ROADMAP TO VEHICLE
CONNECTIVITY

September 2018

DISCLAIMER

This report was funded by Crown Castle, the nation's largest provider of wireless infrastructure, in an effort to promote thought and consider the needs of carriers, vehicle manufacturers and local governments as they prepare to meet the infrastructure, regulatory, and security requirements of the connected and autonomous vehicles ecosystem. The views, opinions, and recommendations expressed herein are exclusively those of the authors and do not necessarily reflect those of Crown Castle.

LIST OF AUTHORS

Scott Belcher, SFB Consulting, LLC – Scott Belcher is the President and CEO of SFB Consulting, LLC which focuses on the intersection of technology, communications and transportation. He is currently working with clients on smart mobility, smart cities, edge computing, data processing and transfer, connected and autonomous vehicles, vehicle testing, and vehicle emission reductions. Scott served as the Chief Executive Officer (CEO) of the Telecommunications Industry Association (TIA) and the Intelligent Transportation Society of America (ITS America) where he focused on bridging the gaps between the legacy transportation industry and the communications and technology industries. He also worked for a number of other prominent trade associations. scottfbelcher@gmail.com

Edward Merlis – Ed Merlis is a business, public affairs and government relations consultant with extensive experience in transportation and communications. At various times he has served as a consultant to the Intelligent Transportation Society of America, Senior Vice President, Government and Regulatory Affairs of the U.S. Telecom Association, Vice President, National Cable Television Association, as well as on the staffs of several U.S. Senate committees including the Committee on Commerce, Science, and Transportation where he was Staff Director. edmerlis@edmerlis.com

Justin McNew, **JMC Rota Inc.** – Justin McNew's career started with the development and deployment of cellular communications and positioning systems. He has worked in the telecommunications and connected vehicle industries for over 20 years, for large telecommunications and ITS companies, as well as startups. Justin founded JMC Rota in 2013 to provide strategic consulting services and technical expertise to the wireless, automotive and transportation industries. He supports automakers and their suppliers, technology companies, and other stakeholders, in the research and development, standardization, regulatory support and testing of connected and automated vehicle solutions. He has 15 patents and numerous publications. justinm@jmcrota.com

Morgan Wright – Morgan Wright is an internationally recognized expert on cybersecurity strategy, cyberterrorism, and privacy. He's a Senior Fellow at The Center for Digital Government, and a national security contributor to TheHill.com. Morgan's landmark testimony before Congress on Healthcare.gov changed how the government collected personally identifiable information. Morgan was a Senior Advisor in the U.S. State Department Antiterrorism Assistance Program and the Senior Law Enforcement Advisor for the 2012 Republican National Convention. In addition to 18 years in state and local law enforcement as a highly decorated state trooper and detective, Morgan has developed solutions in defense, justice and intelligence for the largest technology companies in the world. He's a contributing author in the 4th Edition Computer Security Handbook, and has been quoted in two New York Times bestsellers. morgan@morganwright.us

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Manufacturers, technology providers, and national and regional governments have invested billions of dollars in connected and autonomous vehicle research, pilots and demonstrations. Underlying the potential success for these important life-saving technologies is the need for communications infrastructure and interoperability. The questions invariably remain: what communications technology best serves the most? Who will build the infrastructure on which it will operate? Who will pay for it? Building that infrastructure will, in large measure, be the responsibility of the private sector pursuing communications business opportunities. The building of the necessary communications infrastructure is reminiscent of the "chicken and egg" metaphor, which in our opinion requires that the specifications for Connected Vehicles (CVs) and Autonomous Vehicles (AVs) come first. As a result, the recommendations in this report focus on how to establish a clear path forward for CVs and AVs. Based on these findings, we believe that the necessary infrastructure will fall into place.

This report was funded by Crown Castle, the nation's largest provider of communications infrastructure, in an effort to consider and support the needs of carriers, vehicle manufacturers and local governments as they prepare to meet the infrastructure, regulatory, and security requirements of the connected and autonomous vehicles ecosystem. The views, opinions, and recommendations expressed herein are exclusively those of the authors and do not necessarily reflect those of Crown Castle.

The authors of this report completed an exhaustive review of currently available material and interviewed more than 50 individuals from organizations representing a cross section the transportation and technology spectrum. The list of organizations interviewed is provided in Appendix A. While interviewees did not necessarily answer all questions, we believe that the responses we received are representative of the industry.

KEY FINDINGS

1. **As the Telecommunications Industry Builds Out its 5G Network, it Should Consider the Needs of Connected Vehicles.** The transition from 4G to 5G will require increased network densification. Many estimate that 5G will require approximately five times the number of small cells that are currently deployed. The 5G build-out provides an excellent opportunity for collaboration. As the network providers build out their networks, they should work with local governments to incorporate connected vehicle infrastructure needs into their plans. Doing so could result in access to fiber or siting locations and potentially reduce the overall cost of building out both carrier and operator infrastructure.

2. **The Automotive, Technology and Telecommunications Industries Support a Federally Led Connected Vehicle Program to Save Lives, Time and Money.** We interviewed representatives from all segments of the industry and found uniform support for a federally led connected vehicle program. While there is skepticism that meaningful deployment would occur in a timely manner, interviewees agreed that if the technology were available and ubiquitous, the automotive industry would take advantage of it and it would have significant safety benefits.

3. **While the Automotive and Technology Industries are Divided on the Need for Vehicle Connectivity in Autonomous Vehicles, Most Agree That if it is Available, They Will Use it.** Most automobile manufacturers and tier one providers that we interviewed believe that autonomous

vehicles will require vehicle connectivity, at a minimum for redundant safety purposes. Many technology companies that we interviewed are designing systems that do not require vehicle connectivity, largely because they do not want to rely on systems or data they do not own. All agree, however, that if vehicle connectivity were available and reliable, they would take advantage of it.

4. **U.S. DOT Should Continue to Support the Build-Out of Connected Vehicle Infrastructure to Expedite the Deployment of Connected Vehicles.** U.S. DOT has seeded the connected vehicle market with the Safety Model Deployment Program, Connected Vehicle Pilots, and its overall support of multiple pilots and demonstrations around the country. This support, along with other programs such as the AASHTO SPaT challenge, has resulted in over 2,000 intersections being outfitted with connected vehicle radios. This increased deployment has encouraged the automotive industry to allocate resources toward connected vehicle technology and innovation. Continued funding of local infrastructure deployment will spur rapid adoption of connected vehicle technology and result in immediate safety benefits.

5. **The Data Collection, Transfer, Analysis and Storage Needs of Connected and Autonomous Vehicles Will be Significant.** We know that the 2,800 connected vehicles in the Safety Model Pilot Deployment utilized more than 60% of the city of Ann Arbor's fiber capacity; 1,000 connected vehicles in the New York City Pilot produced 250 terabytes of data in 18 months; and that former Intel CEO Brian Krzanich estimated that autonomous vehicles would produce 4,000 gigabytes of data a day by 2020. Even if most data transfers are only conducted once per day, there will still be the need for a robust communications infrastructure that can transfer significant volumes of data wirelessly, process at the edge, and have adequate fiber backhaul to the cloud.

6. **Much of the Industry is Technologically Agnostic Regarding DSRC and C-V2X.** Our research indicates that there is a strong sentiment that a single technology be agreed upon, whether DSRC or C-V2X. From an industry standpoint, those interviewed see very little difference between the two technologies.

RECOMMENDATIONS

We have divided our recommendations between connected and autonomous vehicles, although a number of the recommendations apply to both.

Connected Vehicles

U.S. DOT has concluded that the deployment of connected vehicle technology can reduce non-impaired crashes by more than 80%. This is greater than any previous automotive safety technology. As such, the industry should do its best to install this technology in vehicles and on the roadside as soon as possible. To facilitate this, the authors recommend:

- **The Federal Communications Commission Should Preserve the 5.9 Ghz Spectrum for Connected Vehicles.** In 1999, the FCC set aside the 5.9 Ghz ITS spectrum for the connected vehicle program

to promote safety and save lives.   We are finally seeing deployment of DSRC by many transportation agencies and manufacturers. We are also seeing many companies testing C-V2X , a competing technology, on the 5.9 Ghz spectrum. As such, we are on the cusp of finally seeing the promised safety benefits of connected vehicles and now is not the time to open the spectrum to non-licensed users or to sharing without a guarantee that there would not be interference.

- **U.S. DOT Should Mandate the Deployment of Vehicle to Vehicle (V2V) Connectivity to Enhance Safety, Minimize Market Confusion, and Reduce Costs.** In 2017, U.S. DOT issued a Notice of Proposed Rulemaking that would require connected vehicle technology in new model vehicles sold after 2023. Our respondents voiced strong support for a government mandate to insure consistent and widespread adoption of this life saving technology.

- **U.S. DOT Should Drive the Industry to a Single V2V Technology.** The Notice of Proposed Rulemaking on connected vehicle technology focused on DSRC but opened the door to competing technologies.   While our respondents tended to prefer one technology over another, they uniformly believed that a single technology is preferable to competing technologies and that the costs and complexity of operating multiple interoperable systems outweighed its flexibility.

- **U.S. DOT Should Financially Support the Deployment of Vehicle to Everything (V2X) Technology**. Over the past decade, U.S. DOT has funded research and pilots of connected vehicle technology. These investments have seeded the market for connected vehicles. Continued support of local government deployment of connected vehicle technology will expedite the deployment of this life-saving technology.

- **Operators Should Upgrade Their Traffic Signal Technology with Connected Vehicle Technology.** As state and local governments upgrade their infrastructure, they should upgrade to the most current technology that includes connected vehicle radios. They should also look to their carrier partners to avoid unnecessary duplication of hardware and fiber deployment.

Autonomous Vehicles

U.S. DOT has also concluded that more than 94% of traffic accidents are the result of human error. If we reduce the human factor in the equation, we can dramatically reduce or eliminate crashes. While this technology holds great promise, it is still under development. The following recommendations are intended to support the development of this technology and its roll-out.

- **U.S. DOT Should Require That AVs Are Connected.** All respondents of our survey agreed that if connected vehicle technology were available and reliable that they would use it. If U.S. DOT mandates connected vehicle technology, it should include autonomous vehicles in this mandate to ensure the greatest level of safety possible.

