles related to deploying CV technologies:

- **Intelligent Transportation Systems Joint Program Office.** The office is responsible for advancing research and other efforts related to advanced technology throughout DOT. This office has issued

[19] Other federal agencies have roles that intersect with CV technologies and the spectrum on which these technologies are designed to operate, including the National Transportation Safety Board, which investigates significant highway and other accidents, and the National Telecommunications and Information Administration (NTIA), which manages spectrum allocated for federal uses.

strategic plans for deploying Intelligent Transportation Systems, including plans for CV technologies, for two decades.

- **Federal Highway Administration (FHWA).** FHWA is responsible for improving mobility and increasing the safety of the country's highways through funding, research, and guidance. FHWA provides guidance on transportation planning, roadway design, operations, and other areas to support state and local transportation agencies.
- **National Highway Traffic Safety Administration (NHTSA).** NHTSA is responsible for regulating the safety of motor vehicles, including developing and enforcing Federal Motor Vehicle Safety Standards, which are minimum safety requirements.[20] Automakers and manufacturers of motor vehicle equipment self-certify their conformance with these safety standards.

Since 1999, DOT and multiple transportation industry stakeholders have been involved in efforts to deploy CV technologies in the 5.9 GHz spectrum band:

- Industry associations such as the Alliance for Automotive Innovation and the American Association of State Highway and Transportation Officials, and standards bodies such as the Society of Automotive Engineers have helped to develop operational standards and communication protocols for CV technologies.
- State and local transportation agencies (transportation agencies) have invested in and managed CV pilot and operational projects.
- Automakers and automotive parts suppliers have collaborated with DOT on research and development of CV applications.

DOT's CV efforts are part of its broader efforts to increase roadway safety by advancing vehicle automation. According to DOT, automated vehicle technologies could greatly increase roadway safety, but will take decades to deploy at the national scale.[21] We reported in 2017 that DOT had begun to take efforts, but that the wide scale adoption of automated vehicles would require addressing key challenges such as the need for significant roadway improvements, which would likely require investments by state and local governments. We also reported that DOT had begun to

[20] NHTSA also enforces other related requirements, including a requirement for automakers and manufacturers to recall and remedy any safety-related defects or non-compliance with the Federal Motor Vehicle Safety Standards.

[21] According to DOT, automated vehicle technologies have the potential to help mitigate many crashes tied to human error. Automated vehicle technologies range from cars that assist drivers with some driving tasks to fully self-driving cars.

study potential synergies between CV and automated vehicle technologies, and had determined that CV technologies could enhance capabilities of automated vehicles. For example, many current passenger vehicles have some systems designed to help with crash prevention, such as sensors and cameras. According to DOT officials, CV technologies could work in concert with the automated vehicles' systems to provide these vehicles with situational awareness beyond the cameras' and sensors' line of sight.[22]

DOT opposed FCC's 2020 decision to repurpose a portion (45 of 75 MHz) of the 5.9 GHz spectrum band because of the anticipated effect on CV technologies. In its comments to the FCC's 2019 Notice of Proposed Rulemaking, DOT stated that the reallocation of spectrum would slow the pace of CV deployment, asserting that the remaining 30 MHz would not provide sufficient spectrum for achieving the technologies' full range of potential safety and other benefits.[23] DOT has also expressed concerns that C-V2X, which FCC ultimately established as the new communication protocol for CV technologies, is nascent technology that had not been adequately tested. Further, DOT stated that the operation of Wi Fi devices in the repurposed 45 MHz of spectrum could lead to CV technologies becoming unusable in the adjacent 30 MHz of spectrum because of interference.[24]

In June 2021, a lawsuit was filed by transportation industry and advocacy associations in federal court to challenge FCC's repurposing of the 5.9 GHz spectrum band.[25] Their arguments included alleging that FCC exceeded its authority and failed to properly consider transportation safety when making its decision. They claimed that FCC did not adequately work with DOT or address concerns about the feasibility of

[22] See GAO, *Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges*, GAO-18-132. (Washington, D.C., Nov 2017) See also appendix II for more details on DOT's efforts to promote the connected and automated vehicle systems to improve roadway safety overall.

[23] "*Comments of the U.S. Department of Transportation." In the Matter of Use of the 5.850-5.925 Band*, ET Docket No. 19-138. March 9, 2020.

[24] Generally, unlicensed wireless devices transmit signals that adhere to the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard, and are called Wi Fi devices. In this report, we refer to these as Wi Fi devices, and we refer to the device users as Wi Fi operators.

[25] *Intelligent Transportation Society of America v. FCC*, No. 21-1130 (D.C. Cir. filed June 2, 2021).

continued CV technology's operation in the remaining spectrum. They cited letters DOT sent to FCC asserting that FCC's proposed actions would eliminate safety benefits, undermine transportation safety innovation, and likely subject CV technologies to harmful interference. In response, FCC argued that it acted within its authority to manage spectrum use, that the Commission considered and met the needs of transportation safety, and that the administrative record supports its conclusions that the remaining spectrum is sufficient to accommodate reasonably anticipated CV safety features. In August 2022, the court found that the FCC acted within its statutory authority and adequately explained its conclusions and dismissed the lawsuit.[26]

FCC Efforts to Increase Spectrum for Unlicensed Wireless Uses and Related Decisions

FCC has reported that the agency expects societal benefits from allowing more spectrum access for devices that use Wi Fi and other unlicensed standards.[27] According to FCC, such societal benefits include providing greater access to low-cost wireless connectivity to help bridge the digital divide that encompasses disparities in access to education, healthcare, employment, and other services important to peoples' lives. Further, according to FCC, the expected economic benefits of allowing unlicensed

[26] *Intelligent Transportation Society of America v. FCC*, No. 21-1130 (D.C. Cir. Aug. 12, 2022). The court's decision was subject to appeal until November 10, 2022.

[27] For example, see *Unlicensed Use of the 6 GHz Band, Expanding Flexible Use in Mid-band Spectrum Between 3.7 and 24 GHz, Report and Order and Further Notice of Proposed Rulemaking,* 35 FCC Rcd. 3852 (2020).

Wi Fi users to access the lower 45 MHz of the 5.9 GHz spectrum band outweighed the costs of moving incumbent CV users from it.[28]

In recent years, FCC has taken several actions to make more spectrum available for unlicensed wireless uses in consideration of these societal and economic benefits. For example, according to agency officials, between March 2020 and July 2021, FCC granted special temporary authority to 155 wireless internet service providers, allowing them to use the lower 45 MHz of the 5.9 GHz band to help alleviate the channel congestion that occurred with the increase in households' use of Wi Fi as a result of the COVID-19 pandemic. In another example, in April 2020, FCC permitted unlicensed wireless users to access up to 1,200 MHz of spectrum in the 6 GHz band.[29]

In describing its November 2020 decision to repurpose spectrum in the 5.9 GHz band, FCC stated that the real-world use of DSRC-based CV technologies had been limited, while the spectrum needs for unlicensed wireless technologies have increased dramatically.[30] FCC also stated that

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[28] In its first report and order, FCC noted that the benefits expected from repurposing this spectrum would be about $6 billion for each of the years 2023 through 2025, for a total of about $17.2 billion in benefits in that timeframe. See *Use of the 5.850-5.925 GHz Band, First Report and Order, Further Notice of Proposed Rulemaking, and Order of Proposed Modification*, 35 FCC Rcd. 13440, 13490, ¶ 125 (2020). However, in comments to FCC, DOT officials raised concerns that FCC did not adequately consider the benefits stemming from the future implementation of CV technologies. According to DOT, such future benefits are likely to reach over $800 billion with the reduction of costs associated with public safety and first responder response to crashes as well as insurance and medical costs associated with fatalities, severe injuries, and property damage. See *Comments of the U.S. Department of Transportation, "In the Matter of Use of the 5.850-5.925 Band, ET Docket No. 19-138," March 9, 2020, pdf p. 4.* See also *Comments of the U.S. Department of Transportation, "In the Matter of Use of the 5.850-5.925 GHz Band,* ET Docket No. 19-138," November 6, 2020. In its report and order, FCC rejected some of DOT's estimated costs for the economic harms resulting from police-reported vehicle crashes in the U.S. that are not specifically tied to changes to the dedicated spectrum. See 35 FCC Rcd. at 13496 ¶ 138. As noted above, this GAO report primarily focuses on DOT's efforts to facilitate the further deployment of CV technologies and address associated challenges. We did not assess the economic analyses presented by either FCC or DOT.

[29] The 6 GHz band consists of spectrum from 5.925 GHz through 7.125 GHz, divided into four sub-bands. According to FCC, the largest groups of incumbent licensed users that operated in the band prior to the 2020 change included utilities, commercial and private entities, and public safety agencies. *See* 35 FCC Rcd. at 3853, 3855.

[30] In response to this FCC statement, DOT officials have stated that a significant reason for the limited deployment of CV was FCC's 2013 action, when it solicited public comments about opening the 5.9 GHz band to sharing between CV users and Wi Fi users, and thus introduced uncertainty regarding the continued availability of spectrum.

it found that 30 MHz would be sufficient for widespread deployment of core vehicle safety-related ITS functions. Further, in describing its decision to change the protocol for use in this band from DSRC to C-V2X, FCC stated that communications applications are increasingly based on cellular technologies, and the development of C-V2X reflects industry efforts to integrate these technologies into CV applications. FCC explained that changing the communications protocol to C-V2X, which is based on cellular technology, could potentially allow CV technology to achieve more rapid development, deployment, and greater pace of advancement compared to DSRC.[31]

DOT's Efforts Have Helped Facilitate the Deployment of Connected Vehicle Technologies in Discrete Locations across States

DOT and Industry Efforts Advanced CV Technologies that Use DSRC from Concept to Being Ready for Operational Use

DOT's plans helped to guide research, testing, and transportation stakeholders' deployment of CV technologies over the last two decades. As of March 2020, DOT estimated that the nation's investments into CV-related collective efforts totaled more than $2.7 billion, which included direct federal investments of about $804 million into research and testing of CV systems, and another $23 million into researching cooperative automated driving systems.[32] Since 2000, DOT has periodically issued strategic plans that outline the Department's vision and related efforts for promoting ITS technologies, including CV technologies and automated vehicle systems. To implement these plans, DOT's ITS Joint Program Office uses a five-phase technology transfer framework that tracks the status of ITS technologies, where Phase 5 means technologies have

[31] FCC stated that adopting C-V2X as the communication protocol could leverage cellular networks to reduce infrastructure costs. FCC concluded that phasing out existing DSRC technology, rather than allowing two different communication protocols to use the band, is important for the sake of efficient use of the 30 MHz of spectrum. In addition, FCC stated that this change would help deliver benefits to the American public. See 35 FCC Rcd. at 13479–83.

[32] "*Comments of the U.S. Department of Transportation." In the Matter of Use of the 5.850-5.925 Band*, ET Docket No. 19-138 (submitted to FCC by NTIA on Mar. 13, 2020).

been deployed nationwide (see table 1). In September 2015, we reported that DOT and stakeholders had advanced CV technologies that use the DSRC communication protocol to the testing phase (Phase 3); and that DOT had a roadmap for implementing CV technologies nationwide by 2040.[33] According to agency officials, DOT and stakeholders were completing Phase 5 activities by November 2020 when the FCC announced the spectrum changes.

