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Issues in Autonomous Vehicle Testing and Deployment

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SUMMARY

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Issues in Autonomous Vehicle Testing and Deployment

Autonomous vehicles have the potential to bring major improvements in highway safety. Motor vehicle crashes caused an estimated 37,133 fatalities in 2017; a study by the National Highway Traffic Safety Administration (NHTSA) has shown that 94% of crashes are due to human errors. For this reason, federal oversight of the testing and deployment of autonomous vehicles has been of considerable interest to Congress. In the 115th Congress, autonomous vehicle legislation passed the House as H.R. 3388, the SELF DRIVE Act, and a separate bill, S. 1885, the AV START Act, was reported from a Senate committee. Neither bill was enacted. In the 116th Congress, interest in autonomous vehicles remains strong, but similar comprehensive legislative proposals have not been introduced. The America's Transportation Infrastructure Act, S. 2302, which has been reported by the Senate Environment and Public Works Committee, would encourage research and development of infrastructure that could accommodate new technologies such as autonomous vehicles.

In recent years, private and government testing of autonomous vehicles has increased significantly, although it is likely that widespread use of fully autonomous vehicles—where no driver attention is needed—may be many years in the future.

The U.S. Department of Transportation (DOT) and NHTSA have issued three reports since 2016 that inform the discussion on federal autonomous vehicle policies, suggesting best practices that states should consider in their vehicle regulation; a set of voluntary, publicly available self-assessments by automakers showing how they are building safety into their vehicles; and a proposal to modify the current system of granting exemptions from federal safety standards.

Proponents of autonomous vehicles contend that lengthy revisions to current vehicle safety regulations could impede innovation, as the rules could be obsolete by the time they took effect. Federal and state regulatory agencies are addressing vehicle and motorist standards, while Congress is considering legislative solutions to some of the regulatory challenges.

Legislation did not pass the 115th Congress due to disagreements on several key issues. These included the following:

- The extent to which Congress should alter the traditional division of vehicle regulation, with the federal government being responsible for vehicle safety and states for driver-related aspects such as licensing and registration, as the roles of driver and vehicle merge.
- The number of autonomous vehicles that NHTSA should permit to be tested on highways by granting exemptions to federal safety standards, and which specific safety standards, such as those requiring steering wheels and brake pedals, can be relaxed to permit thorough testing.
- How much detail legislation should contain related to addressing cybersecurity threats, including whether federal standards should require vehicle technology that could report and stop hacking of critical vehicle software and how much information car buyers should be given about these issues.
- The extent to which vehicle owners, operators, manufacturers, insurers, and other parties have access to data that is generated by autonomous vehicles, and the rights of various parties to sell vehicle-related data to others.

Congress may address these issues in legislation reauthorizing surface transportation programs. The current surface transportation authorization expires at the end of FY2020. Policy decisions about the allocation of radio spectrum and road maintenance also may affect the rate at which autonomous vehicle technologies come into use.

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Introduction

Fully autonomous vehicles, which would carry out many or all of their functions without the intervention of a driver, may someday bring sweeping social and economic changes and "lead to breakthrough gains in transportation safety."[1] Motor vehicle crashes caused an estimated 37,133 fatalities in 2017;[2] a study by the National Highway Traffic Safety Administration (NHTSA) has shown that 94% of crashes are due to human errors.[3]

Legislation that would encourage development and testing of autonomous vehicles has faced controversy in Congress. In the 115th Congress, the House of Representatives passed an autonomous vehicle bill, H.R. 3388, by voice vote in September 2017. The Senate Committee on Commerce, Science, and Transportation reported a different bill, S. 1885, in November 2017, but after some Senators raised concerns about the preemption of state laws and the possibility of large numbers of vehicles being exempted from some Federal Motor Vehicle Safety Standards, the Senate bill did not reach the floor. No further action was taken on either bill before the 115th Congress adjourned.

Although some Members of Congress remain interested in autonomous vehicles, no legislative proposals have become law. Several fatal accidents involving autonomous vehicles raised new questions about how federal and state governments should regulate vehicle testing and the introduction of new technologies into vehicles offered for sale. A pedestrian was killed in Arizona by an autonomous vehicle operated by Uber on March 18, 2018,[4] and three Tesla drivers died when they failed to respond to hazards not recognized by the vehicles.[5] These accidents suggest that the challenge of producing fully autonomous vehicles that can operate safely on public roads may be greater than developers had envisioned, a new outlook voiced by several executives, including the Ford Motor Co. CEO.[6] However, with the authorization of federal highway and public transportation programs set to expire at the end of FY2020, a surface transportation reauthorization bill could become a focus of efforts to also enact autonomous vehicle legislation.

Advances in Vehicle Technology

While fully autonomous vehicles may lie well in the future, a range of new technologies is already improving vehicle performance and safety while bringing automation to vehicular functions once performed only by the driver. The technologies involved are very different from the predominantly mechanical, driver-controlled technology of the 1960s, when the first federal vehicle safety laws were enacted. These new features automate lighting and braking, connect the

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[1] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*, October 2018, p. 1, https://www.transportation.gov/av/3/preparing-future-transportation-automated-vehicles-3.

[2] Over the past 40 years, annual highway traffic fatalities generally declined from more than 50,000 in 1973 to 32,675 in 2014. In 2015 and 2016 that downward trend reversed and highway crash deaths rose: 35,485 and 37,806, respectively. Fatalities in 2017 showed a 1.8% decrease from 2016. National Highway Traffic Safety Administration, *2017 Fatal Motor Vehicle Crashes: Overview*, DOT HS 812 603, October 2018, p. 1, https://www.nhtsa.gov/press-releases/us-dot-announces-2017-roadway-fatalities-down.

[3] S. Singh, *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*, National Highway Traffic Safety Administration, DOT HS 812 115, February 2015.

[4] See National Transportation Safety Board, "Car with automated vehicle controls crashes into pedestrian," press release, March 21, 2018, https://www.ntsb.gov/investigations/Pages/HWY18FH010.aspx.

[5] Neal Boudette, "Despite High Hopes, Self-Driving Cars Are 'Way in the Future,'" *New York Times*, July 17, 2019, https://www.nytimes.com/2019/07/17/business/self-driving-autonomous-cars.html.

[6] Aarian Marshall, "Ford Taps the Brakes on the Arrival of Self-Driving Cars," *WIRED*, April 9, 2019, https://www.wired.com/story/ford-taps-brakes-arrival-self-driving-cars/.

car and driver to the Global Positioning System (GPS) and smartphones, and keep the vehicle in the correct lane. Three forces are driving these innovations:

- technological advances enabled by new materials and more powerful, compact electronics;
- consumer demand for telecommunications connectivity and new types of vehicle ownership and ridesharing; and
- regulatory mandates pertaining to emissions, fuel efficiency, and safety.

Manufacturers are combining these innovations to produce vehicles with higher levels of automation. Vehicles do not fall neatly into the categories of "automated" or "nonautomated," because all new motor vehicles have some element of automation.

The Society of Automotive Engineers International (SAE), an international standards-setting organization, has developed six categories of vehicle automation—ranging from a human driver doing everything to fully autonomous systems performing all the tasks once performed by a driver. This classification system (**Table 1**) has been adopted by the U.S. Department of Transportation (DOT) to foster standardized nomenclature to aid clarity and consistency in discussions about vehicle automation and safety.

Table 1. Levels of Vehicle Automation

SAE Automation Category	Vehicle Function
Level 0	Human driver does everything.
Level 1	An automated system in the vehicle can sometimes assist the human driver conduct some parts of driving.
Level 2	An automated system can conduct some parts of driving, while the human driver continues to monitor the driving environment and performs most of the driving.
Level 3	An automated system can conduct some of the driving and monitor the driving environment in some instances, but the human driver must be ready to take back control if necessary.
Level 4	An automated system conducts the driving and monitors the driving environment, without human interference, but this level operates only in certain environments and conditions.
Level 5	The automated system performs all driving tasks, under all conditions that a human driver could.

Source: DOT and NHTSA, *Federal Automated Vehicles Policy*, September 2016, p. 9, https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016.

Note: SAE is the Society of Automotive Engineers International, http://www.sae.org.