- **Congress Should Expand Federal Funding for Autonomous Vehicle Research.** In 2018, Congress provided an additional $100M for autonomous vehicle research. These funds will continue essential research. Additional research needs exist that will not likely be addressed uniformly or comprehensively by the private sector such as privacy, liability, ethics, artificial intelligence, rural access, data ownership, etc.

- **Congress Should Pass Legislation to Clarify Federal and State Authorities and Responsibilities in the Autonomous Vehicle Space.** Both houses of Congress have passed legislation that seeks to clarify the roles and responsibilities of federal and state governments. Congress should pass a consensus bill and then continue to monitor the deployment of AVs to ensure that no confusion remains with respect to federal and state roles and responsibilities.

- **Autonomous Vehicle Stakeholders Should Promote and Participate in the Development of International Standards.** International standards will be key for global deployment of these life-saving technologies. The various stakeholders should engage in the standards process to ensure that their company is not disadvantaged by the standards process and that the U.S. industry is not placed at a competitive disadvantage vis-à-vis other regions developing autonomous vehicles or the infrastructure to support them.

- **U.S. DOT Should Facilitate Greater Collaboration Among the Parties.** One of the most common complaints voiced by our respondents was the lack of collaboration among the parties. There continues to be stove-piped conversations within communities rather than across them. Specifically, the need to bring the technology community and local governments into the discussion was highlighted.

- **Manufacturers Should Support Campaigns to Educate the Public About Autonomous Vehicles.** There are regular articles about waning enthusiasm and trust of autonomous vehicles. These articles generally refer to a lack of understanding of autonomous vehicle technology by the public. Waymo recognized this and recently launched a public education campaign with a number of partners in Arizona. Additional public education will result in less suspicion and a higher adoption rate.

Roadmap To Connectivity:

Improving Safety Through Automation

"Some ninety percent of motor vehicle crashes are caused at least in part by human error."

The Center for Internet and Society, Stanford Law School

Each year, of the more than 1.2 million lives lost to traffic crashes worldwide, roughly 40,000 of those are in the United States. And whether these collisions result in death or injury to drivers, passengers, or pedestrians, the vast majority of those collisions are the result of human error.

Safety is the holy grail of transportation. Over the last 150 years, from the patenting of the railway air brake by George Westinghouse in 1868, to the current development of autonomous vehicles (AVs), engineers have sought to perfect systems that ensure the safe operation of every mode of transportation. Safety innovations in aviation and rail – many of which focus on eliminating human error – suggest both the scope of the benefits that can be derived from technology, as well as the complexity.

With respect to motor vehicles, improvements in roads and automobile designs have steadily reduced injury and death rates around the world. Notwithstanding these improvements, automobile collisions remain the leading cause of injury-related deaths.

Technological developments, from anti-lock braking systems to monitoring sensors; from vehicle to vehicle (V2V) communications to autonomous vehicles (AVs), hold the promise of reducing if not eliminating the single most dangerous element in vehicular transportation – the driver. We know this from the data and from the parallels we have seen in the significant reduction in human error related deaths and injury in aviation and rail. Trains operate on fixed tracks that are under the control (switches, signals, etc.) of the track owner and are driven by an individual generally trained by, or operating pursuant to, instruction by and permission of the track owner. Aircraft operate in three dimensional planes, under the control of finely-honed technology, as well as pilots and generally air traffic controllers who consistently monitor and communicate each aircraft's position.

The path to fulfillment of the promise of zero traffic fatalities is far more complex on the road. Intersections, traffic signals, road signs, road conditions, variable speeds of a multiplicity of vehicles of different sizes and weights operating in the same spatial plane exacerbate the potential for collision and make the delivery of technological fixes to override the potential for human error far more difficult. Add pedestrians, manually operated vehicles and AVs to the mix and the complexity grows exponentially.

1 ROLE OF COMMUNICATIONS AND DATA TRANSFER IN VEHICLE CONNECTIVITY

As transportation moves towards an environment that includes connected and autonomous vehicles, the role of communications and data transfer becomes essential. We are now in a transition period with an explosion of connectivity offerings and autonomous vehicles. Ultimately, these enhanced safety-related offerings need a robust communications system that is 100% reliable if they are to fulfill their potential. Yet, there is no common communications roadmap for the transition from the current environment where small volumes of data are transmitted wirelessly, to one where vehicles are communicating seamlessly with one another and the transportation infrastructure for safety and efficiency.

The report catalogs the status of many current connected and autonomous vehicle initiatives as well as factors related to vehicle connectivity and data transfer and proposes a connectivity roadmap for the next decade to meet the needs of the parties involved including telecommunications carriers (carriers), vehicle and system manufacturers (manufacturers) and local government owner and operators (operators). Crown Castle is committed to providing communications infrastructure regardless of which technology or technologies are ultimately adopted by autonomous and connected vehicle manufacturers. Crown Castle is technology neutral.

To prepare this report, the team performed a literature review and conducted extensive interviews with individuals representing or affiliated with more than 50 key stakeholders and thought leaders including carriers and their partners; manufacturers and their technology partners; technology companies; operators; and other government officials.[1]

The team sought to identify, clearly and comprehensively, the communications approaches for CVs and AVs currently being deployed as well as those that are under development, and the associated infrastructure needs that will be necessary to meet deployment requirements. A number of important issues, however, including coverage in rural areas, limitations in urban areas, data ownership, data format, liability, cybersecurity and data privacy are not addressed in detail in this report and call for additional study and analysis.

---

[1] A number of companies that we sought to interview chose not to be interviewed. Not all individuals interviewed were sufficiently familiar with all of the issues about which we asked them, and some chose not to discuss or respond to certain questions.

2 WHAT ARE CONNECTED VEHICLES?

"Connected Vehicle" is a broad term that describes a wireless connectivity capability on vehicles that can be used for applications ranging from infotainment to navigation to vehicle safety. Usually this connectivity is provided by the manufacturers, but in some cases connectivity may be provided via the aftermarket. There is also a large potential market for connectivity with other road users such as heavy-duty vehicles, pedestrians, cyclists, etc., but this report focuses on connected and autonomous light duty vehicles.

For the purpose of this report, we segregate connected vehicle application scenarios into three categories:

- Non-time-critical communications
- Time-critical safety communications
- Integrated communications (supports both non-time-critical and time-critical safety applications).

2.1 NON-TIME-CRITICAL COMMUNICATIONS

Many of the applications that use a non-time-critical communication interface already exist and are typically delivered over a 3G or 4G cellular interface. Navigation/map data, traffic data, streaming music and traditional telematics services are examples of the type of data that flows over this type of interface. While some of this data may be used in real-time scenarios, it is typically downloaded into the vehicle well before the information needs to be used. For example, an autonomous vehicle may download map data within 25 square kilometers of its current location so that it is available as needed.

Other non-time-critical uses of communications include vehicle maintenance and Customer Relationship Management (CRM) applications. Today's 3G and 4G networks can readily support these applications and 4G is already being used to support the genesis of autonomous vehicles with mapping, navigation and fleet management. Satellite-based services may also be used for non-time-critical connectivity. For example, traffic and traveler information can currently be delivered with satellite radio services.

2.2 TIME-CRITICAL SAFETY COMMUNICATIONS

Safety applications are often cited as time-critical, but this is not necessarily the case. There is a specific variety requiring a special low latency interface that provides access to the necessary data typically within 0.1 to 0.5 seconds of the corresponding event (e.g., if a vehicle brakes suddenly, it broadcasts a corresponding message to other cars within 0.1 seconds).[2] Traditional cellular networks, including 4G networks, are not suited to consistently deliver this level of performance. Consequently, specific

---

[2] "Latency" is the delay before a transfer of data begins following an instruction for its transfer. With respect to connected vehicles, latency is typically 0.1 to 0.5 seconds.

technologies such as Dedicated Short-Range Communications (DSRC) or Cellular Vehicle to Everything (C-V2X) have been or are being developed and tested to address this need.

Time-critical safety applications may include both passive and active safety. Passive safety typically means that the driver receives an alert from the vehicle in time to make a decision that could prevent an accident, and many commercially available cars have passive safety features on them today (e.g., lane departure warning systems).   Active safety typically means that the car does something for the driver (e.g., autonomous emergency braking). Both of these examples do not require connectivity, but each of the V2V applications introduced below require V2V communications and can be in active or passive scenarios.

V2V communications-based applications are usually cited as requiring low latency because the relationship between nearby vehicles is constantly changing and vehicle behavior is more random compared to fixed transportation infrastructure.

The V2V safety applications used to develop the requirements specified in the Society of Automotive Engineers International's (SAE) J2945/1 standard for V2V communications[3] include:

- Forward Collision Warning – alerts the driver of a potential collision with the rear of a vehicle ahead.
- Emergency Electronic Brake Lights – alerts the driver of a hard-braking car ahead.
- Intersection Movement Assist – alerts the driver of vehicles approaching an intersection from other directions.
- Blind Spot Warning/Lane Change Warning – alerts the driver of vehicles in blind spot when attempting to make a lane change.
- Left Turn Assist – alerts the driver of oncoming traffic when trying to make a left turn.
- Control Loss Warning – alerts the driver of a nearby vehicle control loss.
- Do Not Pass Warning – alerts the driver that it is not safe to pass.

Because V2V communications needs a relatively high number of vehicles equipped with the technology to provide the life-saving benefits commonly associated with connected vehicles, the National Highway Transportation Safety Administration (NHTSA) is considering imposing a mandate in cooperation with the manufacturers. Some studies have suggested that equipping as little as 10% of the fleet will provide significant life-saving benefits. Autonomous vehicles could also better coordinate among themselves with V2V technology and provide additional safety.

Certain vehicle to infrastructure (V2I) applications may also be time-critical. For example, some contend that Signal Phase and Timing (SPaT), which provides information about traffic light status to vehicles, requires a real-time interface to vehicles. As noted later in this report, some companies like Audi are

---

[3] SAE J2945/1, the V2V communications standard, was developed cooperatively by the automobile original equipment manufacturers (OEMs) and the U.S. DOT National Highway Traffic and Safety Administration (NHTSA) and published by SAE in March 2016.

currently using 3G and 4G for this purpose. For safety applications, particularly in the case of autonomous vehicles, knowledge of traffic signal status in real time is critical for making life-saving decisions.