Table 1: Department of Transportation's (DOT) Technology Transfer Phases and Categories of Efforts

Lifecycle Phases	Description of Phase	Categories of Efforts in Phase for Connected Vehicle (CV) Technologies
Phase 1	Identify and assess potential or emerging technologies	Assessment, research, and development of CV technologies
Phase 2	Coordinate and lead research and development efforts	Assessment, research, and development of CV technologies
Phase 3	Demonstrate the value of emerging technologies through testing in controlled and real-world environments.	Testing of CV technologies
Phase 4	Support the implementation of proven technologies by communicating the benefits to the public and providing assistance to stakeholders deploying those technologies.	Support implementation and nationwide deployment of CV technologies
Phase 5	Maintain proven technologies over time by scaling adoption to realize the full potential benefits.	

Source: GAO analysis of DOT documents. | GAO 23-105069

The following summarizes the actions taken by DOT and transportation industry stakeholders to transition CV technologies that use the DSRC protocol through the five phases of DOT's technology transfer framework.

Phase 1 and Phase 2: Assessment, Research, and Development

In these phases, DOT and transportation industry stakeholders conducted research and developed the basic requirements for CV technologies that use the DSRC protocol to function effectively. DOT and stakeholders began by assessing available wireless technologies and determined that DSRC could enable fast, reliable transmission of safety messages between vehicles traveling at highway speeds. From 1999 through 2003, DOT funded research efforts related to CV messaging standards,

[33] See GAO-15-775.

licensing, technical processes and other policy and technical issues.[34] These efforts built upon existing operational standards and resulted in detailed proposals from the transportation industry that informed FCC's decisions about rules for using the 5.9 GHz band.[35] In 2003, FCC largely adopted those proposals.[36]

Phase 3: Testing

After reaching agreement with other spectrum users concerning the use of the 5.9 GHz band in 2008, DOT partnered with research institutions and transportation industry stakeholders to research and test CV technologies that use the DSRC protocol, including:

- **Driving clinics.** From 2011 to 2012, DOT and the Crash Avoidance Metrics Partners (a group of researchers from several automakers) conducted driver clinics at six sites to assess drivers' interest in and likely acceptance of CV technologies. At each clinic, about 100 drivers tested equipped vehicles in a controlled environment. After the tests, about 90 percent of participating drivers indicated that they would be willing to equip their personal vehicles with CV technologies.[37]
- **Connected Vehicle Safety Pilot.** From 2012 through 2014, DOT funded a real-world deployment of CV technologies in Ann Arbor, Michigan. This deployment involved 2,800 cars, trucks, and transit vehicles and 24 roadside units. According to DOT and stakeholders, equipped vehicles exchanged secure communications during the deployment and the tested CV safety applications effectively mitigated or prevented potential crashes.

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[34] In 1999, FCC deferred making decisions about how ITS users should be licensed, and about how to address related issues, in order to give DOT and industry stakeholders time to conduct research and develop standards in those areas.

[35] See more information about CV messaging standards and related technical requirements in appendix III.

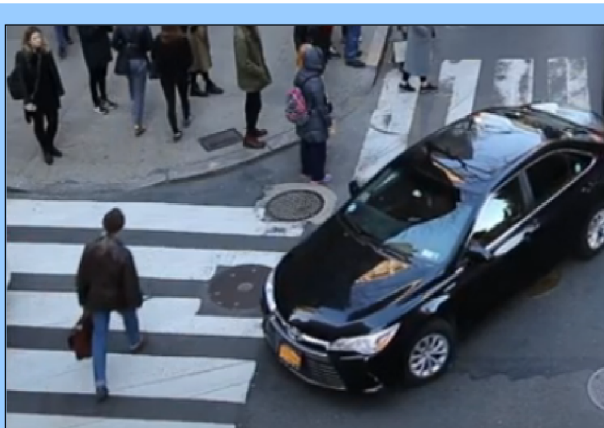
[36] Although this was a major step forward, according to transportation stakeholders, they were not able to use CV technologies in the 5.9 GHz band until they negotiated agreements with the incumbent (continuing) users of this band. In 2008, representatives of the transportation industry reached an agreement with the Satellite Industry Association, and submitted the agreement to FCC.

[37] Harding, J., Powell, G., R., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., Lukuc, M., Simons, J., & Wang, J. (2014, August). *Vehicle-to-vehicle communications: Readiness of V2V technology for application*. (Report No. DOT HS 812 014). Washington, DC: National Highway Traffic Safety Administration, p. 161.

- **Connected Vehicle Pilot Deployment:** Starting in 2015, DOT expanded on its previous testing by funding several projects to deploy CV technologies in disparate settings involving different use cases. The three goals of this pilot program were to: (1) spur innovation among early adopters of CV technologies; (2) demonstrate the potential safety, mobility, and environmental benefits of CV technologies; and (3) create sustainable momentum for the nationwide deployment of CV technologies. From 2015 through 2021, DOT provided over $45 million in funding for pilot programs in Wyoming, New York, and Florida.
    - The Wyoming Department of Transportation used CV technologies to generate alerts about adverse weather conditions to improve the safe and efficient movement of heavy trucks on a commercial corridor that crosses the state (see fig. 3).
    - The New York City Department of Transportation tested CV technologies in a dense urban environment in an attempt to reduce the number and severity of crashes, particularly those involving pedestrians (see fig. 3).
    - The Tampa Hillsborough Expressway Authority (Florida) tested multiple mobility and safety applications that aimed to improve roadway safety, reduce rush-hour congestion, improve safety for pedestrians at intersections, and keep public transit buses on schedule.

According to agency officials, DOT is funding evaluations of these pilot projects to measure the impacts and benefits of these real-world deployments, which might include reducing collisions, improving mobility, or reducing greenhouse gas emissions. DOT plans to publish detailed evaluation reports by 2023, according to officials.

Figure 3: Examples of Connected Vehicle Pilot Tests and Projected Benefits



New York City (NYC) Department of Transportation

In Manhattan, 73 percent of all vehicle crash fatalities involve pedestrians, compared to 14 percent of total nationwide fatalities. The NYC Connected Vehicle (CV) Pilot included 14 CV applications that sought to improve safety in selected locations in NYC, including several applications related to speed compliance and pedestrian safety. For example, one application alerted drivers about pedestrians crossing at signalized intersections so that drivers could avoid pedestrian collisions.

Wyoming Department of Transportation (WYDOT)

In Wyoming, Interstate 80 (I-80) supports the transit of about 32 million tons of freight annually. However, local winter weather conditions can lead to road closures and vehicle crashes, such as a 2015 pileup of over 65 vehicles. WYDOT used its CV Pilot project to improve the transmission of safety information in places with wintry and hazardous conditions. For example, equipped infrastructure gathered real-time data about road conditions, which WYDOT then transmitted to drivers using a variety of communication methods, such as dynamic information boards on roadways, and updates on WYDOT's smart phone app and website. By alerting drivers about potential hazards, WYDOT aims to reduce the number and severity of vehicle crashes and to improve the reliability of freight transportation on I-80.

Sources: NYC Department of Transportation (left) and WYDOT (right). | GAO-23-105069

Phases 4 & 5: Support Implementation and Nationwide Deployment

In these phases, DOT took several actions to support the transportation industry's deployment of CV technologies that use the DSRC protocol, and to scale the adoption of those technologies nationwide. These actions included DOT (1) proposing rules to require the use of DSRC or interoperable communications, (2) incentivizing adoption through grant programs for transportation agencies, and (3) providing guidance and technical assistance to such operators and other industry stakeholders deploying CV technologies.

NHTSA proposed rules to require CV technologies. After analyzing data gathered during the abovementioned Connected Vehicle Safety

Pilot, NHTSA estimated that CV technologies using the DSRC protocol could have the potential to prevent approximately a half million crashes and save more than 1,000 lives each year if fully deployed.[38] Informed by these results and from other CV testing, in 2014 NHTSA issued an advance notice of a proposed rulemaking that would require new light vehicles to be equipped to send vehicle-to-vehicle messages.[39] In 2017, NHTSA published the proposed standard, which would have required all light vehicles to have DSRC or another protocol interoperable with DSRC to enable vehicle-to-vehicle communications. However, the final standard has not been issued.[40]

DOT sought to incentivize CV adoption through grants. Although the Connected Vehicle pilot program has been DOT's main CV-related program, the agency has also supported other CV-related projects using funding from grant programs with broader goals, including the following:

- *Smart City Challenge:* DOT provided $40 million to the City of Columbus, OH, from 2016 through 2021. One component of the project was a 6-month CV demonstration that involved 85 equipped intersections and over 1,000 equipped vehicles. Benefits observed during this demonstration in October 2020 through March 2021 included faster response times for emergency vehicles and improved safety in school zones. During the demonstration, the proportion of drivers who complied with speed limits in school zones increased from 18 percent to 56 percent.
- *Advanced Transportation and Congestion Management Technologies Deployment grants:* these grants have been used by state and local transportation agencies to support CV projects. For example, officials at the Georgia Department of Transportation told us they are combining two DOT grants with other funds to deploy CV and other technologies across the state over the next 10 years. Their plan involves: (1) deploying CV equipment along interstate routes; (2) deploying CV equipment at all signalized intersections on state roadways; (3) equipping public transit vehicles with CV equipment to

[38] In NHTSA's definition, the full deployment of CV technologies based on the DSRC protocol would occur once 80 percent of traffic signals nationwide and 90 percent of passenger vehicles are equipped for exchanging messages.

[39] According to NHTSA, light vehicles include vans, sport utility vehicles, crossover utility vehicles and light pickup trucks with a gross vehicle weight rating (GVWR) less than or equal to 10,000 pounds.

[40] In its January 2022 report on significant rulemakings, DOT reported that this rulemaking's current stage and next steps are undetermined.

facilitate transit signal priority throughout the region; and (4) equipping the department's highway emergency response vehicles with CV technologies.

DOT issued guidance for stakeholders deploying CV technologies. To support the continued deployment of CV technologies, DOT houses a wide range of resources on its website that transportation agencies can reference when they prepare to launch CV deployments. For example:

- FHWA issued vehicle-to-infrastructure deployment guidance in 2017, which, according to officials, was designed to assist transportation agencies in planning for and deploying CV technologies.[41] For example, the guidance includes information about FCC's rules, licensing requirements, and considerations for deployment planning.
- DOT's website has a number of resources related to past CV pilots and other resources for transportation agencies deploying CV projects. These include reports about lessons learned during the pilots and guidance that DOT developed on a wide range of topics, such as on DOT grant funds available.

According to DOT officials, because FCC recently changed the allowed communication protocol from DSRC to C-V2X in the 5.9 GHz band and reduced the spectrum for CV uses, DOT and transportation stakeholders must repeat much of the research and testing that they previously completed for DSRC. As noted above, DOT and industry stakeholders were conducting Phase 5 research for the DSRC protocol in November 2020. As of September 1, 2022, DOT and industry stakeholders were conducting Phase 2 research for the C-V2X protocol, according to agency officials.[42]

Some Transportation Agencies Have Deployed CV Technologies on Roadside Infrastructure, but Few

[41] U.S. Department of Transportation. *Recommended Practices for DSRC Licensing and Spectrum Management: A Guide for Management, Regulation, Deployment, and Administration for a Connected Vehicle Environment*. FHWA-JPO-16-267. 2015.