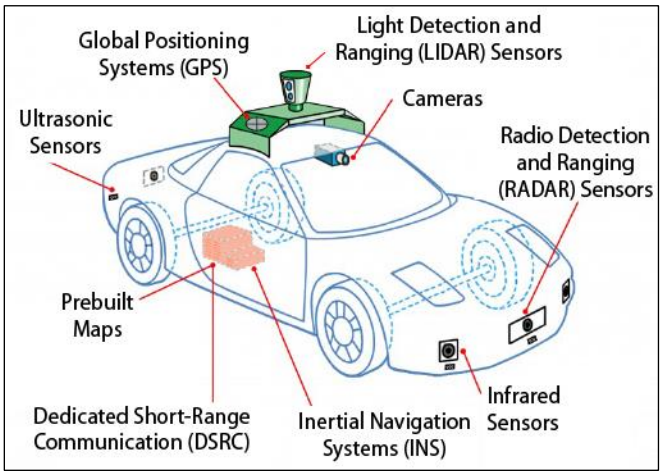
Vehicles sold today are in levels 1 and 2 of SAE's automation rating system. Although some experts forecast market-ready autonomous vehicles at level 3 will be available in a few years,[7] deployment of fully autonomous vehicles in all parts of the country at level 5 appears to be more distant, except perhaps within closed systems that allow fully autonomous vehicles to operate

[7] James Hedlund, *Autonomous Vehicles Meet Human Drivers: Traffic Safety Issues for States*, Governors Highway Safety Association, February 2, 2017, p. 5, http://www.ghsa.org/resources/spotlight-av17.

without encountering other types of vehicles. Testing and development of autonomous vehicles continue in many states and cities.[8]

Technologies that could guide an autonomous vehicle (**Figure 1**) include a wide variety of electronic sensors that would determine the distance between the vehicle and obstacles; detect lane markings, pedestrians, and bicycles; park the vehicle; use GPS, inertial navigation, and a system of built-in maps to guide the vehicle direction and location; employ cameras that provide 360-degree views around the vehicle; and use dedicated short-range communication (DSRC) to monitor road conditions, congestion, crashes, and possible rerouting. As 5G wireless technology infrastructure is installed more widely, DSRC may evolve and become integrated with it, enabling vehicles to offer greater interoperability, bandwidth, and cybersecurity.[9] Some versions of these autonomous vehicle technologies, such as GPS and rear-facing cameras, are being offered on vehicles currently on the market, while manufacturers are studying how to add others to safely transport passengers without drivers.

Figure 1. Autonomous Vehicle Technologies



Source: CRS, based on "Autonomous Vehicles" fact sheet, Center for Sustainable Systems, University of Michigan.

Manufacturers of conventional vehicles, such as General Motors and Honda, are competing in this space with autonomous vehicle "developers" such as Alphabet's Waymo. In addition, automakers are aligning themselves with new partners that have experience with ride-sharing and artificial intelligence:

- Ford and Volkswagen have announced that they expect to use autonomous vehicle technology in a new ride-sharing service in Pittsburgh, PA, as early as 2021;
- GM acquired Cruise Automation, a company that is developing self-driving technology for Level 4 and 5 vehicles. GM has also invested $500 million in the Lyft ride-sharing service;
- Honda, after breaking off talks about partnering with Waymo, purchased a stake in GM's Cruise Automation;

[8] Aarian Marshall, "Don't Ask When Self-Driving Cars Will Arrive—Ask Where," *Wired*, January 2, 2019, https://www.wired.com/story/when-self-driving-cars-will-arrive-where/.

[9] Brian Wassom, "DSRC vs. 5GLTE: Which Will It Be for Connected Vehicles?," *Ward's Auto*, July 23, 2018, https://www.wardsauto.com/industry-voices/dsrc-vs-5glte-which-will-it-be-connected-vehicles.

- Volvo and Daimler have announced partnerships with ride-sharing service Uber; and
- BMW partnered with the Mobileye division of Intel, a semiconductor manufacturer, to design autonomous vehicle software.

Cybersecurity and Data Privacy

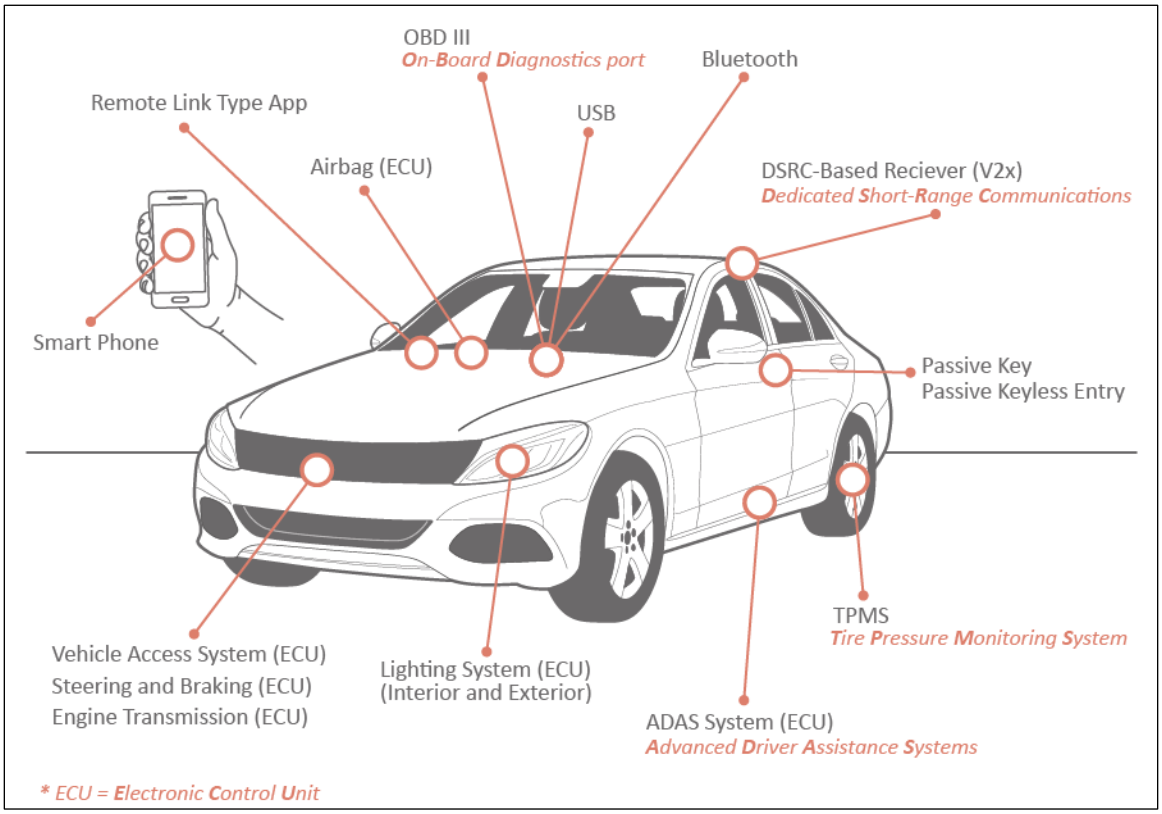
As vehicle technologies advance, the security of data collected by vehicle computers and the protection of on-board systems against intrusion are becoming more prominent concerns. Many of the sensors and automated components providing functions now handled by the driver will generate large amounts of data about the vehicle, its location at precise moments in time, driver behavior, and vehicle performance. The systems that allow vehicles to communicate with each other, with roadside infrastructure, and with manufacturers seeking to update software will also offer portals for possible unauthorized access to vehicle systems and the data generated by them.

Protecting autonomous vehicles from hackers is of paramount concern to federal and state governments, manufacturers, and service providers. A well-publicized hacking of a conventional vehicle by professionals[10] demonstrated to the public that such disruptions can occur. Hackers could use more than a dozen portals to enter even a conventional vehicle's electronic systems (**Figure 2**), including seemingly innocuous entry points such as the airbag, lighting systems, and tire pressure monitoring system (TPMS).[11] Requirements that increasingly automated vehicles accept remote software updates, so that owners do not need to take action each time software is revised, are in part a response to concerns that security weaknesses be rectified as quickly as possible.