2.3 INTEGRATED COMMUNICATIONS

Until recently, non-time-critical applications and time-critical safety were assumed to be segmented across different technological solutions. Organizations such as the 5G Automotive Association (5GAA)[4] have been promoting 5G (the next generation of wireless technology) as an integrated suite of Internet of Things (IOT) technologies that will address both non-time-critical applications and time-critical safety. The 5GAA was rapidly established and already has over 90 members, which indicates a high level of interest among industry stakeholders to be prepared for and use 5G for connected vehicles.

As the specifications for 5G are still in development, it is not yet clear if carriers will directly support the connectivity mechanisms needed for the low latency and reliability requirements of time-critical safety. The ultimate automotive solution could consist of a chipset-level integrated suite of technologies that includes both cellular and time-critical interfaces as opposed to having all applications delivered over a carrier-operated service.

3 THE TECHNOLOGY CANDIDATES

The technology candidates that have been proposed to satisfy time-critical safety include DSRC and C-V2X. While the line between today's C-V2X and 5G tends to get blurred, we divided C-V2X into two categories: current (4G LTE and PC5) and future (5G and beyond).

3.1 DEDICATED SHORT RANGE COMMUNICATIONS (DSRC)

A detailed history of DSRC and connected vehicles is provided in Section 6. This section provides a brief technical overview.

DSRC is based on a configuration of the IEEE 802.11 Wireless Local Area Network (LAN) standard[5] and is capable of delivering data rates between 3 and 27 Mbps in the 5.9 GHz Intelligent Transportation Systems (ITS) spectrum. In the U.S., DSRC also relies on the IEEE 1609[6] suite of communications middleware and security standards, and uses a data dictionary developed by SAE International (SAE J2735).

---

[4] http://5gaa.org/about-5gaa/about-us/

[5] http://www.ieee802.org/11/

[6] https://standards.ieee.org/develop/wg/1609.html

DSRC was explicitly developed to provide the low-latency interface that time-critical safety applications require. It was extensively tested for safety applications during the Safety Pilot Model Deployment (SPMD),[7] and it continues to be deployed at multiple sites around the country and in the Connected Vehicle Pilot (CVP) programs.[8] The proponents of DSRC argue that it is the only technology ready for deployment today, as indicated by the success of the pilot programs and the surprisingly large number of companies that participated in a recent OmniAir Plugfest. OmniAir is a trade association promoting the interoperability and certification of DSRC connected vehicles.

During the course of our interviews, we surveyed the respondents regarding which technology is ready today. 49 of the interviewees responded to this question, and DSRC was overwhelmingly picked as the technology ready for deployment. Note that seven respondents indicated both DSRC and CV2X (PC5, see Section 3.2.2), so 38 of 49 respondents believe DSRC is ready for deployment, and 10 of 49 believe CV2X (PC5) is ready.

Figure 1. Which Connected Vehicle Technology is Ready for Deployment?

Source: Interviews

---

[7] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812171-safetypilotmodeldeploydeltestcondrtmrep.pdf.
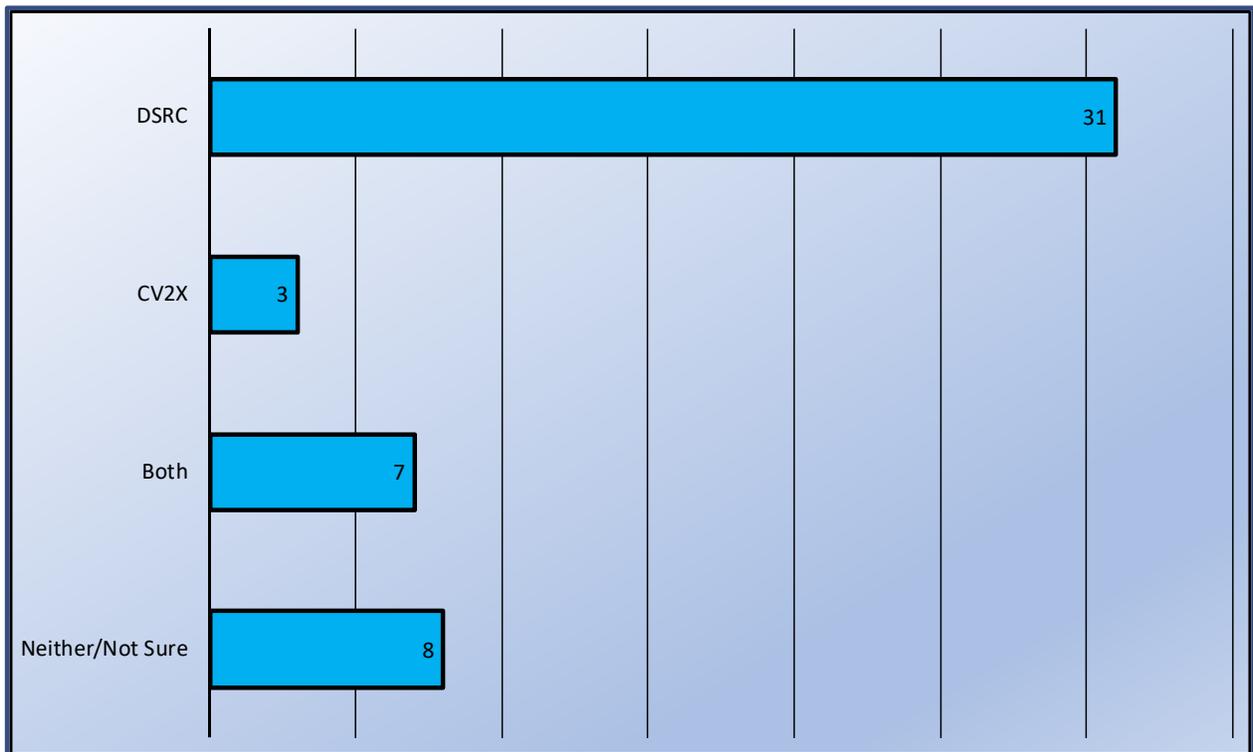
[8] https://www.its.dot.gov/pilots/cv_pilot_faq.htm

DSRC was designed to support communications both between vehicles and between vehicles and roadside infrastructure, generally within a range of about 300 meters although range may be greater in roadside to vehicle communications environments. DSRC deployment has faced delays and challenges for several reasons:

- The market for DSRC has been generally limited to V2V and certain intersection-oriented applications that use traffic signal information to prevent crashes at intersections.
- There has been limited funding for DSRC infrastructure deployment by operators.
- There is confusion over which technology to use (DSRC, C-V2X or 5G).
- There is regulatory uncertainty regarding deployment.
- Few have been willing to invest in a technology that without a government mandate may not be deployed or, if deployed, may take years to reach penetration levels needed to add value.
- Many believe that the technology is outdated and of limited value.
- Autonomous vehicles need high availability of the information (e.g., at all urban intersections).

It is noteworthy that the IEEE 802.11 Working Group recently began studying the development of a backward-compatible standard for next generation DSRC. The corresponding new features may provide an evolution path toward 5G that is comparable to the evolution path for C-V2X.

Finally, note that much work has been done on security during the development of DSRC technology. While the security for connected vehicles, particularly DSRC (and PC5, see Section 3.2.2), has been developed, the corresponding Security Credential Management System (SCMS) policies are still being developed and need to be completed and finalized. Among the interviewees there was a general sense that security for DSRC is complete, notwithstanding finalizing the SCMS policies and deployments (see Section 4). C-V2X (PC5) also benefits from the tremendous efforts that were made to develop DSRC security. Safety applications, such as those that rely on V2V or SPaT data from intersections, are currently being deployed using DSRC with SCMS-issued certificates.

3.2   CURRENT CELLULAR – VEHICLE TO EVERYTHING TECHNOLOGY (C-V2X)

3.2.1   TRADITIONAL 4G LTE CELLULAR

Traditional cellular-based connected vehicle technology relies on today's 3G and 4G LTE cellular networks[9] and is already in use by connected and autonomous vehicles. A significant number of vehicles currently rely on 4G networks for navigation, infotainment, CRM, maintenance, and ordinary telematics services. Some vehicles rely on 4G for passive safety applications, such as accident and wrong-way driver alerts, but most of the data is focused on operations, navigation, and traffic.

---

[9] Note that 3G is also currently used for basic non-time critical C-V2X, but for purposes of this report, we focused mainly on 4G and beyond.

3.2.2 3GPP PC5

More recently, the 3rd Generation Partnership Project (3GPP)[10] finalized the release of 14 standards which specify a potential V2X communications option interface referred to as PC5. PC5 is based on current 4G LTE technology and like DSRC, it can be deployed with or without the presence of infrastructure. PC5 also supports lower latency communications between vehicles and potentially between vehicles and infrastructure in the 5.9 GHz ITS band. Several members of 5GAA are actively promoting PC5 for V2V as a replacement for DSRC using the 5.9 GHz spectrum currently allocated for DSRC. Proponents of PC5, as supported by preliminary 5GAA test campaigns, claim that its range and performance is superior to DSRC and that it would better facilitate the move to 5G. As noted in a V2X White Paper by NGMN Alliance,[11] there are a number of other potential advantages, as cellular technology, which PC5 is based on, is generally designed for mobility and scalability. Whereas Wi-Fi, which DSRC is based on, was initially designed for relatively stationary environments. However, while 3GPP Release 14 is complete, as of late 2018 limited test data has been made available and commercial implementations are not readily available for commercial production.   Chipsets may be available in late 2018 or early 2019 according to corresponding suppliers.

Based on preliminary standards development efforts within SAE, PC5 will be integrated with the same communications middleware, security (IEEE 1609), and V2V application data as DSRC. Since PC5 reuses much of the V2X security and applications technology already developed by IEEE 1609 and SAE, it is being rapidly developed and like DSRC it can be deployed without the presence of infrastructure. Note that an update to the FCC rules for the 5.9 GHz DSRC band is required to enable the deployment of PC5 in that band.