[42] According to DOT officials, the phase 2 research for C-V2X focuses on the performance and sensitivity to interference of the devices' radios to understand their basic ability to support safety-of-life CV applications. Subsequent testing of C-V2X devices will focus on assessing the performance of applications using the protocol. Officials stated that the application testing will be particularly important since C-V2X technology does not operate in a manner similar to DSRC and may perform differently with the applications.

Automakers have Produced Vehicles Equipped with This Technology

Roadside Infrastructure

Most investment in CV technologies in the U.S. has been in infrastructure, such as traffic signals, rather than in vehicles. A number of transportation agencies used DOT funds to support their deployments. According to DOT, as of May 2022, transportation agencies in 38 states held active FCC licenses to use CV technologies using the DSRC protocol in the 5.9 GHz band.[43] Transportation agencies that have implemented these CV projects aim to achieve a range of safety, mobility, economic, and environmental benefits from their deployments. See sidebars for examples of how one state transportation agency and one local transportation agency used CV technologies to improve, respectively, the reliability of public transit operations in the state and the response times of emergency vehicles in the local community.

Example of Expected Mobility Benefits:
Increased Public Transit Reliability

Source: deberarr/stock.adobe.com. | GAO-23-105069

Utah Department of Transportation

The Utah Transit Authority is using connected vehicle (CV) technologies to keep its public transit vehicles on schedule. Equipped buses send messages to traffic signals to request a longer green light if they are behind schedule. The use of these transit signal priority applications has improved the schedule reliability of buses from 88 percent to 94

[43] According to agency officials, updated deployment information is available at DOT's Interactive Connected Vehicle Deployment Map on its website, https://www.transportation.gov/research-and-technology/interactive-connected-vehicle-deployment-map. [accessed September 6, 2022]

percent. Reducing the time that buses are delayed at traffic signals also saves fuel and reduces greenhouse gas emissions.

Source: Utah Smart Transit Signal Priority Website | GAO-23-105069

According to representatives of two transportation agencies in our review, by installing roadside equipment, improved safety and other benefits are possible from CV technologies even if few vehicles on these roads are equipped for CV communications. Since the average domestic vehicle's lifespan is estimated at around 12 years, it will take years for new equipped vehicles to replace older non-equipped vehicles.[44] Transportation agency representatives involved in several pilot projects demonstrated that it is possible to use a relatively small number of equipped vehicles combined with equipped infrastructure to provide benefits to all the drivers in the targeted areas.

For example, one transportation agency gathered information from a fleet of equipped vehicles about roadway conditions (including indicators of unsafe weather conditions such as ice patches) and used this information to improve the accuracy and timeliness of information on the local dynamic message boards. This enabled all drivers in the targeted areas to receive earlier alerts about hazards on the road ahead. As representatives from this agency told us, the better information drivers receive, the more likely they will be to avoid potential collisions.

Equipped Vehicles

The deployment of vehicles equipped with CV technologies has been more limited than deployment of roadway infrastructure. Currently, the number of DSRC-equipped vehicles on U.S. roadways is much smaller than in Europe and East Asia. In the U.S., General Motors is the only automaker that has moved beyond testing to produce equipped vehicles. After NHTSA issued its advance notice of proposed rulemaking in 2014, the automaker announced it would produce the first equipped vehicles on the market.[45] From 2017 through 2019, General Motors manufactured about 25,000 equipped Cadillac vehicles according to company representatives. However, according to these representatives, the company has since paused manufacturing equipped vehicles because of the overall uncertainty around use of the spectrum. In addition, company

[44] See Congressional Research Service *Motor Vehicle Safety: Issues for Congress*, June 8, 2020. In this report, CRS states that the average age of light vehicles on the road in 2019 was 11.8 years, according to the Bureau of Transportation Statistics, *Average Age of Automobiles and Trucks in Operation in the United States.* This bureau is part of the U.S. DOT.

[45] GM. *“Cadillac to Introduce Advanced ‘Intelligent and Connected’ Vehicle Technologies on Select 2017 Models.”* GM press release, September 7, 2014.

representatives expressed specific concerns that the remaining 30 MHz may not provide sufficient protection from interference for CV technologies to function effectively.[46]

Example of Expected Mobility Benefits: *Improved Emergency Vehicle Response Time*

Source: bluraz/stock.adobe.com. | GAO-23-105069

Maricopa County Department of Transportation

In Arizona, collisions involving emergency response vehicles occur every 4 days, most frequently with another vehicle at an intersection. To address this issue, the Department designed, developed, and deployed connected vehicle applications that, among other things, give priority to emergency vehicles at equipped traffic signals. The use of these applications has reduced crashes involving emergency vehicles and decreased the average response times of first responders in target areas.

Source: Comments of the Maricopa County Department of Transportation, In the Matter of Use of the 5.850-5.925 Band, ET Docket No. 19-138, March 5, 2020 | GAO-23-105069

Other automakers have also suspended plans to deploy equipped vehicles in the U.S., citing concerns about uncertainty regarding the future availability of spectrum. For example, in 2019, Toyota announced that it had paused its deployment plans because company leaders were concerned about potential interference from unlicensed Wi Fi operators and a possible reduction in the spectrum available for DSRC according to company representatives.[47] In 2020, the Alliance for Automotive Innovation, an association that represents major automakers, committed in an open letter to deploying 5 million capable radios by 2025 if FCC preserved the full 75 MHz in the 5.9 GHz band. The automakers represented by the alliance include Ford, General Motors, Honda, Hyundai, Toyota, Volkswagen, and Volvo.[48] However, according to Toyota representatives, after FCC's 2020 decision reduced the allocated spectrum, automakers have remained skeptical about investing in CV deployments.

[46] "*Comments of General Motors LLC." In the Matter of Use of the 5.850-5.925 Band*, ET Docket No. 19-138. March 9, 2020.

[47] *Letter from Hilary Cain, Director of Technology and Innovation Policy at Toyota*, to Marlene Dortch, FCC Secretary, April 26, 2019.

[48] Although most of these automakers have pursued efforts to research CV technologies using the DSRC protocol, some (including Ford and BMW) have also been involved in research with C-V2X protocol. In this 2020 letter to the FCC, theses automakers also argued that the industry would determine which technology (DSRC or C-V2X) should be further deployed in the band.

Deployment of Connected Vehicle Technologies in Europe

Source: GAO. | GAO-23-105069

In Europe, Dedicated Short Range Communications technology was deployed in 1990 after research began in the late 1980s. In 1992, the European Radio Communications Committee designated spectrum to support systems that facilitate communication between vehicles and infrastructure.

Volkswagen's 2019 decision to equip the Golf, a very popular vehicle in the European market, helped accelerate the pace of deployment. Volkswagen representatives estimated that the company had produced about 500,000 Golf vehicles per year starting with model year 2019, for a total of over 2 million equipped vehicles in the European Union by 2022. In addition, according to European Union documents, there are about 2,300 deployed roadside units, covering 20,000 kilometers of roadways.

Source: GAO analysis of Volkswagen and European Union information | GAO-23-105069

According to some transportation stakeholders, DOT started its CV efforts at a similar time as other countries, some of which have moved ahead of the U.S. in widely deploying CV technologies. For example, the European Union began conducting research and development efforts, including developing operational standards for CV-equipped vehicles and roadside infrastructure in the mid-1990s. For more information about international efforts to implement CV technologies, see appendix III. In addition, see sidebars for information about efforts in the European Union and in Japan to deploy CV technologies.

DOT is Assessing Spectrum Availability and Other Challenges, but Clearer Communication about the Department's Strategy for Further Deploying Connected Vehicles Technologies Could Help Stakeholders Adapt

Stakeholders Identified Reduced Spectrum, Potential Interference, and the Changed Communication Protocol as Key Challenges

As noted previously, in November 2020, FCC repurposed 60 percent of the spectrum previously reserved for CV uses and changed the communication protocol authorized for use in the remaining spectrum from DSRC to C-V2X. DOT officials and transportation stakeholders that we spoke with identified reduced spectrum, potential interference, and the changed communication protocol as key challenges. In addition, most transportation stakeholders told us that federal actions have compounded their uncertainty about the regulatory environment for connected vehicles.

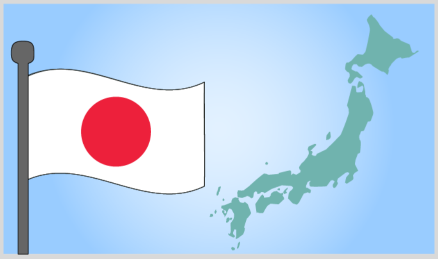
Reduced Available Spectrum

DOT and representatives of all 23 transportation stakeholders told us it will not be possible to operate all previously envisioned CV applications in the spectrum that remains following the FCC's decision to repurpose spectrum. In response, transportation stakeholders have made efforts to prioritize specific CV applications. For example, ITS America, a transportation industry association, organized meetings in 2020 and created a working group to assist with this prioritization.[49] The working group estimated the spectrum needs for various CV applications based on assumptions reflecting existing deployments and current technologies. Its initial report outlined CV applications that would likely be included and excluded from deployment in the remaining spectrum.[50] Some of the high-priority safety applications that the group identified as possible in the remaining 30 MHz include:

[49] The Intelligent Transportation Society of America (ITS America) advances the research and deployment of intelligent transportation technologies to save lives, improve mobility, promote sustainability, and increase efficiency and productivity.

[50] ITS America, *The Future of V2X: 30 MHz Application Map* (Washington, D.C.: Jan. 27, 2021), accessed September 14, 2022, https://itsa.org/wp-content/uploads/2021/01/ITS-America-30-MHz-Application-Map-1-27-21 According to ITS America, the working group will continue to do more analysis to prioritize V2X applications for deployment, in coordination with stakeholders.

Deployment of Connected Vehicle Technologies in East Asia



Source: GAO. | GAO-23-105069

In Japan, Dedicated Short Range Communications technology has been deployed since 1997. There are nearly 60,000 roadside units on local roads and expressways. As of 2021, officials estimated that about 240,000 vehicles were equipped.

Source: GAO. | GAO-23-105069

China aims to widely deploy Cellular-Vehicle to Everything (C-V2X) technologies, according to documents we reviewed. Chinese and U.S. automakers have begun to sell equipped vehicles in China. In addition, nearly 7,000 roadside units have been deployed. According to the Smart Vehicles Innovation Development Strategy published in 2020, China plans to install C-V2X devices in half of its new vehicles by 2025.

Source: GAO analysis of Information from Japanese Ministry of Land, Infrastructure, Transport and Tourism and China Industry Innovation Alliance for Intelligent and Connected Vehicles. | GAO-23-105069

- Forward collision warning (alert of approaching a stopped or decelerating vehicle).
- Approaching emergency vehicle warning (alert about an emergency vehicle nearby).
- Emergency vehicle signal preemption (giving emergency vehicles priority at traffic signals).
- Curve speed warning (alert about a sharp curve ahead with reduced speed limit).