[10] Hackers showed that they could remotely disable a Jeep's engine and brakes; Fiat Chrysler later addressed the vulnerability. Andy Greenberg, "Hackers Remotely Kill a Jeep on the Highway—With Me in It," *Wired*, July 21, 2015, https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/.

[11] TPMS is an electronic system designed to monitor the air pressure inside pneumatic tires.

Figure 2. Potential Entry Points for Vehicle Hacking



Source: CRS.

To address these concerns, motor vehicle manufacturers established the Automotive Information Sharing and Analysis Center (Auto-ISAC),[12] which released a set of cybersecurity principles in 2016. DOT's autonomous vehicle policies designate Auto-ISAC as a central clearinghouse for manufacturers to share reports of cybersecurity incidents, threats, and violations with others in the vehicle industry.

Aside from hackers, many legitimate entities would like to access vehicle data, including vehicle and component manufacturers, the suppliers providing the technology and sensors, the vehicle owner and occupants, urban planners, insurance companies, law enforcement, and first responders (in case of an accident). Issues pertaining to vehicle data collection include vehicle testing crash data (how is it stored and who gets to access it); data ownership (who owns most of the data collected by vehicle software and computers);[13] and consumer privacy (transparency for consumers and owner access to data). At present, no laws preclude manufacturers and software providers from reselling data about individual vehicles and drivers to third parties.[14]

[12] https://www.automotiveisac.com.

[13] Most new conventional vehicles on the road have an event data recorder (EDR), which captures a limited amount of information about a vehicle, the driver, and passengers in the few seconds before a crash (e.g., speed and use of seat belts). The most recent surface transportation legislation (P.L. 114-94) enacted the Driver Privacy Act of 2015 to address data ownership with regard to EDRs—establishing that EDR data is property of the vehicle owner—but it does not govern the other types of data that will be accumulated by autonomous vehicles.

[14] Two motor vehicle trade associations have developed *Privacy Principles for Vehicle Technologies and Services*, Alliance of Automobile Manufacturers and the Association of Global Automakers, https://autoalliance.org/connected-cars/automotive-privacy-2/principles/.

Pathways to Autonomous Vehicle Deployment Abroad

Autonomous vehicles are being developed and tested in many countries, including those that produce most of the world's motor vehicles. Several analyses have evaluated the factors that are contributing to the advancement of autonomous vehicles in various countries:

- **Innovation.** Benchmarks in this area include the number and engagement of domestic automakers and technology developers working on automation, the partnerships they forge with academic and related businesses, the prevalence of ride-sharing services, and autonomous vehicle patents issued.
- **Vehicle infrastructure.** Autonomous vehicles will need new types of infrastructure support and maintenance, including advanced telecommunications links and near-perfect pavement and signage markings. Planning and implementing these highway improvements may enable autonomous vehicles to be fully functional sooner. In addition, many test vehicles are currently powered by electricity, so the availability of refueling stations could be a factor in their acceptance.
- **Workforce training.** The increased reliance on autonomous vehicle technologies may require different workforce skills. Many traditional mechanical parts may disappear, especially if autonomous vehicles operate entirely on battery power, while the arrangement and function of dashboards and seating may be reinvented. Components suppliers that are already switching to this possible new product demand and reorienting their workforce will assist in the transition to autonomous vehicles.[15]
- **Government laws and regulations that encourage development and testing.** Fully autonomous vehicles may not have standard features of today's cars, such as steering wheels and brake pedals, as there will not be a driver. By law or regulation, motor vehicles built today are required to have many of these features. Some governments are taking a lead by modifying vehicle requirements for purposes of pilot programs and tests.[16] Permanent changes in standards will most likely be necessary if autonomous vehicle technologies are to be commercialized.
- **Level of consumer acceptance.** Markets are more likely to embrace autonomous vehicles if many residents in cities see autonomous vehicles on the road, a high

[15] For a discussion of possible U.S. manufacturing employment losses with a shift from internal combustion engine vehicles to electric vehicles, see CRS In Focus IF11101, *Electrification May Disrupt the Automotive Supply Chain*, by Bill Canis.

[16] While the U.S. Congress has not passed legislation addressing autonomous vehicle legislation and DOT considers how it will ensure safety if some current motor vehicle safety standards are relaxed, it is noteworthy that the European Union is moving forward with a framework for regulating autonomous vehicles developed and proposed by a United Nations regulatory forum. The UN's World Forum for Harmonization of Vehicle Regulations (WP.29) is a worldwide regulatory forum within the institutional framework of the UN Economic Commission for Europe's Inland Transport Committee. Its proposed regulations have formed the basis of many countries' vehicle regulations since 1958. United Nations Economic and Social Council, *Revised Framework document on automated/autonomous vehicles*, September 3, 2019, https://www.unece.org/fileadmin/DAM/trans/doc/2019/wp29/ECE-TRANS-WP29-2019-34-rev.1e.pdf.

level of technology is in use (including internet access and mobile broadband), and ride-hailing services are more widely used.

Several surveys have been conducted analyzing many of these factors. For example, a 2018 Harvard University report highlights plans in China, South Korea, Japan, and the United States to "seize the benefits" of autonomous vehicles.[17] In a report on innovation policies in four Asian countries (China, Japan, South Korea, and Singapore), the United Nations Economic and Social Commission for Asia and the Pacific ranked Singapore first in autonomous vehicle readiness because of its policies and new laws governing their deployment and its high consumer acceptance. The report also notes that South Korea's K-City facility is "intended to be the world's largest testbed for self-driving cars."[18]

A more detailed comparison of factors affecting autonomous vehicle development and deployment has been conducted by KPMG International, which has developed an index to measure how 25 countries are guiding autonomous vehicles (**Table 2**).

Table 2. Autonomous Vehicles Readiness Index

Rankings of Top Five Countries

Overall Rank	Country	Technology and Innovation	Policy and Legislation	Infrastructure	Consumer Acceptance
1	The Netherlands	10	5	1	2
2	Singapore	15	1	2	1
3	Norway	2	7	7	3
4	United States	3	9	8	6
5	Sweden	6	10	6	4

Source: Richard Threlfall, *Autonomous Vehicles Readiness Index*, KPMG International, 2019, https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf.

Notes: In developing this index, KPMG used publicly available information, a consumer survey in the 25 countries, and other research. Each of the four categories is given the same weight in devising the overall country ranking. KPMG *Autonomous Vehicles Readiness Index*, p. 42.

The Netherlands ranked first overall in the KPMG report, where it was cited as "an example of how to ready a country for AVs by performing strongly in many areas," as well as first in infrastructure.[19] Singapore came in first on policy and legislation because it has a single government entity overseeing autonomous vehicle regulations, it is funding autonomous vehicle pilots, and it has enacted a national standard to promote safe deployment.[20] Contributing to its

[17] Aida Joaquin Acosta, *What Governments Across the Globe Are Doing to Seize the Benefits of Autonomous Vehicles*, Berkman Klein Center for Internet and Society at Harvard University, Policy Primer on Autonomous Vehicles, July 13, 2018, https://cyber.harvard.edu/publication/2018/what-governments-across-globe-are-doing-seize-benefits-autonomous-vehicles.

[18] United Nations Economic and Social Commission for Asia and the Pacific, *Evolution of Science, Technology and Innovation Policies for Sustainable Development*, January 14, 2018, p. 65, https://www.unescap.org/publications/evolution-science-technology-and-innovation-policies-sustainable-development-experience.

[19] The Netherlands work on infrastructure includes deploying truck platooning along major commercial corridors there and in adjoining Belgium and Germany, installing 1,200 "smart" traffic lights, and building out a network of electric vehicle charging stations. KPMG International, *Autonomous Vehicles Readiness Index*, 2019, p. 14.

[20] *Autonomous Vehicles Readiness Index*, 2019, p. 15.

rank was a World Economic Forum (WEF) report that ranked it first among 139 countries in having an effective national legislature and efficient resolution of legal disputes.[21] Singapore also scored first place on the consumer acceptance metric, primarily because its extensive autonomous testing is being conducted throughout the island nation, thereby familiarizing residents with autonomous passenger vehicles and buses.

Two other major auto-producing countries—Germany and Japan—fall just below the United States on technology and innovation, according to KPMG, while Japan ranks higher on autonomous vehicle infrastructure (**Table 3**).