One of the claims of PC5 supporters is that PC5 provides a seamless pathway toward 5G. This may be true assuming future communications chipsets support both PC5 and 5G, but it is not currently anticipated that the PC5 interface will otherwise be forward compatible with 5G. (Note that DSRC could also be integrated with future 5G chipsets.) While proponents of the PC5 solution contend that it will be more cost effective because of chip-level integration, the decision to integrate PC5 and not DSRC into future 5G chipsets will be dependent upon business decisions by chipmakers. If either PC5 and/or DSRC are integrated into future 5G chipsets, both will be forward and backward compatible. Regardless of whether

---

[10] The 3rd Generation Partnership Project (3GPP) brings together multiple telecommunications standard development organizations including: Association of Radio Industries and Businesses - (Japan); Alliance for Telecommunications Industry Solutions – (USA); China Communications Standards Association; European Telecommunications Standards Institute; Telecommunications Standards Development Society – (India); Telecommunications Technology Association – (Korea); Telecommunication Technology Committee – (Japan); and their members to produce reports and specifications that define 3GPP technologies.

[11] https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2018/V2X_white_paper_v1_0.pdf

DSRC or PC5 is used, forward and backward compatibility with future evolutions of V2X technology will be essential to a successful deployment.

We conclude that DSRC and PC5 are essentially equivalent and the primary potential advantages to PC5 might be future integration into 5G chipsets and slightly better range. If DSRC were also integrated into future 5G chipsets, PC5 and DSRC would be nearly indistinguishable, depending on the outcome of the PC5 performance testing by the 5GAA. While DSRC and PC5 may be technically equivalent, using PC5 instead of DSRC will likely delay deployment by at least three years as additional testing will be needed to prove out safety applications.

3.2.3 FUTURE C-V2X: 5G AND BEYOND

A future version of C-V2X presumably supports the "integrated" scenario and brings to bear all of the promise of both DSRC and current C-V2X (both traditional 4G LTE and PC5) using a 5G or later interface. However, 5G technology and standards are still in development, and the focus of wireless carriers seems to be on their bread and butter customers – smart phone users. Whether or not the wireless carriers who plan to operate 5G networks will commit to supporting the performance and latency requirements of real-time safety applications is still a question, and several auto-industry experts have expressed skepticism as to whether a 5G system that is not dedicated to vehicle safety can deliver the necessary performance and reliability.

The promise of dense small cell deployments in urban and suburban areas, more fiber, and the high bandwidth capabilities of 5G, could open the door to sharing a network between time-critical safety, cooperative autonomous vehicles, and traditional cellular applications. For autonomous vehicles, 5G provides a pathway to cooperative applications and sensor data sharing that rely on 5G-based V2X communications, and the communications interface is expected to be available in vehicles for traditional telematics services regardless of its use for V2X. Nonetheless, sharing a general purpose 5G network between smart phone applications (e.g., streaming video) and time-critical vehicle-safety applications still needs to be addressed. Priority would need to be given to time-critical vehicle-safety applications if connected and autonomous vehicles are to rely on a shared 5G network.

3.3 TECHNOLOGY CANDIDATES SUMMARY

Figure 2 provides a comparison of the technology candidates by communications scenarios and readiness, based on the current state of the technologies and extensive interviews conducted.

Figure 2. Connected Vehicle Technology Readiness

	DSRC	Current C-V2X (4G LTE Cellular)	Current C-V2X (PC5)	Future C-V2X (5G and Beyond)
Non-Time-Critical Communications	Yes	Yes	Yes	Yes
Time-Critical Safety Communications	Yes	No	Yes	Yes
Integrated Communications	No	No	No	Yes[12]
Path to 5G	Possible[13]	Yes	Likely[13]	Yes
Communications Standards Complete	Yes	Yes	Partial[14]	No
Ready for Deployment	Yes	Yes	No[15]	No

Source: Interviews

4   MANAGEMENT OF THE DIGITAL/SECURITY INFRASTRUCTURE

As vehicles become more of a network-enabled device than a traditional automobile, new ways to manage and measure security will be required. The SCMS forms the basis of trust for V2V and V2I communication. Authorized users of the V2X system receive digital certificates issued by the SCMS to authenticate and validate safety and mobility messages. The certificates contain no Personally Identifiable Information (PII) or vehicle identifiers. Instead, they serve as system credentials so that other users in the system can trust the source.

---

[12] Assumes a sharing strategy is implemented to prioritize time-critical safety.

[13] Depends on business decisions by chip suppliers and future IEEE 802.11 standards.

[14] SAE J3161 is currently in development for V2V over PC5.

[15] Testing is currently underway.

NHTSA released a Request for Information (RFI) in 2014.[16] This RFI looked for a unique type of information, namely which private entities that "…might have an interest in exploring the possibility of developing and/or operating components of a V2V Security Credential Management System." This indicates that the federal government is considering a potential public-private partnership to manage security.

The SCMS is still a proof-of-concept (POC) system designed to facilitate information exchange between vehicles, roadway infrastructure, traffic management centers, and wireless mobile devices. It currently uses a Public Key Infrastructure (PKI) methodology that utilizes innovative forms of encryption and certificate management to establish trusted communications. The U.S. DOT has indicated the POC will end services in December 2020. A commercial SCMS solution must be deployed in its place; the management of such a nationwide system will be a complex undertaking.

The key to scaling an architecture nationwide will be the role of the Certificate Authority (CA), or root CA. The CAs will create, distribute, and if needed, revoke certificates. The SCMS is the first implementation of a CA, and it will be establishing a misbehavior authority. Through a process of misbehavior detection and reporting, the SCMS will determine if enough reports have been received to revoke certificates from a misbehaving device.

Figure 3. Simplified SCMS Architecture Design
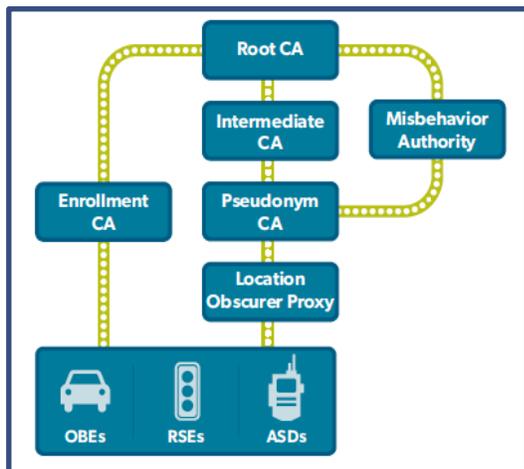
Source: https://www.its.dot.gov/factsheets/pdf/CV_SCMS.pdf

---

[16] https://www.federalregister.gov/documents/2014/10/15/2014-24482/vehicle-to-vehicle-security-credential-management-system-request-for-information

In March 2018, a paper entitled "A Security Credential Management System for V2X Communications" was published in the "IEEE Transactions on Intelligent Transportation Systems"[17] journal. Considerations were given for the time periods the certificate was valid, the number of certificates that would be valid simultaneously, and the overall covered time span. The authors of the papers proposed:

- Certificate validity time period: 1 week
- Number of certificates valid simultaneously (batch size): minimum 20 certificates
- Overall covered time-span: 1 – 3 years.

An in-depth discussion of the SCMS, including the certificate revocation list and associated models, are beyond the scope of this report. The previously discussed IEEE white paper on SCMS contains an in-depth discussion of the key issues.

With regard to security services for application and management messages, IEEE adopted standard 1609.2-2016, most recently revised and approved in March of 2016.[18] The standard seeks to protect "messages from attack such as eavesdropping, spoofing, alteration, and replay." While IEEE 1609.2 was developed for DSRC operating at 5.9 GHz, it can also be applied to PC5 and other systems in other frequency bands.

---

[17] https://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=6979

[18] https://ieeexplore.ieee.org/document/7426684/

5 WHAT ARE AUTONOMOUS VEHICLES?

Autonomous vehicles are often referred to as self-driving cars. They are machine-operated vehicles that may require little or no interaction or intervention by the driver, depending on the capability level. Autonomous vehicles utilize a variety of different methods to sense and respond to their surroundings. SAE has developed a taxonomy defining various levels of automation (Figure 4) ranging from those which provide warnings to a driver behind the wheel, to vehicles for which a steering wheel is not even necessary or present.

Figure 4. SAE Autonomous Vehicle Taxonomy

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: SAE International, SAE J3016[19]

In today's market there are several commercially available examples of cars that support Levels 0 through 2. A number of vehicles support features such as automatic braking or self-parking (Level 0), several vehicles support adaptive cruise control (Level 1), and OEMs such as Tesla and GM are now offering Level

---

[19] https://www.sae.org/binaries/content/assets/cm/content/news/press-releases/pathway-to-autonomy/automated_driving.pdf

2 vehicles. A number of technology companies are also testing levels 3 and 4 vehicles on the road today. Locations such as Las Vegas, NV; Ann Arbor, MI; and San Ramon, CA are operating low speed, fully autonomous shuttles in geofenced areas. Waymo, Uber, and GM have been testing level 3 and level 4 vehicles for as many as nine years in places like San Francisco, Phoenix, and Pittsburgh. In most cases this testing has been done with drivers that can take control, but in some cases the vehicles have been tested without a driver.

The need for autonomous vehicles to be connected has been an important topic among connected and autonomous vehicle stakeholders. In fact, all autonomous vehicles Level 2 or higher require some form of connectivity, but today the connectivity is used for non-time-critical applications (e.g., maps, fleet management, CRM).

When it comes to time-critical connectivity, some developers of AV systems believe that the lack of availability makes time-critical connectivity a non-starter. In fact, at the 2018 Consumer Electronics Show (CES), Waymo CEO John Krafcik stated that he is a lot more interested in "curb space than high-tech things like vehicle-to-vehicle or vehicle-to-infrastructure communications" because, he said, "sometimes they aren't going to work...so we're designing our driver to be robust to failures in V2V or V2I." Survey respondents uniformly agreed, however, that if that connectivity were readily available and densely deployed, they would certainly make use of it. Moreover, they agreed that to reach a truly automated and near accident-free transportation system that low latency vehicle connectivity will be required.

6   THE STATUS OF CONNECTED VEHICLE DEPLOYMENT IN THE UNITED STATES

As of today, more than 30 states have active connected vehicle deployments with over 70,000 vehicles and over 65,000 other devices.[20] These deployments are dominated by DSRC; although, there are a few small deployments that intend to use C-V2X. The remainder of this section highlights a number of the recent and active connected vehicle projects, programs, and deployments in the U.S.