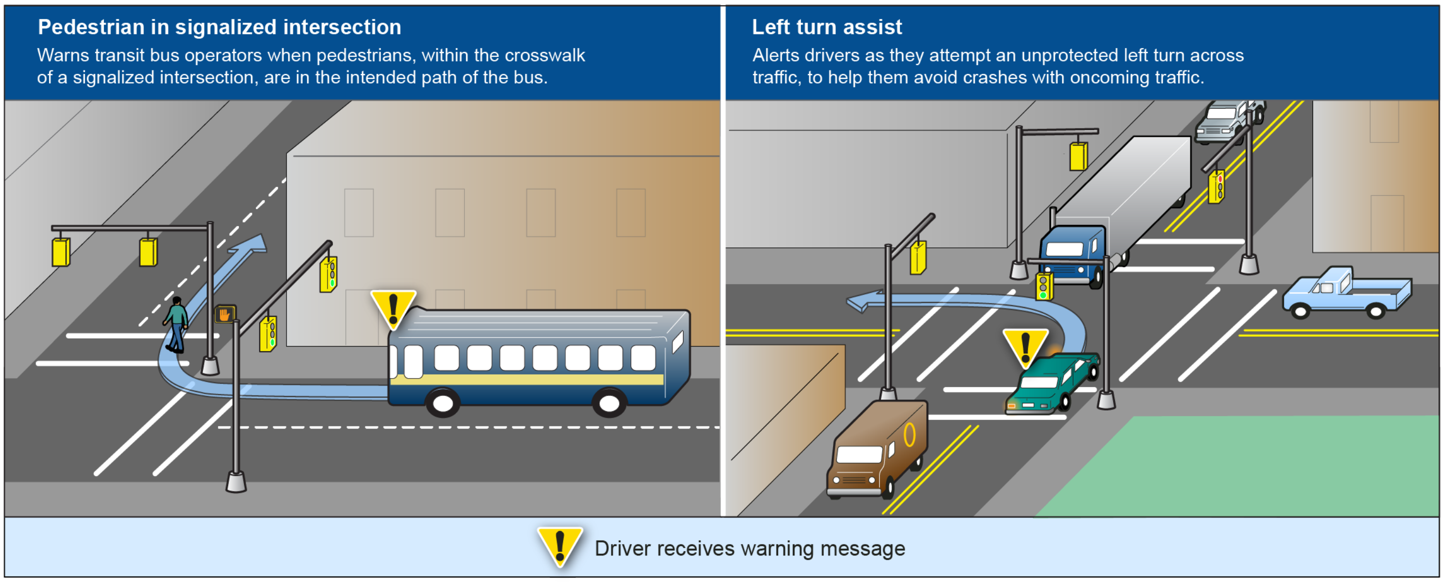
The applications likely precluded from operating in the remaining 30 MHz of dedicated 5.9 GHz spectrum according to the working group include:

- Pedestrian safety applications such as those supported by the broadcast of a personal safety message. See figure 4 for a depiction of such an application.
- Left Turn Assist, which notifies a driver attempting to make a left turn through oncoming traffic that it is unsafe to proceed because of a vehicle outside of the driver's line of sight. (See fig. 4)
- Advanced CV applications that could support safety in automated vehicles. Such applications would allow automated vehicles to, for example, communicate with and use information from nearby automated vehicles about their position, heading, and speed to safely coordinate maneuvers such as multiple vehicles changing lanes in close proximity and simultaneously.

In its November 2020 Report and Order, FCC noted that some commenters indicated that 30 MHz would be sufficient for supporting basic safety applications.[51] FCC further stated that using spectrum more efficiently could allow transportation stakeholders to provide the same level of safety to vehicles in the 30 MHz band as could be done in the original 75 MHz.

[51] See 35 FCC Rcd. at 13454–55, ¶ 33.

Figure 4: Depictions of Connected Vehicle Applications for Pedestrian Safety and Left Turn Assist



Source: GAO analysis of US Department of Transportation information. | GAO-23-105069

In addition, DOT and some (6 of 23) transportation stakeholders expressed concerns that the remaining spectrum would not be sufficient to ensure the cybersecurity of CV-equipped vehicles and infrastructure that exchange messages.[52] A related concern voiced by a couple of transportation stakeholders is that the spectrum would not be sufficient to perform remote updates needed to maintain CV software within the equipped vehicles. FCC did not specifically address cybersecurity and software update issues in its rulemaking. See appendix III for technical aspects related to, among other things, cybersecurity of CV technologies.

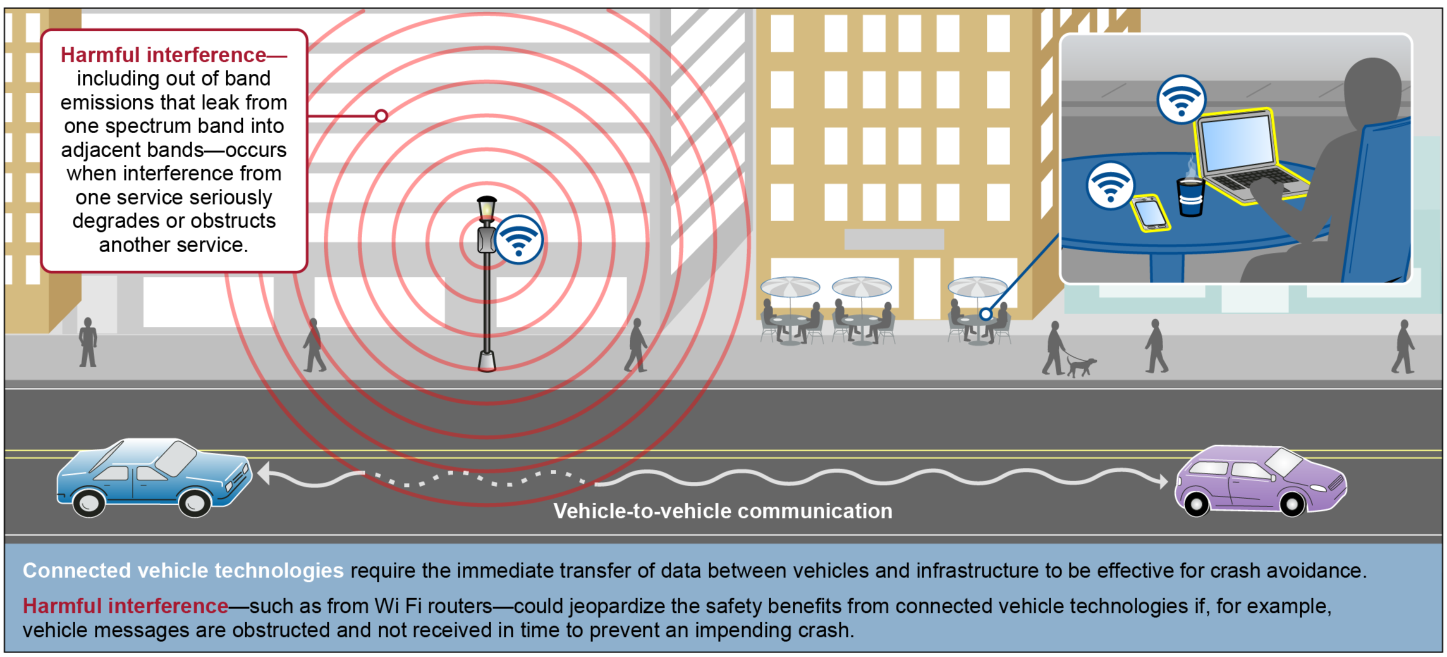
Interference Risk from Devices in Adjacent Spectrum

DOT officials and almost all (21 of 23) transportation stakeholders we spoke with expressed concern that interference from Wi Fi device emissions in the adjacent spectrum could impact the operation of safety-critical CV applications. Some (eight) of these stakeholders expressed concern in particular, about unlicensed outdoor and mobile devices, such as Wi Fi hotspots, that could eventually operate in the lower part of the

[52] For example, DOT officials told us that with the remaining 30 MHz of spectrum, there would be limited bandwidth to receive and refresh security certificates, which were designed to protect the privacy and cybersecurity of vehicles and devices exchanging CV messages.

5.9 GHz band once the FCC sets the operating parameters for these devices. Because of the potential for harmful interference caused by these devices to the operation of CV devices in the upper part of the 5.9 GHz band, most (18 of 23) transportation stakeholders suggested that FCC should require stronger limits on emissions than proposed in November 2020. Figure 5 illustrates how interference caused by “out of band emissions” could affect the operation of CV technologies and potentially lead to diminished benefits.

Figure 5: Potential Impact of Harmful Interference on Connected Vehicle Technologies



Source: GAO. | GAO-23-105069

Notes: This graphic illustrates potential future harmful interference as described to us by transportation stakeholders, which they told us depends on factors including the Federal Communications Commission’s (FCC) final rules for Wi Fi operations in the 5.9 GHz spectrum band. As of September 1, 2022, FCC had not finalized these rules.

FCC has yet to set final rules for all aspects of power limits for devices that operate in adjacent bands. In November 2020, FCC established initial rules allowing limited Wi Fi operations in the lower 45 MHz of the 5.9 GHz spectrum band, and proposed further rules allowing broader operations in the future, under proposed limits.[53] In May 2021, FCC solicited comments on these proposed limits. However, as of September 1, 2022, FCC had not yet announced final rules. In July 2022, agency officials told us that the final rulemaking remained pending while the lawsuit against FCC regarding this spectrum band was pending.[54] As noted above, in August 2022, the court dismissed the lawsuit against FCC.[55]

Change in communication protocol from DSRC to C-V2X

While a few (three) transportation stakeholders told us they believe C-V2X has advantages over DSRC in the long term, and others (nine) expressed neutrality about the communications protocol, most (16) stakeholders as well as DOT officials expressed concerns about the immediate ramifications to CV technology operability resulting from the change to C-V2X. These concerns related to several main issues:

- C-V2X is not as mature a communication protocol as DSRC;
- Future versions of C-V2X may not be compatible with currently available versions; and
- The transition to C-V2X will result in additional costs and program disruptions for transportation agencies that have already deployed DSRC-based infrastructure.

[53] In its November 2020 First Report and Order, FCC established rules allowing indoor Wi Fi operations in the lower 45 MHz of the 5.9 GHz band on the effective date of the rule, which was July 2, 2021. FCC proposed power limits for outdoor Wi Fi operations in the band as recommended by the Wi Fi Alliance, of 23 dBm/MHz or 36 dBm radiated power and out of band emission limits of -5 dBm/MHz at 5.895 GHz, decreasing linearly to -27 dBm/MHz at 5.925 GHz, measured using a root mean squared measurement. For indoor operations of Wi Fi devices that serve as access points (such as Wi Fi internet routers), FCC proposed increasing transmit power limits from a limit of 20 dBm/MHz that was established for indoor operations effective in July 2021, to 23 dBm/MHz.