Table 3. Autonomous Vehicle Readiness Index for Major Auto Producing Countries

Overall Rank	Country	Technology and Innovation	Policy and Legislation	Infrastructure	Consumer Acceptance
8	Germany	4	6	13	13
10	Japan	5	15	3	18
12	Canada	11	8	16	11
13	South Korea	7	16	4	19
20	China	19	20	18	14
23	Mexico	23	24	22	21

Source: Richard Threlfall, *Autonomous Vehicles Readiness Index*, KPMG International, 2019, https://assets.kpmg/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf.

Issues in Federal Safety Regulation

Vehicles operating on public roads are subject to dual regulation by the federal government and the states in which they are registered and driven. Traditionally, NHTSA, within DOT, has regulated auto safety, while states have licensed automobile drivers, established traffic regulations, and regulated automobile insurance. Proponents of autonomous vehicles note that lengthy revisions to current vehicle safety regulations could impede innovation, as the rules could be obsolete by the time they take effect.

In 2016, the Obama Administration issued the first report on federal regulations affecting autonomous vehicles.[22] Since then, DOT has issued two follow-up reports and has said it anticipates issuing annual updates to its regulatory guidance. In addition, the Federal Communications Commission (FCC) is reconsidering the allocation of electromagnetic spectrum currently reserved for motor vehicle communications, and its decisions may affect how autonomous vehicles evolve.

[21] In the WEF ranking of 139 countries on a broad technology measurement of "networked readiness," the United States ranked 49th on the effectiveness of its lawmaking bodies. World Economic Forum, *Networked Readiness Index*, 2016, http://reports.weforum.org/global-information-technology-report-2016/economies/#economy=USA.

[22] U.S. Department of Transportation and National Highway Traffic Safety Administration, *Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety*, September 2016, https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016.

Obama Administration Policy Direction

DOT's 2016 report proposed federal and state regulatory policies in these areas:

- A set of *guidelines* outlining best practices for autonomous vehicle design, testing, and deployment. DOT identified 15 practices and procedures that it expected manufacturers, suppliers, and service providers (such as ridesharing companies) to follow in testing autonomous vehicles, including data recording, privacy, crashworthiness, and object and event detection and response. These reports, called Safety Assessment Letters, would be voluntary, but the report noted that "they may be made mandatory through a future rulemaking."[23]
- A *model state policy* that identifies where new autonomous vehicle-related issues fit in the current federal and state regulatory structures. The model state policy, developed by NHTSA in concert with the American Association of Motor Vehicle Administrators and private-sector organizations, suggests state roles and procedures,[24] including administrative issues (designating a lead state agency for autonomous vehicle testing), an application process for manufacturers that want to test vehicles on state roads, coordination with local law enforcement agencies, changes to vehicle registration and titling, and regulation of motor vehicle liability and insurance.
- A *streamlined review process* to issue DOT regulatory interpretations on autonomous vehicle questions within 60 days and on regulatory exemptions within six months.[25]
- Identification of *new tools and regulatory structures* for NHTSA that could build its expertise in new vehicle technologies, expand its ability to regulate autonomous vehicle safety, and increase speed of its rulemakings. Two new tools could be expansion of existing exemption authority[26] and premarket testing to assure that autonomous vehicles will be safe. Some of the new regulatory options cited would require new statutory authority, while others could be instituted administratively. The report noted that "DOT does not intend to advocate or oppose any of the tools.… [I]t intends … to solicit input and analysis regarding those potential options from interested parties."[27]

Trump Administration Policy Guidelines and Proposed Safety Rules

The two follow-up reports issued by the Trump Administration describe a more limited federal regulatory role in overseeing autonomous passenger vehicle deployment, while also broadening the scope of DOT oversight by addressing the impact of autonomous technology on commercial

[23] Ibid., p. 15.

[24] Ibid., p. 37.

[25] Ibid., pp. 48-67.

[26] Current law permits NHTSA to exempt up to 2,500 vehicles from federal motor vehicle safety standards. Expansion to 25,000 or more vehicles would allow more testing of autonomous vehicles on roads; such an expansion would require a statutory change. Ibid., pp. 75-76.

[27] Ibid., p. 70.

trucks, public transit, rail, and ports and ships.[28] The policies described in these reports replace those recommended by the Obama Administration in several ways, including the following:

- Encouraging *integration of automation across all transportation modes*, instead of just passenger vehicles.[29] The October 2018 report *Automated Vehicles 3.0* outlines how each of DOT's agencies will address autonomous vehicle safety within its purview.
- Establishing *six automation principles* that will be applied to DOT's role in overseeing passenger cars, trucks, commercial buses, and other types of vehicles. These include giving priority to safety; remaining technology-neutral; modernizing regulations; encouraging a consistent federal and state regulatory environment; providing guidance, research, and best practices to government and industry partners; and protecting consumers' ability to choose conventional as well as autonomous vehicles.[30]
- Reiterating the traditional roles of federal and state governments in regulating motor vehicles and motorists, respectively. The reports cite *best practices that states should consider* implementing, such as minimum requirements for autonomous vehicle test drivers, and discuss how DOT can provide states with technical assistance.[31]
- Recommending voluntary action in lieu of regulation. This could include suggesting that manufacturers and developers of autonomous driving systems issue and make public voluntary safety self-assessments to demonstrate transparency and increase understanding of the new technologies and industry development of "voluntary technical standards" to "advance the integration of automation technologies into the transportation system."[32]
- Accelerating NHTSA decisions on requests for exemptions from federal safety standards for autonomous vehicle testing.[33]
- Promoting development of *voluntary technical standards* by other organizations, such as the Society of Automotive Engineers, the government's National Institute of Standards and Technology, and the International Organization for Standardization.[34]

DOT has indicated that it wants to revise regulations pertinent to autonomous vehicles, such as redefining the terms "driver" and "operator" to indicate that a human being does not always have

[28] DOT and NHTSA, *Automated Driving Systems 2.0: A Vision for Safety*, DOT HS 812 442, September 2017, https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf and DOT and NHTSA, *Preparing for the Future of Transportation: Automated Vehicles 3.0*, October 2018, https://www.transportation.gov/av/3/preparing-future-transportation-automated-vehicles-3.

[29] Transportation agencies mentioned in the 2018 report and their regulatory areas are: National Highway Traffic Safety Administration (passenger vehicles and light trucks); Federal Transit Administration (local transit buses, subways, light and commuter rail, and ferries); Federal Motor Carrier Safety Administration (large trucks and commercial buses); Federal Aviation Administration (aviation); Federal Railroad Administration (railroads); Federal Highway Administration (highways, bridges, and tunnels).

[30] *Preparing for the Future of Transportation: Automated Vehicles 3.0*, pp. iv-v.

[31] Ibid., pp. 19-20.

[32] *Preparing for the Future of Transportation: Automated Vehicles 3.0*, p. viii.

[33] Ibid., p. 8.

[34] Ibid., Appendix C, pp. 49-63.

to be in control of a motor vehicle. It also said it plans to require changes in standards for the inspection, repair, and maintenance of federally regulated commercial trucks and buses.[35] Along these lines, NHTSA issued a Notice of Proposed Rulemaking in May 2019, requesting comments on testing and verifying how autonomous vehicle technologies may comply with existing federal safety standards.[36]

Federal Safety Standards Exemption Process

NHTSA has a legislative mandate[37] to issue Federal Motor Vehicle Safety Standards (FMVSS) and regulations. Manufacturers of motor vehicles and motor vehicle equipment must comply with these standards to protect against unreasonable risk of crashes occurring as a result of the design, construction, or performance of motor vehicles. The FMVSS regulations cover a wide range of vehicle components including windshield wipers, brakes, lighting, tires, mirrors, seating, seat belts, airbags, and child restraint systems.

Under current law, NHTSA can exempt up to 2,500 vehicles per manufacturer per year from existing FMVSS. In the past, this exemption authority has been used when a manufacturer has had a unique vehicle, such as an armor-plated security vehicle that has thick windshields not in compliance with federal windshield standards. NHTSA can exempt the automaker from a specific standard after a public comment period.