---

[20] Source: Volpe / US DOT

Figure 5. Connected Vehicle Deployment Locations
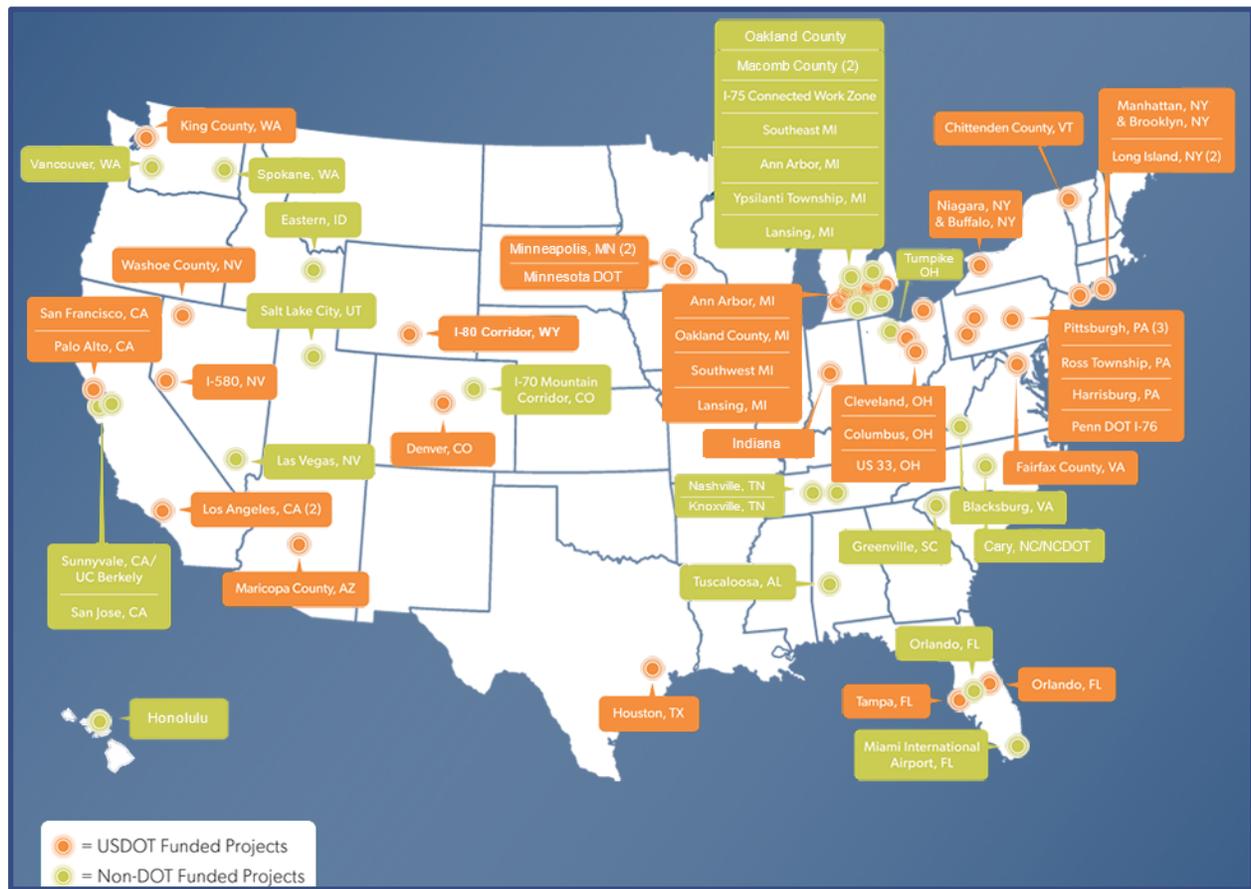
Source: Volpe – The National Transportation Systems Center (U.S. DOT)

6.1 VEHICLE-TO-VEHICLE (V2V) COMMUNICATIONS BACKGROUND

In 1999, the Federal Communications Commission (FCC) allocated 75 MHz of wireless spectrum at 5.850-5.925 GHz band for ITS services using DSRC (5.9GHz band).[21] In the subsequent years, U.S. DOT has worked with the industry and public sector to develop and evaluate new CV technologies.

In 2012, the research on CV technologies culminated in the largest U.S. deployment and evaluation of DSRC technologies and safety applications, the Safety Pilot Model Deployment (SPMD). This deployment

---

[21] https://www.fcc.gov/document/fcc-allocates-spectrum-59-ghz-range-intelligent-transportation-systems-uses.
In 2003, the Commission adopted a Report and Order establishing licensing and service rules for DSRC Communication. https://www.fcc.gov/wireless/bureau-divisions/mobility-division/dedicated-short-range-communications-dsrc-service

was funded by U.S. DOT and led by the University of Michigan Transportation Research Institute (UMTRI) in Ann Arbor. The main focus of the SPMD was:

> "To collect data to support (1) the functional evaluation of V2V safety applications, (2) the assessment of the operational aspects of messages that support vehicle-to-infrastructure (V2I) safety applications, and (3) comprehension of the operational and implementation characteristics of a prototype security operating concept."[22]

Over 2,800 vehicles and 25 infrastructure sites were deployed for the SPMD program. The vehicles included several different types of vehicle fleets and radio manufacturers. The SPMD relied on a version of the SCMS. The results were deemed a success and research from the SPMD showed that CV technology has the potential to address a very significant number of light vehicle and heavy truck crashes by unimpaired drivers.[23]

These results supported NHTSA's decision to move forward with a V2V communications rulemaking for light duty vehicles which NHTSA announced in an Advanced Notice of Proposed Rulemaking (ANPRM) in August 2014. NHTSA documented its conclusions in a report titled, "Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications" (NHTSA Technology Readiness Report).[24]

As noted in the ANPRM:

> "NHTSA believes that V2V capability will not develop absent regulation, because there would not be any immediate safety benefits for consumers who are early adopters of V2V. V2V begins to provide safety benefits only if a significant number of vehicles in the fleet are equipped with it and if there is a means to ensure secure and reliable communication between vehicles. NHTSA believes that no single manufacturer would have the incentive to build vehicles able to "talk" to other vehicles, if there are no other vehicles to talk to—leading to likely market failure without the creation of a mandate to induce collective action."[25]

Subsequently, NHTSA issued a Notice of Proposed Rulemaking (NPRM) which, if approved, would require new vehicles sold in 2023 in the United States to have DSRC based V2V connectivity.[26] In early November

---

[22] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812171-safetypilotmodeldeploydeltestcondrtmrep.pdf.

[23] Id. Prior to the SPMD, U.S. DOT sponsored a number of proof of concept pilots and research.

[24] https://www.its.dot.gov/pilots/future_cv_activities.htm

[25] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

[26] Id.

2017, reports surfaced that the Administration had dropped further consideration of the proposed rule, but NHTSA attempted to rebut those reports, issuing a statement that read in part:

> "The Department of Transportation and NHTSA have not made any final decision on the proposed rulemaking concerning a V2V mandate. Any reports to the contrary are mistaken.
>
> NHTSA is still reviewing and considering more than 460 comments submitted and other relevant new information to inform its next steps. An update on these actions will be provided when a decision is made at the appropriate time…While DOT withdrew or revised 13 rules this year, V2V is not one of them, and it remains on DOT's significant rulemaking report."[27]

Between the August 2014 publication of the ANPRM and the end of 2017 when it became clear that further federal action on a V2V mandate would be delayed, in excess of 100,000 motor vehicle deaths occurred.[28] Meanwhile, the V2V Communications Standard, SAE J2945/1, was developed with federal support from the SAE DSRC Technical Committee to support the potential mandate.

One additional factor in the delay is recent FCC action to refresh the regulations on the 5.9 GHz DSRC band. The FCC has been under tremendous pressure over the past five plus years to open the 5.9 GHz spectrum for other uses. When the spectrum was initially allocated, it was not considered as desirable as it is today. However, as technology has evolved, and lower frequencies become more congested, the spectrum has become more valuable and other users have sought access to it. FCC Commissioners have expressed frustration that the spectrum is not being more fully utilized and have initiated spectrum sharing tests.[29] Stakeholders currently using unlicensed Wi-Fi technology such as 802.11ac have been aggressively advocating for allowing coexistence between ITS and traditional wireless local area network (LAN) connectivity. An updated rulemaking regarding the allowable usage of the 5.9 GHz spectrum is expected later this year or in 2019.

---

[27] In lieu of a May 2018 Report on Significant Rulemakings, DOT directed readers to the Office of Management and Budget's (Reinfo.gov) "Spring 2018 Unified Agenda of Regulatory and Deregulatory Actions." The NPRM related to the V2V mandate, RIN 2127-AL55, does not appear on the Unified Agenda, suggesting that it is no longer under active consideration even though final agency action has not been taken. The June 2018 Report on Significant Rulemakings, however, continues to identify this rulemaking although without any dates as to expected action.

[28] According to NHTSA data, 37,461 lives were lost on U.S. Roads in 2016, an increase of 5.6 percent from calendar years 2015's 35,485 lives lost. Assuming a 1% decrease for 2017 as projected by the National Safety Council, the total for the 2015 – 2018 is 110,032 lives lost to traffic fatalities.

[29] https://www.fcc.gov/document/59-ghz-public-notice

In February 2013, the FCC released an NPRM[30] that would allow sharing of the DSRC band[31] with unlicensed devices (a proposed U-NII-4 band) that would allow services such as Wi-Fi to use some or all of the DSRC band. Since the NPRM, the FCC and other organizations have been testing and developing potential band sharing solutions. Compounding the confusion over potential regulatory changes are efforts to replace DSRC with PC5, which would also be deployed in the 5.9 GHz band. The potential for new regulations in the spectrum currently allocated for DSRC has muddied the water with respect to deployment of V2X at 5.9 GHz.

6.2   SAFETY PILOT MODEL DEPLOYMENT

Since the completion of the SPMD program, UMTRI has continued to operate the connected vehicle test environment. While federal funds will run out at the end of 2018, private funds have been obtained to support another three years of operation. UMTRI and its partners have deployed DSRC throughout Ann Arbor, MI. Participating vehicles are getting SPaT messaging and traffic flow information. UMTRI is also deploying four test sites at pedestrian crossings with pedestrians who are using personal devices. UMTRI is currently updating the technology on 3,100 vehicles and 25 roadside units with new radios that are compliant with current security and DSRC standards. It is also deploying an additional 45 roadside units.