[54] In the Federal Register publication of the final rule, FCC stated that CV technologies must transition out of the lower 45 MHz of the spectrum, 5.850 to 5.895 GHz, by July 5, 2022. 86 Fed. Reg. 23281, 23297 (May 3, 2021) (codified at 47 C.F.R. § 90.370). FCC sought comments on the transmitter power and emissions limits related to full-power outdoor unlicensed operations across the 5.850-5.895 GHz band in the Further Notice of Proposed Rulemaking published in the Federal Register. 86 Fed. Reg. 23,323 (May 3, 2021). FCC also sought comments on other issues, including the timeframe for CV operations in the remaining dedicated spectrum to transition to C-V2X.

[55] *Intelligent Transportation Society of America v. FCC*, No. 21-1130 (D.C. Cir. Aug. 12, 2022). The decision is subject to appeal until November 10, 2022.

According to FCC officials, the agency's November 2020 decision to change the CV communication protocol from DSRC to C-V2X was influenced by many comments from stakeholders in support of using C-V2X technology, including automakers and automotive and technology industry associations. FCC officials noted that in making this decision, the agency had also invited parties to seek waivers to begin operating C-V2X devices while the final C-V2X technical rules were pending.[56] However, DOT officials and most (18 of 23) transportation stakeholders we spoke with expressed concern that the C-V2X communication protocol is less mature than DSRC, which they said could delay further CV deployment.[57] Transportation stakeholders told us that since C-V2X is in the early stages of development, it is difficult to purchase devices that operate using the C-V2X protocol. For example, a state transportation official told us that the state's local agency partner planned to deploy only C-V2X equipment for an ongoing CV project, but faced issues procuring enough C-V2X devices.[58] However, a few (four) stakeholders suggested that while C-V2X standards need more development, the ability to adapt many DSRC-based standards for C-V2X could speed further deployment of technologies.[59]

DOT officials and seven transportation stakeholders raised additional potential concerns about backward compatibility between current C-V2X equipment and future versions of equipment. According to literature we

[56] See 35 FCC Rcd. at 13464 ¶ 55. According to FCC officials, since December 2021, the FCC has received waiver requests for early C-V2X deployment from multiple parties, including automakers, equipment manufacturers and state departments of transportation.

[57] In the context of technical standards, maturity means that standards development organizations have written and approved a set of standards that compel manufacturers to produce equipment that will work as intended. This provides some assurance to those deploying the equipment that it will work as intended, with respect to safety, security, and interoperability. According to DOT and industry stakeholders, standards development for safety-related technology takes much time and effort, in large part because of the high bar for the reliability of equipment meant to save lives.

[58] In October 2021, representatives from this state transportation agency told us that due to delays in receiving the C-V2X devices they had ordered, the local agency decided to employ devices that use the DSRC protocol for this CV project. Of the C-V2X units ordered in 2021, these representatives said that the agency had only received a handful by November 2021. According to the representatives, the agency ordered 750 C-V2X units, mostly in 2021. As of June 2022, these representatives reported that the agency had procured 279 C-V2X devices.

[59] According to DOT officials, the DSRC-based standards at the application layer could be applied to C-V2X. See appendix III for more details on the status of DSRC and C-V2X protocols and the related operating standards.

reviewed, the Third Generation Partnership Project (3GPP), which creates specifications for cellular devices, did not write the C-V2X specifications in a way that ensures that newer versions are compatible with older versions of the technology, as a main design principle.[60] However, representatives from 3GPP stated they assumed devices developed with the newer version would be built with both versions, enabling them to communicate with legacy devices using older applications.

While four transportation stakeholders, including two automakers and two transportation agencies, told us they may pursue projects using C-V2X, others told us this backward compatibility issue could deter them from investing in C-V2X. For example, an automaker representative told us his company is not planning to equip its vehicles with C-V2X because company managers want assurance that any safety technology installed now will be useful throughout vehicles' 15 to 20 year lifespan, and that older versions of the technology will not get stranded by the introduction of newer versions.

In addition, transportation agency stakeholders raised concerns about the high estimated costs and extensive time that may be required to transition from DSRC to C-V2X. For instance, the University of Michigan Transportation Research Institute estimated that it would cost at least $14 million and take a minimum of 2 years to transition the City of Ann Arbor's equipped vehicles and infrastructure to C-V2X from DSRC.[61] In another example, officials from one state transportation agency said they initially estimated the transition would take 18 months, but supply chain difficulties caused them to consider that it might require 4 years or more. The cost and schedule implications of transitioning to C-V2X from DSRC has led to uncertainties in agencies' plans for CV technology deployments. For example, officials from one state transportation agency and from one local transportation agency said that they were undecided about changing their planned deployments to C-V2X. Further, an official

[60] See Z. Ali, S. Lagén, L. Giupponi and R. Rouil, "3GPP NR V2X Mode 2: Overview, Models and System-Level Evaluation," *IEEE Access,* vol. 9 (2021): 89554-89579.

[61] According to this institute, this estimated timeframe includes 6 months for planning procurement specifications, a further 6 months for testing and procurement, and 1 year for the actual retrofit of over 2,000 vehicles and 75 infrastructure sites that were part of their CV operations that used the DSRC protocol. National Academies of Sciences, Engineering, and Medicine, National Cooperative Highway Research Program Web-Only Document 310, *Evaluation and Synthesis of Connected Vehicle Communication Technologies,* (Washington, D.C.: June 2021).

from another local transportation agency said that, due to a lack of funding, they did not have a plan to migrate to the upper 30 MHz of the band (to continue their CV deployment after the repurposing takes effect), let alone transition their previously-equipped infrastructure to C-V2X.

Federal Actions Have Given Transportation Stakeholders Uncertainty about Regulatory Environment for Connected Vehicles

According to transportation stakeholders, FCC's rulemaking affecting the 5.9 GHz spectrum has increased industry uncertainty around the deployment of CV technologies and contributed to some industry stakeholders' current reluctance to invest in CV technologies. Almost all (20 of 23) of the transportation stakeholders we questioned agreed that past actions taken by FCC and DOT contributed to limiting investment in CV technologies:

- *FCC's 2013 solicitation of public comments regarding allowing unlicensed Wi Fi operators to share the 5.9 GHz band with CV users.* According to stakeholders, this announcement decreased certainty in the continued availability of dedicated spectrum, which they said is necessary for CV technologies to perform effectively. When we reported on the status of V2V and V2I technologies, respectively, in 2013 and 2015, selected stakeholders identified concerns about the future availability of sufficient spectrum to support CV technologies as one of several key challenges to the wider deployment of CV technologies.[62]
- *NHTSA and FCC proposing conflicting rules related to the use of CV technologies in the 5.9 GHz band.* Specifically:
    - In 2017, NHTSA proposed a V2V safety standard that would have required all new light vehicles to be equipped with DSRC (or another protocol interoperable with DSRC) to enable CV communications.[63] However, the final safety standard has not been issued.
    - In 2019, as described earlier in this report, FCC proposed and later adopted rules authorizing CV users of this spectrum to use C-V2X, a different protocol that is not interoperable with DSRC.

[62] See GAO-14-13 and GAO-15-775.

[63] NHTSA projected that 16 million new equipped vehicles would have been produced annually beginning in 2023 if the proposed safety standard had been implemented.

Stakeholders told us that the collective impact of these federal actions, combined with FCC's November 2020 decision to reduce the amount of spectrum reserved for CV technologies, has diminished their confidence in a clear path forward to deploy these technologies.

DOT is Assessing C-V2X Potential but Has Not Yet Shared Its Strategy for Responding to Challenges to the Further Development of CV Technologies

As summarized above, DOT and stakeholders progressed CV technologies that use DSRC to being ready for nationwide deployment (Phase 5 in DOT's 5-phase technology transfer framework). According to DOT officials, given FCC's 2020 decisions to repurpose 60 percent of the spectrum reserved for CV technologies and phase out the DSRC communication protocol, DOT is focused on assessing the potential for C-V2X devices to provide safety benefits under the new spectrum use rules. According to officials, in undertaking this assessment, DOT is repeating some steps of the technology development process it followed for the DSRC protocol in order to develop the C-V2X communications protocol. As of September 1, 2022, DOT and industry stakeholders were conducting Phase 2 research for the C-V2X protocol, according to agency officials.

In particular, DOT's immediate efforts focus on testing C-V2X devices in controlled and real-world environments, including multiple scenarios for assessing how well C-V2X devices send and receive signals in the 5.9 GHz band under FCC's new rules for this band. DOT posted its assessment plan for C-V2X devices on its public website. In August 2022, DOT published the results of its initial C-V2X tests.[64] DOT officials also told us that more real-world tests of C-V2X devices will be needed in the future, to better understand how the devices perform under different conditions. For example, this testing could include scenarios that consider

[64] According to agency officials, on August 24, 2022, DOT published the results of initial C-V2X tests on a DOT website: https://its.dot.gov/research_areas/emerging_tech/htm/ITS_V2X_Testing.htm [accessed November 1, 2022].

factors such as traffic congestion, potential unlicensed Wi Fi interference, and vehicles operating at different speeds.[65]

In addition to outlining its plan for testing C-V2X devices, DOT has recently begun to engage stakeholders to inform the next steps of its strategy to transition CV technologies using the C-V2X protocol through the remaining three phases of DOT's 5-phase technology transfer framework. Specifically, in August 2022, DOT sponsored a summit on the future of CV technologies for which the stated objective was to solicit information from stakeholders about the actions DOT should take to further advance CV technologies. In advance of the summit, DOT updated its public website to include the status of its C-V2X device testing and to promote current grant opportunities for state and local transportation agencies deploying CV projects.

While these recent DOT actions are a positive step, DOT officials told us that they understood the need to share additional information about their strategy to support CV deployments to provide more certainty to stakeholders in making their CV investment decisions. Such information could, for example, include the estimated timeframes for key steps to advance CV technologies using the C-V2X protocol through the remaining phases of the technology transfer framework and achieve nationwide deployment.

DOT's communication of information about its strategy for supporting CV deployment in the midst of changed conditions would be consistent with federal standards for internal control. Our prior work has shown that, by following internal control standards, federal agencies can better adapt to changes in the environment that impact key programs.[66] Specifically, federal agencies can more effectively respond to change by: (1) identifying changes in the environment that could influence key programs, (2) developing plans for responding to such changes, and (3)

[65] DOT is conducting these tests in cooperation with stakeholders at various sites, including at FHWA's highway research center in McLean, VA, NTIA's Institute for Telecommunications Sciences in Boulder, CO, and the Tampa-Hillsborough Expressway Authority in Tampa, FL.

[66] See, for example, GAO, *Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices,* GAO-18-539 (Washington. D.C: July 30, 2018) and GAO, *Spectrum Management: Agencies Should Strengthen Collaborative Mechanisms and Processes to Address Potential Interference*, GAO-21-474 (Washington. D.C.: June 29, 2021).

communicating the impacts with those whose participation will be essential for accomplishing key program goals.[67] By communicating early and often, federal agencies managing key programs, such as DOT's effort to facilitate the deployment of CV technologies, can help those industry stakeholders that are most impacted by changes in the environment.[68]

Most selected transportation stakeholders in our review (18 of 23), including officials from four of the five transportation agencies, indicated that additional information about DOT's strategy for facilitating deployment of CV technologies could help address risks that would prevent CV technologies from achieving their intended benefits.[69] By providing additional information about its strategy, DOT could help to mitigate risks such as stakeholders' uncertainty around the deployment of CV technologies and reluctance to invest in these technologies. According to some stakeholders, additional DOT information about the following issues could be helpful.