With the advent of autonomous vehicle systems with no human driver, some vehicles may not need components once thought essential to driving, such as steering wheels or brake pedals. The exemption process has been cited as way to encourage innovation and facilitate field-testing by waiving some of these standards. Applications for temporary autonomous driving-related exemptions were filed in 2018 by General Motors and Nuro, Inc., a California robotics company. NHTSA is reviewing them.

GM's petition asks for a two-year exemption from parts of 16 federal safety standards for its driverless Zero-Emission Autonomous Vehicles, which would be based on the Chevrolet Bolt electric vehicle to provide mobility services in GM-controlled fleets. Among the safety standards from which those vehicles would be exempted if approved by NHTSA are those dealing with rearview mirrors, lighting, brakes, tire pressure monitoring, and side impact protection. Nuro is seeking an exemption from the federal safety standard for low-speed vehicles, which it would operate as low-speed, electric-powered autonomous delivery robots that would carry only cargo and would not have seating or a passenger cabin. Its petition asks for exemptions from rearview mirror, windshield, seating, and backup camera requirements.[38]

Connected Vehicles and Spectrum Allocation

Federal regulation of the spectrum used in vehicle communications may affect how automation proceeds. Autonomous vehicles, whose artificial intelligence and technology are generally self-contained in each vehicle, are part of a larger category of connected vehicles and infrastructure. Federal, state, and industry research and testing of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications has been under way since the 1990s. Together, these two sets of technologies, known as V2X, are expected to reduce the number of accidents by improving detection of oncoming vehicles, providing warnings to drivers, and establishing

[35] *Preparing for the Future of Transportation: Automated Vehicles 3.0*, pp. 40-41.

[36] NHTSA, "Removing Regulatory Barriers for Vehicles with Automated Driving Systems," 84 *Federal Register* 24433, May 29, 2019. Comments on this proposed rulemaking were due by the end of July 2019. See also NHTSA, "U.S. Department of Transportation Seeks Input on Testing Vehicles with Automated Driving Systems Technologies," press release, May 22, 2019, https://www.nhtsa.gov/press-releases/us-department-transportation-seeks-input-testing-vehicles-automated-driving-systems.

[37] 49 U.S.C. §301.

[38] DOT, "U.S. Department of Transportation Seeks Public Comment on GM and Nuro Automated Vehicle Petitions," press release, March 15, 2019, https://www.nhtsa.gov/press-releases/us-department-transportation-seeks-public-comment-gm-and-nuro-automated-vehicle. The press release includes links to the two NHTSA *Federal Register* notices with details of the petitions.

communications infrastructure along roadways that would prevent many vehicles from leaving the road and striking pedestrians. These technologies fall within the broad category of intelligent transportation systems, which have received strong support from Congress due to their potential to improve traffic flow and safety.[39]

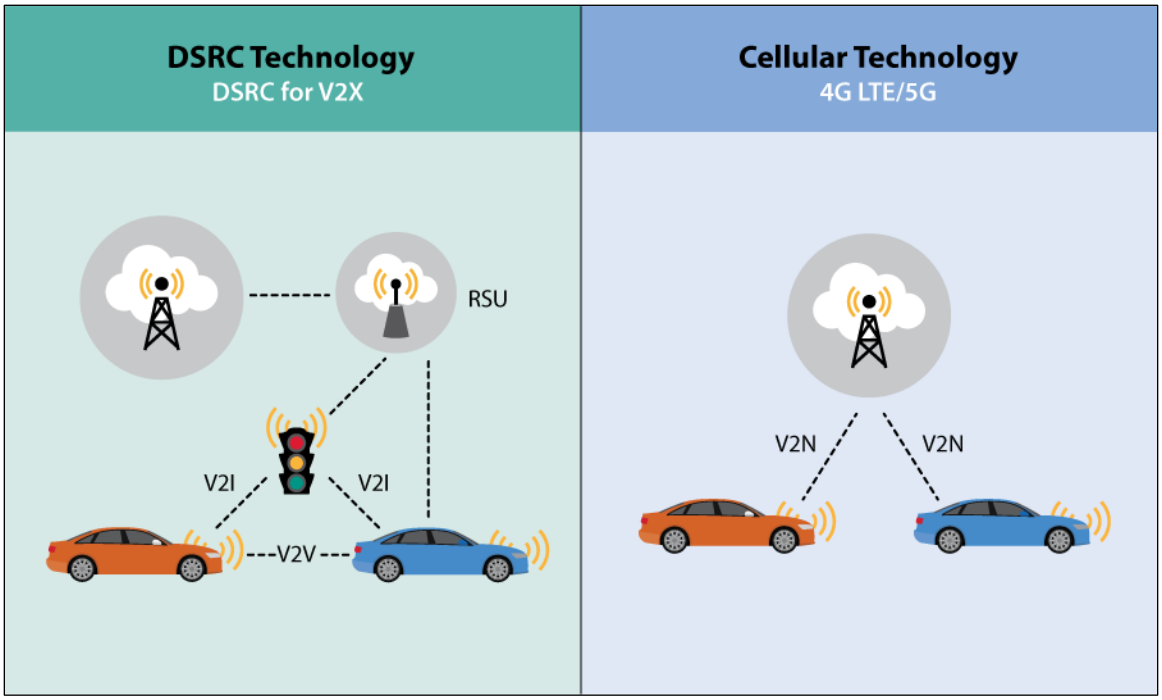
For vehicles to communicate wirelessly, they use radio frequencies, or spectrum, which are regulated by the Federal Communications Commission (FCC). In 1999, the FCC allocated the 5.9 gigahertz (GHz) band for motor vehicle safety purposes and solely for vehicles using Dedicated Short Range Communications (DSRC) uses that enable V2X. Over the past two decades, industry and government agencies have collaborated to develop, test, and deploy DSRC technologies. States have invested in DSRC-based improvements, and this technology is operating in dozens of states and cities.

As industry has continued to explore vehicle automation, an alternative, cellular-based technology has recently emerged, known as C-V2X. The FCC is considering whether to allow the 5.9 HGz band to also be used by C-2VX technologies. In a separate proceeding, the FCC is examining whether the 5.9 GHz band should also be shared with unlicensed devices such as cordless phones and WiFi devices. The FCC has directed testing to determine whether sharing this spectrum could interfere with V2V and V2I communications. DOT has called for retaining the spectrum band for exclusive motor vehicle use. **Figure 3** shows that these two technologies facilitate somewhat different types of vehicle and infrastructure communications. In light of their different characteristics, the European Commission has approved DSRC use for direct V2V and V2I communications, while endorsing cellular-based technology for vehicle access to the cloud and remote infrastructure.[40]

[39] P.L. 105-178, Transportation Equity Act for the 21st Century (TEA-21), Subtitle C-Intelligent Transportation Systems.

[40] Pablo Valerio, "Europe has defined DSRC WiFi as the V2X standard, and now faces 5G vendors revolt," *IoT Times*, May 3, 2019, https://iot.eetimes.com/europe-has-defined-dsrc-wifi-as-the-v2x-standard-and-now-faces-5g-vendors-revolt/.

Figure 3. Vehicle Communications Systems



Source: CRS.

Notes: Symbols used in this image are V2V, vehicle to vehicle communications; V2I, vehicle to infrastructure; V2X, a combination of V2V and V2I; V2N, vehicle to network, connecting vehicles to cellular infrastructure and the cloud so drivers can take advantage of services like traffic updates, and communicate from vehicle to vehicle. In addition, other infrastructure needs include RSUs, roadside units that communicate from vehicles and infrastructure to cell towers; traffic signal controllers that will communicate with the RSUs; a traffic management center that collects and analyzes data from vehicles and infrastructure; and a secure fiber-optic network.