6.3   CONNECTED VEHICLE PILOT DEPLOYMENT PROGRAMS

In 2016, the U.S. DOT followed up on the SPMD program by awarding cooperative agreements, collectively valued at more than $45M, to initiate a Design/Build/Test CV Pilot in three sites: New York City (NYC), Wyoming and Tampa, FL. These three sites are collectively known as the CV Pilot Deployment Program or CV Pilots. The first year each site prepared a comprehensive deployment plan. In 2017, the three sites began a 20-month phase to design, build, and test for the agreed upon CV technologies and applications. On its website, U.S. DOT states that they:

> "Will provide a prototype national-level Security Credential Management System (SCMS) as a key tool for implementing a Public Key Infrastructure (PKI) based system for communication security controls to meet these needs. The SCMS provides digitally signed certificates that can be used as part of the process for signing and encrypting messages."[32]

---

[30] https://docs.fcc.gov/public/attachments/FCC-13-22A1_Rcd.pdf

[31] https://www.ecfr.gov/cgi-bin/text-idx?SID=0e43ee44dd326d95781d7c44c8d62788&mc=true&node=sg47.5.90_1365.sg1&rgn=div7

[32] https://www.its.dot.gov/pilots/cv_pilot_faq.htm

The NYC deployment is primarily focused on safety applications that rely on V2V, V2I, and infrastructure-to-pedestrian communications. These applications provide drivers with alerts so that the driver can take appropriate action to avoid or reduce the severity of a crash.

The NYC deployment is focused in three geographic areas: a four-mile segment of Franklin D. Roosevelt (FDR) Drive in the Upper East Side and East Harlem neighborhoods of Manhattan; four one-way corridors in Manhattan; and a 1.6-mile segment of Flatbush Avenue in Brooklyn. Approximately 5,800 cabs, 1,250 Metropolitan Transit Administration buses, 400 commercial fleet delivery trucks, and 500 NYC vehicles that frequent these areas are being retrofitted with the V2V technology. Approximately 310 signalized intersections also have been augmented with V2I technology. In addition, NYC will deploy approximately eight roadside units along the higher-speed FDR Drive to address challenges such as short-radius curves, a weight limit and a minimum bridge clearance. Thirty-six radios will be installed at other strategic locations throughout NYC to support system management functions. Finally, NYC plans to equip approximately 100 pedestrians with personal devices that will assist them to safely cross streets.

The Wyoming Department of Transportation (WYDOT) deployment will use V2V and V2I connectivity to improve monitoring and reporting of road conditions to vehicles on Interstate 80 (I-80). In southern Wyoming, I-80 runs above 6,000 feet in elevation and is a major freight corridor. During winter, wind gusts can exceed 65 mph and crash rates are three to five times higher than those in the summer.[33]

The WYDOT deployment focuses on the needs of commercial vehicle operators. Four hundred vehicles will be outfitted with on-board radios, at least 150 of which will be heavy trucks that are regular users of I-80. An additional 100 WYDOT fleet vehicles such as snowplows and highway patrol vehicles will be equipped with both on-board units and mobile weather sensors. Seventy-five roadside units are being deployed strategically, which in addition to providing V2V and V2I safety messaging, will provide traveler information through 511 and a commercial vehicle information portal.

The Tampa-Hillsborough Expressway Authority (THEA) deployment will deploy V2V and V2I technology to address urban congestion, reduce collisions, and prevent wrong way entry at the Selmon Reversible Express Lanes (REL). REL ends at major routes into and out of the downtown Tampa commercial business district. Drivers typically experience significant delays during the morning peak hour, which result in a correspondingly large number of rear-end and red-light-running collisions. Because the lanes are reversible, wrong way entry is also a problem. The THEA deployment is also using CV technology to enhance pedestrian safety, speed bus operations, and reduce conflicts between street cars, pedestrians, and passenger cars at locations with high volumes of mixed traffic.[34] THEA is deploying radios along city streets in approximately 1,600 cars, 10 buses, 10 trolleys, with smartphone applications carried by 500 pedestrians, and approximately 40 roadside units.

---

[33] https://wydotcvp.wyoroad.inf

[34] Id. at https://www.its.dot.gov/pilots/pilots_thea.htm

6.4   SMART CITY CHALLENGE

In December 2015, U.S. DOT launched its Smart City Challenge, requesting mid-sized U.S. cities develop ideas for an integrated, first-of-its-kind, smart transportation system that would use data, applications, and technology to help people and goods move more quickly, cheaply, and efficiently. Seventy-eight cities competed for the $40M grant from U.S. DOT and the $10M grant from VULCAN.[35] Columbus, Ohio won the challenge and has parlayed these grants into over $450M in additional private sector pledges. With these funds, Smart Columbus has initiated a number of transportation and data programs ranging from DSRC to smart payment systems. At the heart of this is the Smart Columbus Operating System (SCOS) that is envisioned as a web-based data delivery platform to integrate data from deployed smart technologies and community partners offering an open-source environment for data analysis, software development, and application development. On the connected and autonomous vehicle front, Smart Columbus will:

- Deploy DSRC technology along 50 miles of roadway, at 175 traffic signals, and on 3,000 vehicles.
- Deploy AVs through three routes in the Easton Commercial District.
- Implement driver assisted truck platooning.
- Deploy connected electric AVs to address the first mile/last mile challenges associated with transit use. [36]
- Deploy a low speed self-driving shuttle service.

From a security standpoint, Smart Columbus is in its second iteration of its Data Management and Data Privacy Plans, which define how data will be stored, accessed, secured, retained, and refreshed. With respect to CVs and AVs, the SCOS will process data at the edge and only move data that is needed for analytics purposes. Personally identifiable information will be anonymized before being stored within the SCOS.   Data that is being taken in directly from the vehicle will be processed and stored within a backhaul network that is separate from the SCOS. All data will be encrypted. The vehicles will receive certificates from a statewide SCMS system

Smart Columbus is also connected to the Technology Research Center (TRC), the country's largest independent vehicle test facility, by the US-33 Smart Mobility Corridor, a 35-mile highway corridor that is home to a large concentration of manufacturers, research and development firms, and logistics companies.

Ohio DOT is in the process of installing fiber along the US-33 Smart Mobility Corridor and outfitting it with CV technology that will allow CV and AV manufactures to test their products in a fully outfitted controlled

---

[35] Vulcan Inc. is a privately held company founded in 1986 by philanthropist, investor, and Microsoft co-founder Paul Allen to oversee his business activities and philanthropic endeavors.

[36] https://smart.columbus.gov/projects/

environment at TRC, on the Smart Mobility Corridor connecting TRC to Columbus, in suburban communities outside of Columbus, and in an urban environment in Columbus.

Finally, Smart Columbus is part of the Smart Belt Coalition, which is a regional connected and automated vehicle collaborative connecting Michigan, Ohio, and Pennsylvania. The Smart Belt Coalition plans to connect the freight corridors between the states so that they may test cross state interoperability.

At the end of 2016, U.S. DOT announced an additional $65 million in grants to support other community-driven, advanced technology, transportation projects. These grants will fund 19 projects in local areas to fight congestion, increase connectivity, and improve access to transportation opportunities.[37]

6.5 TRANSPORTATION INFRASTRUCTURE OWNER/OPERATOR DEPLOYMENTS OF DSRC

In January 2018, the Coalition for Safety Sooner, a group of 22 operators deploying DSRC technology, sent a letter to U.S. DOT, the Office of Management and Budget, and the FCC expressing its support for the NPRM mandating the use of DSRC in light duty vehicles.[38] This letter was in response to news reports discussed previously that NHTSA was no longer considering this proposed rule.

The coalition letter cites major DSRC deployments such as the SPMD, the CV Pilots, Smart Columbus, as well as smaller efforts in 26 states and cities in response to the American Association of State Highway Transportation Officials' (AASHTO) "SPaT Deployment Challenge," and provides written descriptions of each deployment. The letter argues that active DSRC deployment is creating a diverse industry, is necessary to save lives, is ready to be deployed now, and will produce benefits even with low penetration. One major automobile manufacturer stated that V2I and state deployment initiatives provide the incentives that they need to move forward with DSRC. This manufacturer believes that with V2I the consumer will receive benefits beyond V2V safety.

Through interviews with key state and local government transportation stakeholders, we learned that in response to the SPaT Challenge, approximately 2,000 intersections have already been outfitted with DSRC radios. This is a significant first step toward the coverage needed to support connected and autonomous vehicles. One State DOT leader said that current manufacturers are having difficulty keeping up with demand, that they had been surprised at the lack of technical sophistication of some of the equipment that they had purchased, and that they had faced some challenges getting different manufacturer equipment to interoperate. Recently, however, U.S. DOT announced that the CV Pilots had successfully demonstrated interoperability of three deployment sites, six device vendors and

---

[37] https://www.transportation.gov/smartcity/what-comes-next

[38] https://www.globalautomakers.org/012318%20Coalition%20for%20Safety%20Sooner.pdf

multiple communications media.[39]   Another transportation director identified the need for regional deployments to address the differences in technology between cities and states.

6.6   AUTOMOBILE MANUFACTURERS' EFFORTS TO DEPLOY DSRC

The Crash Avoidance Metrics Partnership (CAMP), which was formed by Ford Moto Company and General Motors (GM), has been instrumental in the development and deployment of DSRC-based safety applications. Their joint research with NHTSA formed much of the basis for the NPRM. A number of Auto OEMs in addition to Ford and GM participated in CAMP's V2V research programs. CAMP extensively supported the SPMD (See Section 6.1) and continues to support V2X research.

At the 2014 Intelligent Transport Systems World Congress in Detroit, GM CEO Mary Barra announced that the company would begin deploying its Super Cruise driver assist system and DSRC in the 2017 Cadillac CTS. To date, GM has installed DSRC in about 20,000 Cadillac CTSs.[40]

In June 2017, Volkswagen Group announced that it would deploy DSRC in its European models beginning in 2019.[41]

In April 2018, Toyota and Lexus announced that they would deploy DSRC in vehicles for sale in the United States beginning in 2021.[42] The announcement noted that the technology would "enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications – collectively known as V2X DSRC technology, which has been comprehensively tested through government-industry collaborations and is already deployed in some areas of the U.S." Toyota's press release stated that the company had collaborated with other automakers and infrastructure organizations over the previous 15 years to create an industry standard and "encourage[ed] all automakers and transportation infrastructure owner/operators to quickly commit to DSRC technologies in the U.S. to realize the full safety and traffic flow benefits of this technology."