- *How the recent spectrum changes will influence DOT grant funds for deploying CV applications.* Numerous state and local transportation agencies have funded CV projects through various DOT grants. Since DOT grants are likely to remain a key funding source, state and local transportation agencies interested in deploying CV projects will need clear information about the eligible uses of such grants for continued CV project research, development, and implementation.
- *How the new FCC rules affect the path forward for transportation stakeholders currently researching or deploying CV technologies.* DOT has argued that the reduced spectrum will influence the trajectory of CV deployment. However, it has not communicated details of its strategy for developing CV technologies to operate under the new spectrum rules, or revised its guidance for stakeholders deploying CV technologies.
- *How DOT's plans to foster the development of automated vehicle technologies intersect with efforts to foster CV technologies.* Most

[67] See GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September, 2014).

[68] See GAO-18-539.

[69] There were 23 transportation stakeholders in our review, but one did not answer the questions related to this issue.

transportation stakeholders told us that clearer information on DOT's plans for automated technologies could also help CV technologies to yield their intended benefits. In 2017, we recommended DOT develop a comprehensive plan to manage departmental initiatives related to automated vehicles.[70] DOT agreed with this recommendation, and has taken steps to address it, but has not fully implemented it. In our July 2022 report on priority open recommendations to DOT, we included this as one of 16 priority open recommendations.[71]

Conclusions

DOT has supported the development of CV technologies for the past two decades, as the wider use of these technologies could significantly reduce vehicle crashes to save lives. However, the pathway to wide deployment is currently uncertain. The Department is prioritizing testing to assess the potential for CV technologies to work effectively under the new and proposed spectrum rules and with the new C-V2X communications protocol. As DOT continues this testing and forms its strategy for the further development and deployment of CV technologies under the new spectrum rules, it will be important for the Department to continue to engage transportation stakeholders and to address their key concerns, such as how the spectrum rule changes will influence DOT grant funds for CV applications. As the Department formulates its strategy to facilitate the deployment of CV technologies in the new spectrum environment, sharing more information sooner could help to reduce stakeholders' uncertainty and help them plan their own actions related to investing in CV technologies.

Recommendation for Executive Action

The Secretary of Transportation should share additional information about the Department's strategy to support the future deployment of connected vehicle technologies under the new spectrum rules. This information could include, for example, how the spectrum changes could influence

[70] GAO-18-132.

[71] See GAO, *Priority Open Recommendations: Department of Transportation*, GAO-22-105721 (Washington. D.C.: July 2022). We reported that DOT has issued multiple plans that outline its overall approach for managing policy and research issues related to automated vehicles across its modal administrations. However, these published plans lack performance measures and other aspects of comprehensive planning.

DOT’s grant funds that state and local transportation agencies have used to pursue connected vehicle projects. (Recommendation 1)

Agency Comments

We provided a draft of this report to DOT, FCC and NTIA for comment. In its comments, reproduced in appendix IV, DOT concurred with the recommendation. In addition, DOT and FCC provided technical comments, which we incorporated, as appropriate. NTIA reviewed the report, and confirmed it had no comments.

We are sending copies of this report to the appropriate congressional committee, the Secretary of Transportation, the Chairwoman of the Federal Communications Commission, and the Secretary of Commerce, as well as other interested parties. In addition, the report is 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 VonAhA@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 V.

Andrew Von Ah
Director, Physical Infrastructure

Appendix I: Objectives, Scope, and Methodology

This report addresses:

1. efforts the U.S. Department of Transportation (DOT) has taken to facilitate the deployment of connected vehicle (CV) technologies in the United States, and the deployment status of these technologies; and
2. key challenges identified by stakeholders to the further deployment of connected vehicle technologies, and how DOT is addressing these challenges.

To address both of these objectives, we interviewed agency officials at DOT, the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) to learn about key efforts related to the implementation of CV technologies and the 5.9 GHz spectrum band. We also reviewed documents about CV technologies and their deployment status, including

- Documentation of DOT's related efforts, including selected budget documents and strategic plans issued by DOT and its modal administrations over the past two decades
- Documentation of CV projects managed by state and local transportation agencies, including DOT data on CV deployments across the U.S. We interviewed DOT officials to understand how they obtain and update the data, and determined that it was reliable for our purposes.
- Academic literature and reports by research and policy organizations
- Selected comments and other responses filed during the course of a recent FCC rulemaking process.[1] We used these comments for several purposes, including to identify transportation and wireless industry associations and standards bodies to select for interviews. In addition, after selecting stakeholders, we reviewed the comments submitted by these stakeholders to learn more about these entities' views on issues related to CV technologies and the 5.9 GHz spectrum

[1] The recent FCC rulemaking was ET Docket No. 19-138, the rulemaking most often cited in the current report.

band. Finally, we analyzed a selection of comments submitted to FCC by state and local transportation agencies for themes, such as the most frequently cited benefits expected from CV technologies, and some common categories CV projects that state and local transportation agencies have implemented.[2]

Because a lawsuit regarding FCC's 2020 repurposing of the 5.9 GHz spectrum band was ongoing at the time we conducted our audit work, this report does not evaluate FCC's rationale for undertaking this regulatory action.[3] Rather, the report primarily focuses on efforts by DOT to facilitate deployment of CV technologies and to address the associated challenges to deploying these technologies under FCC's new rules for use of the 5.9 GHz spectrum.

We selected for interviews 40 stakeholders from the transportation and wireless industries to include a range of perspectives. These stakeholders include industry associations and standards bodies, transportation industry participants that had been involved in deploying CV technologies—including automakers, auto parts suppliers, and state and local transportation agencies—wireless internet service providers, and others with subject matter expertise. We identified these individuals and organizations based on our reviews of literature, including our prior work, and our review of a selection of comments filed in response to FCC rulemakings.

Our stakeholders include five organizations that had deployed CV technologies, which we refer to as "transportation agencies" in this report. Specifically, we interviewed representatives from three transportation agencies that DOT awarded grants to through the Connected Vehicle Pilot Deployment Program: (1) New York City Department of Transportation, (2) Tampa Hillsborough Expressway Authority, and (3) Wyoming Department of Transportation. We also interviewed representatives from Georgia's state transportation agency, because this entity has pursued efforts to deploy CV technologies using both DSRC and C-V2X communication protocols. Finally, we interviewed

[2] Specifically, we used Nvivo software to review comments submitted by state and local transportation agencies to look for certain phrases or themes. For example, we used this software to find examples of the types of CV projects that transportation agencies have pursued and the types of expected benefits from implementing these various projects (such as traffic safety, traffic efficiency or environmental benefits).

[3] During the course of our work, the D.C. Circuit Court of Appeals denied the petition to review FCC's order. *Intelligent Transportation Society of America v. FCC*, No. 21-1130 (D.C. Cir. Aug. 12, 2022).

representatives from the University of Michigan's Transportation Research Institute (UMTRI), the entity that managed the first real-world demonstration of connected vehicles through its Connected Vehicle Safety Pilot program. UMTRI continues to work closely with the City of Ann Arbor to maintain and operate the Ann Arbor Connected Environment, which is one of the largest real-world deployments of CV technologies in the world. In this report, we include UMTRI as one of the five organizations we refer to as "transportation agencies", even though UMTRI is not an infrastructure owner operator like the other state and local transportation agencies in our selection.

We used semi-structured interviews to gather stakeholders' thoughts about the deployment status and potential future benefits of CV technologies, the potential benefits of operating unlicensed wireless devices in the 5.9 GHz band, and federal polices and efforts related to CV technologies and the 5.9 GHz band spectrum. Table 2 lists the 40 stakeholders we selected for interviews.[4] The views of these entities or individuals are not generalizable to the transportation and wireless industries, but rather provide a range of perspectives about the use of CV technologies and unlicensed wireless devices in the 5.9 GHz band.

Table 2: Connected Vehicle Technologies & Spectrum: Interviewed Stakeholders

Category	Category member
Transportation industry associations & standards bodies	5G Automotive Association (5GAA)
Transportation industry associations & standards bodies	Alliance for Automotive Innovation
Transportation industry associations & standards bodies	American Association of State Highway and Transportation Officials (AASHTO)
Transportation industry associations & standards bodies	Car 2 Car Communication Consortium (C2C CC)
Transportation industry associations & standards bodies	Institute of Electrical and Electronics Engineers (IEEE) 1609 Working Group
Transportation industry associations & standards bodies	Institute of Transportation Engineers (ITE)
Transportation industry associations & standards bodies	Intelligent Transportation Society of America (ITS America)

[4] We conducted interviews with 37 of the 40 stakeholders. The three remaining stakeholders are located abroad, and for logistical reasons, we requested responses to our written questions instead of conducting interviews.

Category	Category member
Transportation industry associations & standards bodies	Motor & Equipment Manufacturers Association (MEMA)
Transportation industry associations & standards bodies	U.S. Technical Advisory Group to International Standards Organization Technical Committee 204 (ISO TC204)
Transportation industry stakeholders	Robert Bosch LLC
Transportation industry stakeholders	Continental AG
Transportation industry stakeholders	DENSO International America, Inc.
Transportation industry stakeholders	Ford Motor Company
Transportation industry stakeholders	General Motors (GM)
Transportation industry stakeholders	Georgia Department of Transportation (GDOT)
Transportation industry stakeholders	New York City Department of Transportation (NYC DOT)
Transportation industry stakeholders	Panasonic Corporation of North America
Transportation industry stakeholders	Qualcomm Incorporated
Transportation industry stakeholders	Tampa Hillsborough Expressway Authority (THEA)
Transportation industry stakeholders	Toyota Motor Corporation
Transportation industry stakeholders	University of Michigan Transportation Research Institute (UMTRI) Center for Connected and Automated Transportation (CCAT) and Mcity
Transportation industry stakeholders	Volkswagen Group of America
Transportation industry stakeholders	Wyoming Department of Transportation (WYDOT)
Wireless industry associations & standards bodies	Third Generation Partnership Project (3GPP)
Wireless industry associations & standards bodies	NCTA – the Internet & Television Association
Wireless industry associations & standards bodies	New America's Open Technology Institute
Wireless industry associations & standards bodies	Wi-Fi Alliance
Wireless industry associations & standards bodies	Wireless Internet Service Providers Association (WISPA)
Wireless industry associations & standards bodies	Wireless internet service providers
Wireless industry associations & standards bodies	Softcom Internet Communications, Inc.
Wireless industry associations & standards bodies	Zirkel Wireless
Researchers and others with subject matter expertise	Representatives of Crash Avoidance Metrics Partners (CAMP)
Researchers and others with subject matter expertise	Investigators and other officials at the National Transportation Safety Board (NTSB)
Researchers and others with subject matter expertise	Representatives of the European Conference of Postal and Telecommunications Administrations (CEPT)
Researchers and others with subject matter expertise	Representatives of the Japanese Ministry of International Affairs and Communications (MIC)
Researchers and others with subject matter expertise	Representatives of the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT)
Researchers and others with subject matter expertise	Representatives of Waymo
Researchers and others with subject matter expertise	Dr. Michelle Connolly, Professor of Economics, Duke University (previously FCC Chief Economist)

Category	Category member
Researchers and others with subject matter expertise	Diana Furchtgott-Roth, Adjunct Professor, The George Washington University (previously Deputy Assistant Secretary for Research and Technology, U.S. Department of Transportation)
Researchers and others with subject matter expertise	Dr. Jon Peha, Professor and Center Director, Carnegie Mellon University (previously FCC Chief Technologist)
Researchers and others with subject matter expertise	Dr. Clifford Winston, Senior Fellow, Economic Studies, Brookings Institution

Source: GAO 23-105069

To learn more about how CV technologies work and challenges to future deployment, we conducted a site visit to two Michigan locations. In Ann Arbor, we interviewed researchers from UMTRI who managed the Safety Pilot Model Deployment, as described above. We learned more about past and current research related to CV technologies, rode along with researchers who drove connected and automated vehicles on a controlled test track, and toured areas of the city where road-side units (capable of sending and receiving vehicle-to-infrastructure messages) had been installed on the transportation infrastructure. We also interviewed researchers at the Crash Avoidance Metrics Partners (CAMP) facility in Farmington Hills, Michigan, to learn more about their study findings on how interference from unlicensed wireless devices can affect the performance of CV technologies.