Numerous industry groups in the United States are calling for different regulatory outcomes. DSRC advocates argue that this technology has been proven by years of testing and is already deployed in many areas. They generally support retaining the 5.9 GHz band for exclusive use for DSRC. C-V2X supporters contend that its cellular-based solution is aligned with international telecommunications standards for 5G technologies and should be allowed to use the 5.9 GHz band alongside DSRC. A group of technology companies, including device makers, argues that additional spectrum is need to accommodate the increasing number of interconnected devices, and that the 5.9GHz band can safely be shared among transportation and non-transportation uses.[41]

Congressional Action

During the 115th Congress, committees in the House of Representatives and the Senate held numerous hearings in 2017 on the technology of autonomous vehicles and possible federal issues that could result from their deployment. Initially, bipartisan consensus existed on major issues: H.R. 3388, the SELF DRIVE Act, was reported unanimously by the House Committee on Energy

[41] See CRS In Focus IF11260, *Smart Cars and Trucks: Spectrum Use for Vehicle Safety*, by Bill Canis and Jill C. Gallagher.

and Commerce, and on September 6, 2017, the House of Representatives passed it without amendment by voice vote.[42]

A similar bipartisan initiative began in the Senate. Prior to markup in the Committee on Commerce, Science, and Transportation, the then-chairman and ranking member issued a set of principles they viewed as central to new legislation:[43]

- *prioritize safety*, acknowledging that federal standards will eventually be as important for self-driving vehicles as they are for conventional vehicles;
- *promote innovation* and address the incompatibility of old regulations written before the advent of self-driving vehicles;
- *remain technology-neutral*, not favoring one business model over another;
- *reinforce separate but complementary federal and state regulatory roles*;
- *strengthen cybersecurity* so that manufacturers address potential vulnerabilities before occupant safety is compromised; and
- *educate the public* through government and industry efforts so that the differences between conventional and self-driving vehicles are understood.

Legislation slightly different from the House-passed bill emerged: S. 1885, the AV START Act,[44] was reported by the Committee on Commerce, Science, and Transportation on November 28, 2017. It was not scheduled for a floor vote prior to adjournment in December 2018 because of unresolved concerns raised by several Senators.[45] To address some of those concerns, a committee staff draft bill that would have revised S. 1885 was circulated in December 2018 that could form the basis of future legislation.[46]

The House and Senate bills addressed concerns about state action replacing some federal regulation, while also empowering NHTSA to take unique regulatory actions to ensure safety and encouraging innovation in autonomous vehicles. The bills retained the current arrangement of states controlling most driver-related functions and the federal government being responsible for vehicle safety. The House and Senate bills included the following major provisions. Where the December 2018 Commerce Committee staff draft proposed significant changes, they are noted in this analysis.

Preemption of state laws. H.R. 3388 would have barred states from regulating the design, construction, or performance of highly autonomous vehicles, automated driving systems, or their

[42] The legislation was passed under suspension of the rules, a House procedure generally used to quickly pass noncontroversial bills; its title is short for Safely Ensuring Lives Future Deployment and Research In Vehicle Evolution Act.

[43] Bipartisan Principles for Self-Driving Vehicles were announced by Senators John Thune, Bill Nelson, and Gary Peters on June 13, 2017. Senator Gary Peters, "Senators Release Bipartisan Principles for Self-Driving Vehicles Legislation," press release, June 13, 2017, https://www.commerce.senate.gov/public/index.cfm/2017/6/enators-release-bipartisan-principles-for-self-driving-vehicles-legislation.

[44] American Vision for Safer Transportation through Advancement of Revolutionary Technologies Act.

[45] Five Senators wrote on March 14, 2018, to the bill's sponsors, Senators Thune and Peters, outlining their concerns about how preemption, exemption authority, and cybersecurity might not adequately advance vehicle safety. Letter from Senators Dianne Feinstein, Kirsten Gillibrand, Richard Blumenthal, Edward Markey, and Tom Udall to Senators John Thune and Gary Peters, March 14, 2018, https://www.feinstein.senate.gov/public/index.cfm/press-releases?ID=46E4DC09-C5AB-4301-98C1-CBB225AE24F8.

[46] Eno Center for Transportation, *AV START Act—December 3, 2018 Revised Discussion Draft*, December 3, 2018, https://www.enotrans.org/etl-material/av-start-act-december-3-2018-revised-discussion-draft/.

components unless those laws are identical to federal law.[47] The House-passed bill reiterated that vehicle registration, driver licensing, driving education, insurance, law enforcement, and crash investigations should remain under state jurisdiction as long as state laws and regulations do not restrict autonomous-vehicle development. H.R. 3388 provided that nothing in the preemption section should prohibit states from enforcing their laws and regulations on the sale and repair of motor vehicles.

S. 1885 would also have preempted states from adopting laws, regulations, and standards that would regulate many aspects of autonomous vehicles, but would have omitted some of the specific powers reserved to the states under the House-passed bill. States would not have been required to issue drivers licenses for autonomous-vehicle operations, but states that chose to issue such licenses would not have been allowed to discriminate based on a disability. The bill provided that preemption would end when NHTSA establishes standards covering these vehicles.

The Senate staff draft sought to clarify that state and local governments would not lose their traditional authority over traffic laws. It also would have added provisions that state common law and statutory liability would be unaffected by preemption, and would have limited use of arbitration in death or bodily injury cases until new federal safety standards are in effect.

Exemption authority. Both the House and Senate bills would have expanded DOT's ability to issue exemptions from existing safety standards to encourage autonomous-vehicle testing on public roads.[48] To qualify for an autonomous-vehicle exemption, a manufacturer would have had to show that the safety level of the vehicle equals or exceeds the safety level of each standard for which an exemption is sought. Current law limits exemptions to 2,500 vehicles per manufacturer per year. The House-passed bill would have phased in increases over four years of up to 100,000 vehicles per manufacturer per year; the Senate bill would have permitted up to 80,000 in a similar phase-in.[49]

provided constraints on the issuance of exemptions from crashworthiness and occupant protections standards; S. 1885 did not address those two issues. DOT would have been directed to establish a publicly available and searchable database of motor vehicles that have been granted an exemption. Crashes of exempted vehicles would have had to be reported to DOT. The Senate bill would not have required the establishment of a database of exempted vehicles, and reporting of exempt vehicle crashes would not have been required.

The Senate staff draft added a provision to ensure that vehicles exempted from federal standards would have been required to nonetheless maintain the same level of overall safety, occupant protection, and crash avoidance as a traditional vehicle. A DOT review of vehicle exemptions would have been made annually. The draft capped exemptions to no more than five years.

[47] The bill would permit states and the federal government to prescribe higher standards for autonomous vehicles they purchase for their own use.

[48] For example, Federal Motor Vehicle Safety Standard 111 governs the performance and location of the rearview mirror. Fully autonomous vehicles would not need to be equipped with such mirrors because they rely on rear-facing sensors.

[49] In H.R. 3388, up to 25,000 vehicles could have been exempted per manufacturer in the first year after enactment, then 50,000 in the second year and 100,000 in each of years three and four. DOT would not have been permitted to raise the cap above 100,000 vehicle exemptions. S. 1885 would have permitted 15,000 exemptions per manufacturer in the first year after enactment, then 40,000 in the second year, and 80,000 in years three and four. A manufacturer could have requested that DOT increase its exemption cap above 80,000. In evaluating the request for an increase in or a renewal of an exemption, DOT would have been required to conduct a safety assessment of the original exemption.

New NHTSA safety rules. The Senate staff draft would have clarified the process by which federal motor vehicle safety standards would be updated to accommodate new vehicle technologies, providing additional time for new rulemaking. Within six months of enactment, DOT would have been required to develop and publicize a plan for its rulemaking priorities for the safe deployment of autonomous vehicles.

To address concerns that autonomous vehicles might make bicycles and pedestrians vulnerable to more accidents, the Senate staff draft would have required a "vision test" to be built into vehicles and manufacturers' safety evaluation reports to ensure road user safety.

Cybersecurity. The House-passed bill provided that no highly autonomous vehicle or vehicle with "partial driving automation"[50] could be sold domestically unless a cybersecurity plan had been developed by the automaker. Such plans would have to have been developed within six months of enactment and would include

- a written policy on mitigation of cyberattacks, unauthorized intrusions, and malicious vehicle control commands;
- a point of contact at the automaker with cybersecurity responsibilities;
- a process for limiting access to autonomous driving systems; and
- the manufacturer's plans for employee training and for maintenance of the policies.