Shortly after Toyota's announcement, FCC Commissioners Michael O'Reilly (R) and Jessica Rosenworcel (D) responded to the Toyota announcement by warning the company that:

> "The Commission, the Department of Transportation, the National Telecommunications and Information Administration, and associated automotive and communications industries currently

---

[39] https://www.its.dot.gov/pilots/crosssite_cvp.htm

[40] http://michiganradio.org/post/gm-become-first-automaker-roll-out-connected-vehicles

[41] http://www.autoconnectedcar.com/2017/06/vw-will-offer-v2v-v2x-v21-as-a-standard-feature-in-2019-models/

[42] http://corporatenews.pressroom.toyota.com/releases/toyota+and+lexus+to+launch+technology+connect+vehicles+infrastructure+in+u+s+2021.htm

are evaluating the potential for future unlicensed operations in spectrum allocated for DSRC ... with the goal of promoting efficient use of the band for spectrum sharing."[43]

The Commissioners went on to state that "it also included looking at potential opportunities to advance automotive safety using newer technology, such as C-V2X." As discussed above, the FCC has long been frustrated with the slow pace of DSRC deployment. A number of entities have petitioned the FCC for release of the spectrum or for spectrum sharing.[44] In fact, WiFiForward recently released an economic report showing the value of unlicensed spectrum to the U.S. economy has grown by 129% since 2013. The report found that unlicensed spectrum generated $525B in value to the U.S. economy in 2017, and projects the economic value of unlicensed spectrum in the United States to reach $834B by 2020.[45]

Toyota responded to the FCC's warning by stating the "decision by Toyota and Lexus to deploy DSRC in the U.S. is just the latest development in the ongoing and persistent move by automakers, infrastructure owners and operators, and other stakeholders to deploy this proven technology throughout the world."[46] The letter then cites Toyota's deployment in Japan, the deployment of DSRC technology outlined in the letter to the FCC from the Coalition for Safety Sooner and the VW Group's announcement that it would deploy DSRC in their vehicles in Europe beginning in 2019 and concludes that they are comfortable with their decision to deploy capital on DSRC in the United States.

Most recently, at the ITS America 2018 Annual Meeting in Detroit, Mark Reuss, GM executive vice president of Global Product Development, announced that GM would expand its deployment of Super Cruise to all Cadillac product lines in 2020 and to all GM brands soon thereafter.[47] He also announced that GM would expand its deployment of DSRC in an unnamed high-volume crossover beginning in 2023 with the goal of expanding the technology across the entire Cadillac portfolio. Like Super Cruise, the technology will likely be expanded to all GM brands. GM has stated that it is in conversations with Toyota to coordinate the roll-out of DSRC and to expand the automakers participating in the effort.

---

[43] https://www.fcc.gov/document/orielly-and-rosenworcel-letter-james-lentz-ceo-toyota-motor-na

[44] https://www.newamerica.org/oti/wireless-future-project/legislativeregulatory-filings/2016/77-public-interest-fcc-comments-wi-fi-sharing-59-ghz-auto-industry-spectrum/

[45] https://www.businesswire.com/news/home/20180517005387/en/Economic-Unlicensed-Spectrum-Reach-834-Billion-2020

[46] https://ecfsapi.fcc.gov/file/10518525607840/Toyota%20Response%20O'Rielly%20Rosenworcel%205.18.18.pdf

[47] https://www.wileyconnect.com/home/2018/6/7/top-5-takeaways-from-its-america-2018-on-the-v2x-path-forward

6.7 AUTOMOBILE MANUFACTURERS'/TECHNOLOGY PROVIDERS' EFFORTS TO DEPLOY C-V2X

As noted earlier, 5GAA was formed to promote 5G-based V2X solutions. In its response to the NPRM, several OEM members acknowledged a desire to explore the merits of deploying C-V2X (PC5 and 5G) in place of DSRC. In 2016, the San Diego Association of Governments (SANDAG) was designated by U.S. DOT as an autonomous vehicle proving ground. In October 2017, SANDAG and Caltrans worked with companies like AT&T, Ford, Nokia, and Qualcomm to formally launch their autonomous vehicle proving ground. The proving ground has included testing of C-V2X technology (PC5).

More recently, Ford, Panasonic, and Qualcomm began working with the Colorado Department of Transportation (CDOT) on the first deployment of C-V2X in the United State as part of Colorado's RoadX program.[48] Note RoadX started with and also includes the deployment of DSRC-based applications. While RoadX is primarily a test bed at this time, it could eventually lead to a commercially available system.

CDOT and Panasonic plan to outfit 90 miles of Interstate 70 for connected cars and autonomous vehicles. CDOT also plans to outfit 2,500 vehicles with aftermarket devices and construct the first commercial scale data platform to process the connected vehicle data. Finally, CDOT plans to instrument the majority of its network with connected vehicle technology by 2021.

To support its partnership with Colorado, Panasonic moved its Panasonic Enterprise Solutions Technology Hub to Denver and, at the 2017 Consumer Electronics Show, announced it would build a smart city with Denver on a 400-acre swath of empty land near the Denver Airport. Panasonic will install C-V2X technology, DSRC, free Wi-Fi, LED street lights, pollution sensors, a solar-powered microgrid, security cameras, and other technology at this smart city.

6.8 AUDI'S DEPLOYMENT OF CELLULAR V2X TECHNOLOGY OVER 4G LTE

Audi of America, in conjunction with Traffic Technology Services (TTS), launched a cellular based V2I system within Audi connect that will be available on all Audi models within the next two years. The system enables a vehicle to communicate with traffic signals in 13 cities and metropolitan areas (approximately 2,250 signalized intersections). TTS has agreements with an additional 60 agencies throughout North America representing an additional 20,000 signalized intersections. Audi plans to expand this technology to all of these cities.

The current technology provides a service that when a connected vehicle approaches a connected traffic light, the vehicle receives SPaT and Map Data information from TTS via an on-board data connection. When the light is red, the vehicle will display the time remaining until the signal changes to green in the instrument cluster in front of the driver or in a heads-up display. When the light is green, and the vehicle

---

[48] https://www.codot.gov/programs/roadx

cannot make it safely through the intersection, the vehicle will display the time remaining until the next green, addressing dilemma zones for drivers. Audi has stated that future updates to this technology could include integration within the vehicle's start/stop function, green light optimized speed advisories, optimized navigation routing, and other predictive services. These updates can be made electronically and turned on at any time within the existing system. All of these services are designed to improve a driver's experience, help reduce congestion, and enhance mobility on crowded roadways.

6.9 ROLE OF THE COMMUNICATIONS INFRASTRUCTURE PROVIDERS IN SUPPORTING V2V

One of the key benefits of V2V communications is that it is transmitted over the 5.9 GHz band and does not require direct network operator participation or infrastructure. As such, there are no network operator fees for V2V communications.

In the NPRM, NHTSA states that it does not regulate the collection or use of V2V communications or data beyond that necessary for safety applications.[49] That fact does not, however, preclude other entities from collecting and aggregating this data. Manufacturers can take the V2V data from its vehicles and combine it with data from other sources to provide or supplement safety and commercial applications. While V2V messages do not directly identify vehicles or their drivers, an OEM's use of that data for other purposes will have privacy implications that it must address with its customers.

The introduction of a communications interface into vehicles will also provide a pathway for state and local governments that operate transportation systems to communicate safety information from the roadside to vehicles. This includes SPaT, which enables red light and railroad crossing warnings, as well as miscellaneous safety advisories such as curve speeds, construction zones and school zones. These additional safety and mobility applications have driven many state and local governments to begin deploying roadside equipment.

To accommodate the information requirements of the local government, roadside units connected to the Traffic Management Center (TMC) will need to be deployed. The roadside units can be stand-alone units or can be combined in some fashion with existing or future small cells Given the volume of data likely to be transmitted, these roadside units will need to be connected to the TMC through some sort of backhaul. This can be done through existing purpose-built wiring, existing carrier operated networks, or fiber deployed specifically for this purpose (and likely others). Fiber connectivity is desirable given the likely data volumes. UMTRI reports that the Model Safety Pilot utilized more than 60% of Ann Arbor's fiber

---

[49] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

capacity and New York City indicated that the deployment of 1,000 connected vehicles over 18 months produced more that 250 terabytes of data.

Roadside equipment will enable connectivity to the roadside, the TMC, or other non-vehicle users (e.g., pedestrians, cyclists). Doing so can provide direct safety benefits to the vehicle, its operator, and non-vehicle users, as well as support traffic management and signal timing optimization on arterials. When combined with traffic management data already being produced and utilized by the TMC, additional safety benefits, as well as new business opportunities for both the government agency and commercial entities, can be created.

Interviews with the operators indicate that most do not want to be responsible for collecting, storing, and analyzing the large volumes of data likely to be produced by the connected vehicle program. Most stated that they do not have the technical capability or resources to do so. UMTRI shared that terabytes of data that it collected during the MSDP and made available to the public for research purposes has rarely been accessed. The gap between the volumes of data being produced by the OEMs and the operators and the need to store, analyze, and make the data actionable creates a ripe opportunity for public-private partnerships such as RoadX.

Without a NHTSA mandate, most respondents interviewed suggested that adoption of vehicle connectivity for safety will be slow and fragmented. However, some were optimistic that an unregulated market would drive adoption faster, especially with the advent of autonomous vehicles. However, connectivity for autonomous vehicles generally focuses on operations (e.g., maps and routing), as opposed to safety. The interview results also suggest that deployment of vehicle safety communications will be slow, if not stalled altogether, without a mandate.

Of the interviewees, 48 responded to the question, "Is a mandate necessary for the success of V2X deployment?" The majority believe a mandate is needed, but most of the respondents also believe the market will continue without a mandate, just at a slower pace.

Figure 6. Is a Connected Vehicle Mandate Needed?