Based on information learned in the semi-structured interviews, we developed and distributed two structured questionnaires for stakeholders—one for transportation industry stakeholders and one for wireless industry stakeholders.[5] We designed the questionnaires to gather consistent information across the stakeholder groups, especially related to views on proposed options for federal actions. Prior to distributing the questionnaires, we conducted pretests with three respondents to ensure that the questions were clearly worded, and that the questionnaires could be administered consistently. The structured questionnaires included questions about, for example, the factors that influenced the deployment of CV technologies, and potential actions that federal agencies could take to advance deployment. We sent the questionnaires in late January 2022 and requested responses by mid-February 2022. For the wireless industry, the response rate was about 83 percent (five of six). For the transportation industry, the response rate

[5] We did not send our structured questionnaires to all 40 selected stakeholders. Given that our questionnaire focused on the domestic status of CV technologies and potential options for federal efforts, for example, we did not ask officials in the Japanese or the European government agencies to respond to our questionnaire.

was about 96 percent (22 of 23). The responses to our questionnaire represent only the viewpoints of the respondents, and cannot be generalized to a broader population.

In addition, we reviewed documents about criteria related to federal agencies' management of strategic programs, which we determined should apply to DOT's effort to facilitate the implementation of CV technologies. We reviewed federal internal control standards related to identifying and responding to changes in the environment, including effectively communicating about the potential impacts of such key changes to stakeholders. We have previously identified in prior GAO work how federal agencies applying internal controls can help such agencies to navigate changes in the environment.[6] We compared DOT's efforts to facilitate the implementation of CV technologies and to address challenges to its further implantation of these technologies against these criteria.

We conducted this performance audit from March 2021 to November 2022 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.

[6] See GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September, 2014) and GAO, *Public Transit Partnerships: Additional Information Needed to Clarify Data Reporting and Share Best Practices,* GAO-18-539 (Washington. D.C: July 30, 2018).

Appendix II: GAO Reports on Department of Transportation (DOT) Efforts to Facilitate Connected and Automated Vehicles

DOT's efforts to foster the deployment of connected vehicle (CV) technologies are part of broader Department efforts to increase roadway safety by advancing vehicle automation and to promote related research and development efforts to increase the efficiency of surface transportation systems. Since at least 2009, GAO has issued numerous reports related to DOT's efforts to implement Intelligent Transportation Systems (ITS), which include CV technologies and automated vehicle systems, as summarized below.[1]

DOT efforts to facilitate the implementation of Vehicle-to-Vehicle (V2V) and Vehicle to Infrastructure (V2I) technologies

In 2013, we reported on the status of Vehicle-to-Vehicle (V2V) technologies and found that DOT and the industry had progressed V2V technologies using the Dedicated Short Range Communications (DSRC) protocol from a concept to the point of real world testing.[2] DOT and stakeholders had begun testing V2V operations in various scenarios, to inform both the messaging standards being developed for sending safety messages and a National Highway Traffic Safety Administration (NHTSA) V2V vehicle safety standard that was in development. We reported that, if broadly deployed, V2V technologies could offer significant safety benefits.

[1] See GAO, *Highway Safety: Foresight Issues Challenge DOT's Efforts to Assess and Respond to New Technology-Based Trends,* GAO-09-56.

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

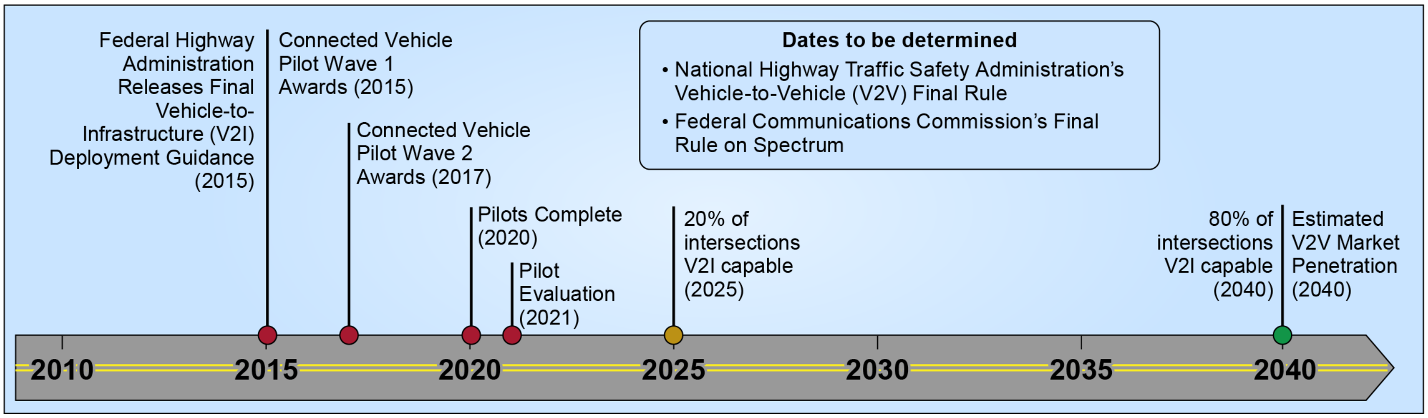
DOT, however, faced key challenges in fostering the wider deployment of these technologies including:

- addressing any concerns the public may have, such as related to privacy, and;
- ensuring that the possible sharing of the 5.9 GHz spectrum with other wireless users would not decrease the performance of V2V technologies.

In a 2015 report on Vehicle-to-Infrastructure (V2I) technologies, we stated that DOT had developed a pathway to the full development of CV technologies. In DOT's definition, the full deployment would mean deploying V2V and V2I nationwide in most passenger vehicles and at most traffic signals. As reproduced in figure 6, DOT's 2015 plan for the full deployment of CV technologies by 2040 included: (1) NHTSA issuing a final rule requiring V2V communications and (2) Federal Highway Administration providing technical guidance for state and local transportation agencies to use in pursuing CV projects. We also reported that DOT was collaborating with stakeholders to identify potential solutions to key deployment challenges, which included, among others:

- Industry concerns about whether sharing spectrum (between CV users and Wi Fi users in the 5.9 GHz band) could decrease V2I's effectiveness.
- State and local transportation agencies lacking the resources needed to widely deploy and maintain V2I technologies.

Figure 6: DOT's Planned Connected Vehicle Path to Deployment, 2010-2040



Sources: GAO analysis of Department of Transportation documents. | GAO-23-105069

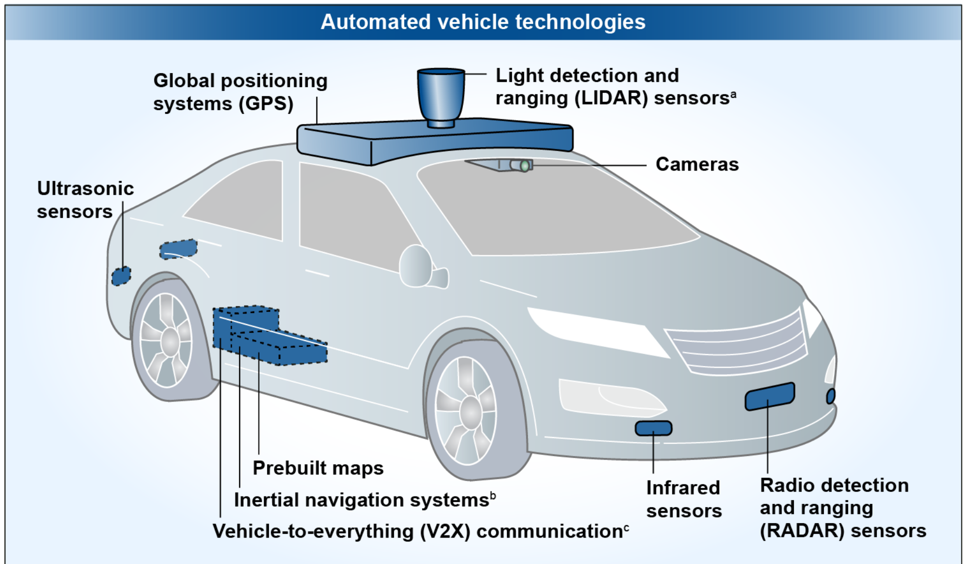
Note: In 2015, GAO reported that DOT had developed a path to deploying connected vehicle technologies, including Vehicle-to-Infrastructure and Vehicle-to-Vehicle communications, nationwide by 2040. This figure was previously included in the report *Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist,* GAO-15-775 (Washington, D.C.: Sept. 2015).

DOT efforts to facilitate the implementation of automated vehicle systems

In 2017, we reported that DOT had undertaken various efforts to advance automated vehicle technologies.[3] Among other actions, DOT had published voluntary guidance for automakers, funded research, and begun to study potential synergies between CV and automated vehicle technologies. DOT officials found CV technologies (sometimes called “Vehicle-to-Everything (V2X)” technologies) could provide additional situational awareness to automated vehicles as if they were equipped with more sensors or cameras. Figure 2 shows DOT’s description of the levels of driving automation.

[3] See GAO-18-132.

Figure 7: Levels of Driving Automation Used by Department of Transportation



Levels of driving automation adopted by Department of Transportation

Level	Name	Definition
0	**No automation**	Human driver controls all aspects of dynamic driving tasks, even when enhanced by warning system
1	**Driver assistance**	Automation controls one vehicle function (e.g., steering or speed)
2	**Partial automation**	Automation controls both steering and speed with driver responsible for monitoring and immediate reengagement
3	**Conditional automation**	Automation controls both steering and speed and monitors environment; driver may be notified to reengage
4	**High automation**	Automation performs all aspects of dynamic driving tasks in some driving modes; driver not required to reengage
5	**Full automation**	Automation performs all aspects of dynamic driving tasks under all roadway and environmental conditions

Sources: GAO and GAO analysis based on U.S. Department of Transportation information. | GAO-23-105069

Note: This figure was previously included in the GAO report *Automated Vehicles: Comprehensive Plan Could Help DOT Address Challenges,* GAO-18-132 (Washington, D.C.: Nov. 2017).