The Senate bill would have required written cybersecurity plans to be issued, including a process for identifying and protecting vehicle control systems, detection, and response to cybersecurity incidents, and methods for exchanging cybersecurity information. A cybersecurity point of contact at the manufacturer or vehicle developer would have had to be named. Unlike the House-passed bill, S. 1885 would have directed DOT to create incentives so that vehicle developers would share information about vulnerabilities, and would have specified that all federal research on cybersecurity risks should be coordinated with DOT.

In addition, S. 1885 would have established a Highly Automated Vehicle Data Access Advisory Committee to provide Congress with recommendations on cybersecurity issues. Federal agencies would have been prohibited from issuing regulations pertaining to the access or ownership of data stored in autonomous vehicles until the advisory committee's report was submitted.

The staff draft would have added several cybersecurity provisions, including an additional study by the National Institute of Standards and Technology that would recommend ways vehicles can be protected from cybersecurity incidents.

Privacy. Before selling autonomous vehicles, manufacturers would have been required by the House-passed bill to develop written privacy plans concerning the collection and storage of data generated by the vehicles, as well as a method of conveying that information to vehicle owners and occupants. However, a manufacturer would have been allowed to exclude processes from its privacy policy that encrypt or make anonymous the sources of data. The Federal Trade Commission would have been tasked with developing a report for Congress on a number of vehicle privacy issues.

Although S. 1885 would not have explicitly required privacy plans by developers and manufacturers, it would have required NHTSA to establish an online, searchable motor vehicle

[50] "Partial driving automation" generally refers to Level 3 or 4 autonomous vehicles, where a driver must remain engaged with the task of driving, while the vehicle has some features, such as acceleration and steering, that may operate autonomously.

privacy database that would include a description of the types of information, including personally identifiable information (PII), that are collected about individuals during operation of a motor vehicle. This database would have covered all types of vehicles—not just autonomous vehicles—and would have included the privacy policies of manufacturers. The database would also have included an explanation about how PII would be collected, retained, and destroyed when no longer relevant.

The Senate staff draft would have added new passenger motor vehicle privacy protections.

Research and advisory panels. Both bills would have established several new advisory bodies to conduct further research on autonomous vehicles and advise DOT on possible new vehicle standards. H.R. 3388 would have established a NHTSA advisory group with a broad cross-section of members to advise on mobility access for senior citizens and the disabled; cybersecurity; labor, employment, environmental, and privacy issues; and testing and information sharing among manufacturers.

S. 1885 would have established other panels, including a Highly Automated Vehicles Technical Committee to advise DOT on rulemaking policy and vehicle safety; a working group comprising industry and consumer groups to identify marketing strategies and educational outreach to consumers; and a committee of transportation and environmental experts to evaluate the impact of autonomous vehicles on transportation infrastructure, mobility, the environment, and fuel consumption. Separately, DOT would have been required to study ways in which autonomous vehicles and parts could be produced domestically, with recommendations on how to incentivize U.S. manufacturing.

The Senate staff draft would have consolidated some of the advisory committees in S. 1885 into a Highly Automated Vehicle Advisory Council with diverse stakeholder representation, and mandated to report on mobility for the disabled, senior citizens and populations underserved by public transportation; cybersecurity; employment and environmental issues; and privacy and data sharing.

No similar comprehensive autonomous vehicle legislation has been introduced in the 116th Congress, although discussions on a bicameral bill have been ongoing.[51] In addition, the Senate Committee on Environment and Public Works has reported America's Transportation Infrastructure Act, S. 2302, which includes several provisions in Subtitle D addressing the possible impact of autonomous vehicles on highway infrastructure. It would establish a grant program to modernize the U.S. charging and fueling infrastructure so that it would be responsive to technology advancements, including autonomous vehicles. The legislation would also require research on ways in which roadway infrastructure should be improved for autonomous vehicles.

State Concerns

State and local rules and regulations may affect how autonomous vehicles are tested and deployed. The National Governors Association (NGA) has noted that state governments have a role with respect to vehicle and pedestrian safety, privacy, cybersecurity, and linkage with advanced communications networks. While supporting technology innovations in transportation, a recent NGA report notes that "the existing regulatory structure and related incentives have not

[51] Maggie Miller, "Cyber rules for self-driving cars stall in Congress," *The Hill*, September 26, 2019, https://thehill.com/policy/transportation/463126-cyber-rules-for-self-driving-cars-stall-in-congress.

kept pace with the new technology"[52] and that "recent accidents have raised concerns about the safety of drivers, pedestrians and other road users in the period during which autonomous and non-autonomous vehicles share the road."[53]

NGA has joined with other state and local government organizations[54] to call for modifications in forthcoming autonomous vehicle legislation, including

- clarity that states and local governments not only can enforce existing laws governing operation of motor vehicles on public roads, but also originate new statutes and regulations;
- requiring submission of more detailed automaker and developer reports to DOT on the safety of their technologies, so that states and cities can be assured that autonomous vehicle testing is being conducted in a safe manner;
- differentiation between limited vehicle testing and the commercial deployment of large numbers of autonomous vehicles through an expanded exemptions process; and
- expansion of plans for consumer education about "safe use and interaction" with respect to autonomous vehicles.[55]

According to the National Conference of State Legislatures (NCSL), 41 states and the District of Columbia have considered legislation related to autonomous vehicles since 2012; 29 states and the District of Columbia have enacted legislation, and governors in 11 states have issued executive orders **(Figure 4).**

[52] National Governors Association, *Governors Staying Ahead of the Transportation Innovation Curve: A Policy Roadmap for States*, July 17, 2018, p. 1, https://www.nga.org/wp-content/uploads/2018/07/Transportation-Innovation-Roadmap-Final-Hi-Res-for-Posting-Online.pdf.

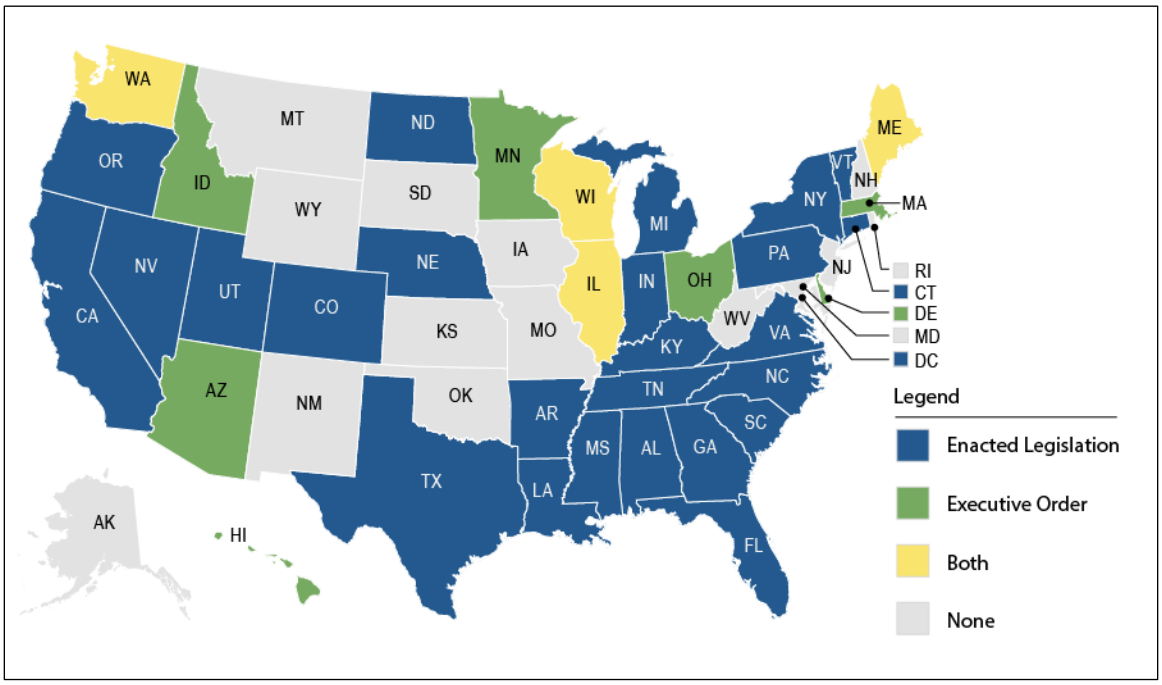
[53] Ibid., p.12.