While it had some efforts underway, DOT had not yet developed a comprehensive plan to manage departmental initiatives related to automated vehicles. We recommended that DOT develop such a plan, including performance measures for tracking progress. DOT agreed and has since taken steps to address this recommendation, but has not fully implemented it. We included this as one of 16 priority recommendations for DOT in our July 2022 report.[4]

[4] See GAO, *Priority Open Recommendations: Department of Transportation*, GAO-22-105721 (Washington. D.C.: July 2022)

Appendix III: Additional Information on Connected Vehicle (CV) Technologies in the U.S. and Abroad

This appendix describes technical aspects of CV technologies that use spectrum in the 5.9 GHz band. Specifically, this appendix summarizes technical aspects related to the following.

- Components of an interoperable CV environment.
- Dedicated Short Range Communication (DSRC) and Cellular Vehicle to Everything (C-V2X) communication protocols
- International efforts to harmonize spectrum for CV technologies around 5.9 GHz.

Components of a CV Environment

CV technologies are designed to deter collisions to increase roadway safety and efficiency by alerting drivers—such as through a dashboard alert or a seat vibration—about potential hazards with sufficient time to react. According to Department of Transportation (DOT) officials, CV technologies are designed to reliably function in rain, snow, fog, or darkness to help drivers to avoid collisions or to lessen the impact of a collision.[1] DOT and some stakeholders also noted that CV technologies can work effectively to deter collisions in conditions that decrease the perceptions of human drivers and of automated vehicle systems widely available in passenger vehicles. In testing, CV technologies have been used to provide perception within a range of about 300 meters.

To create an interoperable CV environment, vehicles, infrastructure, and pedestrians with supporting devices exchange Basic Safety Messages (safety messages) quickly. For example, equipped vehicles continually broadcast their status, about 10 times each second, to other users in the

[1] For this review, GAO selected 40 stakeholders for interviews, including 23 transportation stakeholders. These transportation stakeholders included automakers, auto parts suppliers, industry associations and state and local transportation agencies. See appendix I for additional details on our methodology.

CV environment. To ensure the interoperability of devices in the CV environment, messages are transmitted in a standardized format. Equipped vehicles, for example, transmit standardized messages that include data elements such as on the vehicle's size, position, speed, trajectory, and brake status. In addition, cybersecurity requirements for users of the CV environment follow the Institute of Electrical and Electronics Engineers (IEEE) 1609 standards.[2] Table 3 summarizes aspects of the common language and security credentialing for exchanging messages in the CV environment developed by the listed standards-setting organizations.

Table 3: Selected Standards that Support Connected Vehicle Technologies

Standard	Purpose	Communication Protocol Dedicated Short-Range Communications (DSRC), Cellular Vehicle to Everything (C-V2X) or Both
Society of Automotive Engineers (SAE) International J2735 Message Set Dictionary	Outlines message set and data elements to ensure connected vehicle (CV) devices are interoperable. Among others, applications mentioned in the standard include basic safety messages, collision avoidance warnings, emergency vehicle alerts, and traveler information messages.	Both
Society of Automotive Engineers (SAE) International J2945 series	Sets DSRC system requirements to enable information exchanges between equipped vehicles, equipped roadside units, and management centers. Uses SAE J2735 messaging standards to send CV communications.	DSRC
Society of Automotive Engineers (SAE) International J3161 series	Sets system requirements to enable the exchange of messages between Long Term Evolution-Vehicle to Everything (LTE-V2X) devices using fourth generation cellular technology. Uses SAE J2735 messaging standards to send CV communications. Three standards in the series were published in Spring 2022.	C-V2X

[2] In 2016, when we reported about DOT's efforts to oversee vehicle cybersecurity, DOT officials and transportation stakeholders told us that cybersecurity would become even more important as vehicles become increasingly connected to external systems, including through CV technologies. We reported that NHTSA had taken key steps since 2012 to address vehicle cybersecurity, including establishing a research program, but had not yet defined the role it would have in responding to a real-world attack. We recommended that NHTSA document the agency's planned response to a vehicle cyberattack involving safety-critical systems. DOT agreed with our recommendation and, in 2018, we confirmed DOT had implemented it. See GAO, *Vehicle Cybersecurity: DOT and Industry Have Efforts Under Way, but DOT Needs to Define Its Role in Responding to a Real world Attack,* GAO-16-350 (Washington. D.C.: March 2016).

Standard	Purpose	Communication Protocol Dedicated Short-Range Communications (DSRC), Cellular Vehicle to Everything (C-V2X) or Both
Institute of Electrical and Electronics Engineers (IEEE) 1609 series	Describes requirements for architecture, networking, channel management, and the security and credential management system that enables the authenticity of received communications to be validated, while providing anonymity to the drivers and vehicles communicating with each other.	Both

Source: GAO analysis of SAE and IEEE information. | GAO 23-105069

Dedicated Short Range Communications (DSRC) and Cellular Vehicle to Everything (C-V2X) Communication Protocols

Both the DSRC and C-V2X communication protocols enable device-to-device communications to create the CV operating environment. DSRC is the more mature communication protocol for enabling CV technologies, largely because almost all the research and development of CV applications has used this protocol. DOT and industry stakeholders moved CV technologies using DSRC from a concept to being ready for deployment. One key feature of DSRC, according to transportation stakeholders, is its backward compatibility. This feature would allow current vehicles equipped with DSRC devices to exchange safety messages with equipped vehicles that will be manufactured in the future.

As noted above, C-V2X technologies emerged as a concept for enabling CV operations in 2017. Devices that operate using the C-V2X protocol based on cellular standards are sensitive to the release of updates to these underlying standards:

- Current C-V2X devices use fourth generation cellular technology, sometimes called Long Term Evolution Vehicle to Everything (LTE-V2X). LTE-V2X technology can facilitate device-to-device communications between equipped devices. The Third Generation Partnership Project (3GPP) first published specifications for LTE-V2X devices in 2017, in version 14 of the C-V2X specifications.
- Future C-V2X devices envisioned include those that would use fifth generation cellular systems, sometimes called 5G New Radio (5G NR). These future devices are expected to be capable of device-to-device communications as well as device-to-network communications.

3GPP issued the first specifications for 5G NR in 2020, in version 16 of the C-V2X specifications.

- Some stakeholders we spoke with questioned the extent to which future C-V2X devices would be compatible with those devices that are currently available. The question of backward compatibility and the interoperability of current and future C-V2X devices is a technical issue that is yet to be resolved according to these stakeholders.

There are some key differences between DSRC and C-V2X, according to DOT officials and some transportation stakeholders:

- As noted above, existing LTE-V2X devices may not be able to communicate with future devices that operate on the 5G NR and later standards.
- According to representatives of a supplier we interviewed, suppliers have confronted obstacles in using patented C-V2X technologies, mainly because holders of C-V2X patents may decline to sell licenses to CV suppliers. According to DOT officials and some stakeholders, addressing this licensing issue has delayed the momentum of CV deployment, and could continue to delay deployment if not resolved.

International Efforts to Harmonize Spectrum for CV Technologies around 5.9 GHz

According to the International Telecommunications Union (ITU), most countries that are deploying CV technologies or planning to do so, have allocated spectrum for ITS uses in the 5.9 GHz band in order to harmonize their spectrum allocations with those in other countries.[3] In 2019, delegates at the World Radio Conference approved a recommendation that encouraged member states to use globally or regionally harmonized frequency bands for ITS deployments. The delegates specifically suggested that member states could use 75 MHz in the 5.9 GHz band, based on the ITU's recommendation.[4] Currently, Canada has dedicated 75 MHz and several other countries have

[3] In 2019, the International Telecommunications Union Radiocommunication Sector (ITU-R) issued a report that identified current and planned usage of ITS technologies globally, including the reserved frequency bands, status of applications and deployment status of ITS technologies in various countries. See *Report ITU-R M.2445, Intelligent Transport systems (ITS) Usage, ITU 2019*.

[4] For the proceedings of the 2019 conference and resulting recommendations, see International Telecommunications Union, *World Radiocommunication Conference 2019 (WRC-19) Final Acts*.

dedicated 70 MHz (e.g., Australia, South Korea, and Singapore) to ITS applications in the 5.9 GHz band.

Appendix IV: Comments from the Department of Transportation

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U.S. Department
of Transportation

Office of the Secretary
of Transportation

Assistant Secretary
for Administration

1200 New Jersey Avenue, S.E.
Washington, DC 20590

October 28, 2022

Andrew Von Ah
Director, Physical Infrastructure
U.S. Government Accountability Office (GAO)
441 G Street NW
Washington, DC 20548

In addition to applying technology to improve transportation, reducing traffic fatalities and injuries continues to be a top priority of the U.S. Department of Transportation. Over the past two decades, the Department has worked with industry to develop, test, and deploy advanced vehicle-to-everything (V2X) communications technologies that can create connected transportation environments. As GAO has noted, the U.S. Department of Transportation has led international efforts to harmonize spectrum for connected vehicle (CV) technologies around the 5.9 GHz Safety Band. In November 2020, the Federal Communications Commission (FCC) issued a final order that reallocated 60 percent of the transportation Safety Band for unlicensed national information infrastructure (UNII, which is inclusive of more than Wi-Fi communications).

The U.S. Department of Transportation believes there continues to be significant disruption and challenges posed to current and future transportation safety communications and connectivity due to the reduction in the amount of dedicated spectrum, and the U.S. Department of Transportation concurs with GAO's recommendation. We agree that sharing additional information about the Department's strategy to support the future deployment of connected vehicle technologies under the new spectrum rules will aid in advancing the adoption and implementation of connected vehicle communications technologies by industry and state and local governments. We will provide a detailed response to this recommendation within 180 days of issuance of the final report.

We appreciate the opportunity to comment on the GAO draft report. Please contact Gary Middleton, Director of Audit Relations and Program Improvement, at (202) 366-6512 with any questions or if you would like to obtain additional details.

Sincerely,

Philip A. McNamara
Assistant Secretary for Administration

Accessible Text for Appendix IV: Comments from the Department of Transportation

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Appendix V: GAO Contact and Staff Acknowledgements

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In addition to the individual named above, Mike Armes (Assistant Director); Jessica Bryant-Bertail (Analyst-in-Charge); Oluwaseun Ajayi; Aisha Cabrer; Saar Dagani; Danielle Ellingston; Peggie Garcia; Aaron Harmon, Neelaxi Lakhmani; Terence Lam; Nancy Lueke; Dan Luo; Connor Mason; Josh Ormond; Madhav Panwar; Susmita Pendurthi; Kelly Rubin; Patrick Smith; Michael Soressi; Janet Temko-Blinder; Sarah Veale; and Michelle Weathers made key contributions to this report.

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