[54] National Governors Association, National Conference of State Legislatures, National League of Cities, U.S. Conference of Mayors, National Association of Counties, American Association of State Highway and Transportation Officials, Governors Highway Safety Association, and American Association of Motor Vehicle Administrators, letter to the chairmen of the Senate Committee on Commerce, Science, and Transportation and House Committee on Energy and Commerce, September 12, 2019, https://www.nga.org/letters-nga/coalition-comments-on-potential-federal-legislation-on-autonomous-vehicles/.

[55] Ibid.

Figure 4. State Actions on Autonomous Vehicles

Enacted Legislation and Executive Orders, through September 2019



Source: CRS map based on data from National Conference of State Legislatures, *Autonomous Vehicles/Self-Driving Vehicles Enacted Legislation*, viewed October 24, 2019, http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

Of the states that have enacted laws in 2017, 2018 and through September 2019 pertaining to autonomous vehicles, NCSL reports that the largest number of states have passed laws that clarify certain types of commercial activity, such as how closely autonomous vehicles can follow each other when they are coordinated, as in truck platooning. No recent state laws have been enacted dealing with cybersecurity or vehicle inspection reports. NCSL has organized and categorized the types of state legislation (**Table 4**). For a more thorough description of the legislation passed in 2017, 2018 and through September 2019, the NCSL *Table of Enacted State Legislation* provides more detail.[56]

[56] http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx.

Table 4. Types of Autonomous Vehicle Laws Enacted by the States

2017-2019

Topic	Number of States That Enacted Legislation
Commercial	19
Cybersecurity	0
Definitions	18
Infrastructure and connected vehicles	5
Insurance and liability	8
Licensing and registration	2
Operation on public roads	13
Operator requirements	10
Privacy of collected vehicle data	1
Request for study	5
Vehicle inspection requirements	0
Vehicle testing	10
Other	8

Source: National Conference of State Legislatures, *Autonomous Vehicles State Bill Tracking Database*, viewed October 24, 2019, http://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx.

Notes: Includes the 50 states and the District of Columbia; laws enacted; does not include executive orders.

Implications for Highway Infrastructure

Deployment of fully autonomous vehicles will require not only a suite of new technologies, but also changes to the highway infrastructure on which those vehicles will operate. Autonomous vehicles being tested today rely on clear pavement markings and legible signage to stay in their lanes and navigate through traffic. Major highways as well as side roads in urban and rural settings will need to accommodate autonomous vehicles in addition to a large fleet of conventional vehicles with human drivers.[57]

In this transition period to more autonomous vehicles—which will most likely last several decades[58]—the Federal Highway Administration (FHWA) is expected to play a significant role through its administration of the Manual on Uniform Traffic Control Devices (MUTCD), which sets standards for all traffic control devices, including signs, intersection signals, and road

[57] The average age of light vehicles on U.S. roads is 11.8 years; new vehicles on the road today will most likely still be driven in 2030. Of the 278 million light vehicles on U.S. roads in 2019, most of them are conventional, with internal combustion engines. Daniel Szatkowski, "Average age of vehicles on U.S. roads hits 11.8 years," *Automotive News*, June 27, 2019, https://www.autonews.com/automakers-suppliers/average-age-vehicles-us-roads-hits-118-years.

[58] DOT has estimated that 20% of intersections may be V2I-capable in 2025 and 80% will be V2I capable by 2040. Center for Automotive Research and Public Sector Consultants, *Planning for Connected and Automated Vehicles*, March 2017, p. 17.

markings. For example, overhead signage on Interstate Highways contains white lettering on a green background in all 50 states—easily recognizable to any U.S. driver—due to MUTCD standards. FHWA is in the process of updating the 2009 MUTCD to address issues specific to autonomous vehicle technologies.[59] However, state compliance with MUTCD is voluntary, and not all states uniformly apply all standards. Audi reportedly announced in 2018 that it would not make its new Level 3 autonomous vehicle technology, called Traffic Jam Pilot, available in the United States because of "laws that change from one state to the next, insurance requirements, and things like lane lines and road signs that look different in different regions."[60] Other automakers have made similar complaints about U.S. roads.[61]

In the near term, improvement and better maintenance of pavement markings, signage and intersection design may be the most helpful steps that federal and state transportation officials can take. Despite national standards based on MUTCD, not all states maintain their highway markings at a level that would be useful to guide autonomous vehicles. Inadequate road maintenance may affect the pace of autonomous vehicle deployment. Some 21% of major U.S. roads are in poor condition, and a road with many potholes or temporary pavement repairs may also lack continuous lane markings.[62] Many minor roads, which are generally the responsibility of county or municipal governments, may lack road edge lines as well as center lines, potentially making it difficult for autonomous vehicles to position themselves correctly. Dirt and gravel roads may pose particular challenges for autonomous vehicles, as they generally have no pavement markings and cameras may be unable to detect potholes or edges in low-visibility conditions.

Closely tied to the need for clearer road markings and signage will be ways in which federal and state transportation agencies develop a standardized method to communicate information to vehicles and motorists about construction, road accidents, detours, and other changes to road environments. Many of the perceived benefits of autonomous vehicles—reduced vehicle fatalities, congestion mitigation, and pollution reduction—may depend on the ability of vehicles to exchange information with surrounding infrastructure.[63] The Transportation Research Board (TRB) has been evaluating how states should begin now to plan and develop the types of connected vehicle infrastructure that will be necessary for full autonomous vehicle deployment. TRB's research is also focused on how cash-strapped transportation agencies can identify the large investments that will in turn be necessary to implement connectivity on top of regular maintenance of highways, bridges, and other traditional infrastructure.[64]

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[59] U.S. Department of Transportation, *Preparing for the Future of Transportation: Automated Vehicles 3.0*, October 2018, p. 11.

[60] Alex Davies, "Americans Can't Have Audi's Super Capable Self-Driving System," *WIRED*, May 15, 2018, https://www.wired.com/story/audi-self-driving-traffic-jam-pilot-a8-2019-availablility/.

[61] Angelo Young, "Self-driving cars vs. American roads: will infrastructure speed bumps slow down the future of transportation?," *Salon*, April 20, 2017, https://www.salon.com/2017/04/20/self-driving-cars-vs-crummy-american-roads-will-infrastructure-speed-bumps-slow-down-the-future-of-transportation/.

[62] CRS calculations based on Federal Highway Administration data for federal-aid-highways only. See Appendix A in CRS Report R45250, *Rural Highways*, by Robert S. Kirk, p. 21. Federal-aid highways account for about one-quarter of all the roads in the United States and are generally the best maintained. It is likely that many of the other three-quarters of U.S. roads, including rural dirt roads and suburban cul-de-sacs, are also of a poor quality.

[63] Fast internet connections will be necessary for most V2X communications; state and local governments may be called on to make broadband investments to accommodate autonomous vehicle connectivity, raising questions about how those investments will be funded and steps to ensure compatibility across state lines.

[64] TRB, part of the National Academies of Sciences, Engineering, and Medicine, is expected to complete its report in November 2019. "Business Models to Facilitate Deployment of CV [Connected Vehicle] Infrastructure to Support AV Operations," https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4256.

Other options to facilitate autonomous vehicle travel may include designation of special highway corridors that would include all V2X systems necessary for safe autonomous vehicle operation; three European countries have agreed to build such a corridor.[65]

Over a longer time line, the importance of highway markings may fade as automakers and developers find new ways for autonomous vehicles to navigate, including greater use of guardrails and roadside barriers, sensors, and three-dimensional maps.[66] If highly detailed mapping is deemed to be one replacement for visual cues such as lane markings, then transportation agencies and automakers may need to develop an open standard so that all vehicles will understand the mapping technology. V2X communications through DSRC and cellular may evolve to provide a mechanism for new types of vehicle guidance.

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[65] The Netherlands, Germany, and Austria are undertaking a joint corridor development from Rotterdam through Frankfurt to Vienna. "Tri-national cooperation on the C-ITS Corridor," *ITS International*, viewed October 8, 2019, https://www.itsinternational.com/categories/networking-communication-systems/features/tri-nation-cooperation-on-c-its-corridor/.

[66] Center for Automotive Research and Public Sector Consultants, *Planning for Connected and Automated Vehicles*, March 2017, p. 12.