Response	Count
Yes	30
No	8
Not Sure	10
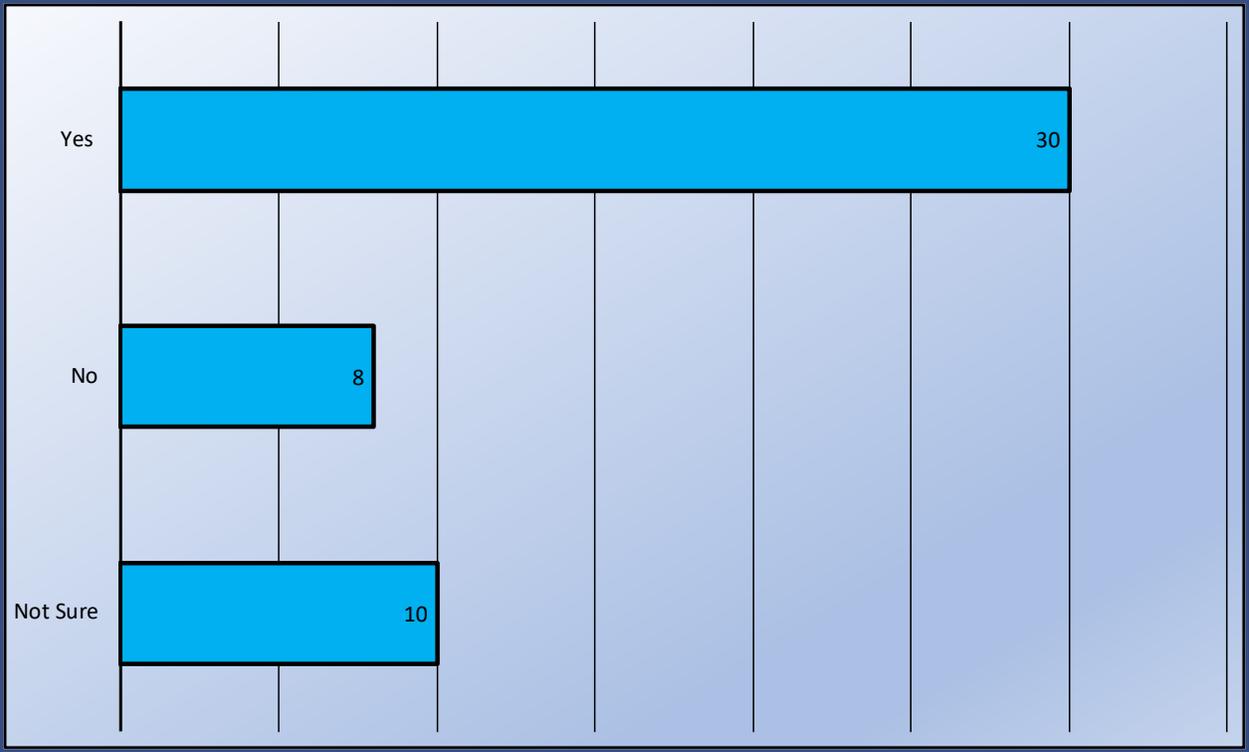
Source: Interviews

6.10 CONNECTED VEHICLE STANDARDS DEVELOPMENT ACTIVITIES

Since the late 1990s, standards have been under development to support V2X applications. For the United States, the currently published key standards include:

- IEEE 802.11p – Physical interfaces standard for DSRC
- IEEE 1609 – Communications middleware (e.g. networking and security)
- SAE J2735 – Data dictionary for connected vehicle applications
- SAE J2945/0 – Common design elements for connected vehicle applications
- SAE J2945/1 – V2V safety communications
- 3GPP Release 14 – V2X features/PC5 (potential DSRC replacement)

In addition, there have been significant standardization activities globally in ETSI, ISO, and in China, much of which is compatible with standards developed for the United States. These standards have been used to support the many pilot deployment projects and efforts by manufacturers to deploy connected vehicle applications. Substantial V2X standards development activities continue, with the expectation that the

market will continue to grow despite the lack of a V2V mandate. In the United States, these efforts generally focus on:

- Continued development of security protocols and policies
- Revisions of existing communications standards to support future applications and technology evolution
- Road weather applications
- Road safety applications addressing areas such as work zones and roadway curves
- Pedestrian and other vulnerable road user safety (e.g., bicycles, motorcycles)
- V2V safety for heavy vehicles (large trucks)
- Cooperative cruise control and platooning

International standards efforts are also supporting similar objectives.

6.11 INTERNATIONAL STANDARDS HARMONIZATION

Notwithstanding the lack of resolution on a V2V mandate in the United States, multiple V2V and AV projects have been undertaken across the America, in Europe, and in Asia, as the significant safety benefits to be derived from V2V and AV technology are recognized globally. Efforts have been undertaken around the world to develop the relevant technology, adapt infrastructure to maximize the value of the technology, and evaluate the means by which these life-saving technologies can be more completely implemented, quickly

The NHTSA Technical Readiness Report and comments filed in the docket addressed the issue of global harmonization extensively. Most commenters that addressed the issue encouraged NHTSA to foster global harmonization between the United States, European Union (EU), and Asia-Pacific regions. Coupling the V2V research and development activities conducted in both Europe and Asia with those undertaken in the United States holds the promise to reduce costs and complexity, facilitate cross-border traffic, and expedite the life-saving deployment of the technology.

Thus far, extensive harmonization of hardware, messaging, and security criteria has occurred voluntarily between the United States and Europe. It is anticipated that common radios and antennas in both the United States and Europe will also facilitate and expedite deployment. While the V2V applications developed in Europe place a priority on mobility and sustainability, the U.S. focus has been on safety applications.

Japan, Korea, and Australia have taken leadership roles in the harmonization in the Asia-Pacific region utilizing DSRC-based V2X communications. Japan's current V2X approach centers on the adaptation of their electronic tolling system operating at 5.8 GHz. They adopted V2X technology more than ten years ago on their major toll roads and highways, and provide drivers with a broad array of traffic and safety information. Additionally, some Japanese OEMs (mainly Toyota) are supporting the deployment of V2X using 760 MHz communications, resulting in more than 100,000 vehicles on the road using V2V technologies. Message sets harmonized between Europe, the United States, and Korea currently use the

5.835-5.855 GHz band for Electronic Toll Collection and DSRC experimentation. Korea has performed field tests for V2V communication in this band and industry sources indicate that Korea may shift DSRC for ITS to 5.9 GHz to be better aligned internationally. Similarly, Australia is investigating potential interference issues and working with license holders to evaluate the feasibility of using the 5.9 GHZ spectrum for V2X in Australia.

Conversely, China has made a commitment to both DSRC and cellular V2X (C-V2X) and has plans to deploy C-V2X on 80% of its roads and in 80% of its vehicles by 2020.[50]

7 RECOMMENDATIONS FOR CONNECTED VEHICLE TECHNOLOGY

Widespread CV and AV technology deployment will require a robust communications system and associated communications infrastructure capable of moving the millions of bits of data generated in a CV/AV ecosystem. Building that infrastructure will, in large measure, be the responsibility of the carriers and their suppliers pursuing communications business opportunities. The building of the necessary communications infrastructure is reminiscent of the "chicken and egg" metaphor, which in our opinion requires that the specifications for CVs and AVs come first. As a result, our recommendations focus on the means by which a clear path forward is established for CVs and AVs. As a result, we believe that the necessary infrastructure will fall into place.

U.S. DOT has concluded that the deployment of CV technology will result in the reduction of non-impaired crash scenarios by more than 80%. Even if they are wrong by half, deployment of this technology will still result in significant savings in terms of lives and property. U.S. DOT has also concluded that without a mandate, connected vehicle technology deployment will be slow and fragmented.[51] As such, we make the following recommendations in this area.

THE FEDERAL COMMUNICATIONS COMMISSION SHOULD CONTINUE TO PROTECT THE 5.9 GHZ ITS BAND FOR VEHICLE SAFETY

In 1999, the FCC set aside 75 MHz of spectrum in the 5.9 band for ITS specifically for connected vehicles. It did so because of the promise that thousands of lives would be saved annually with this technology. We are finally on the cusp of wide-spread deployment and are now seeing increased deployment of CV technology at the state and local level, major manufacturers announcing their intention to adopt the technology, and a competing CV technology that will utilize the 5.9 GHz spectrum. Now is not the time to

---

[50] Information provided by an interviewee.

[51] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

open up the spectrum to un-licensed uses or to spectrum sharing without the guarantee that there will be no interference.

U.S. DOT SHOULD MANDATE THE DEPLOYMENT OF V2V CONNECTIVITY TO ENHANCE SAFETY, MINIMIZE MARKET CONFUSION, AND REDUCE COSTS

U.S. DOT has already demonstrated that connected vehicle technology can save lives. Moreover, U.S. DOT and industry have invested more than $1B in cooperative research. Still, the industry has not been able to coalesce around a deployment scenario. In the ANPRM, U.S. DOT noted that:

> "Most prominently, vehicles need to communicate a standard set of information to each other, using interoperable communication that all vehicles can understand. The ability of vehicles to both transmit and receive V2V communications from all other vehicles equipped with a V2V communications technology is referred to in this document as "interoperability," and it is vital to V2V success. Without interoperability, manufacturers attempting to implement V2V will find that their vehicles are not necessarily able to communicate with other manufacturers' vehicles and equipment, defeating the objective of the mandate and stifling the potential for innovation that the new information environment can create."[52]

Many believe that the likelihood of connected vehicle deployment has increased this year with the leadership of the operators deploying roadside equipment, manufacturers announcing their intention to produce vehicles with CV technology, and a number of major companies willing to put their research and marketing dollars behind C-V2X technology. One respondent said that "having a company like Qualcomm apply their resources to connected vehicle technology is the game changer we have always needed." Another respondent placed the credit at the feet of the state and local operators that are moving forward with the deployment of DSRC infrastructure.

In some respects, this progress has led to more confusion. We now have organizations supporting DSRC, C-V2X (4G LTE cellular or PC5), 5G, or nothing at all, with no clear path to consensus. It is not clear that without a mandate that there will be uniform adoption of CV technology. Rather, we could have manufacturers and operators adopting different technologies that are not necessarily interoperable. If this occurs, the requisite penetration may not be achieved.

U.S. DOT SHOULD DRIVE THE INDUSTRY TO A SINGLE V2V TECHNOLOGY

Technology neutrality should always be the goal of government. It never wants to be accused of picking winners and losers. U.S. DOT Secretary Chao has stated that this Administration intends to act in a

---

[52] https://www.fhwa.dot.gov/fastact/factsheets/apportionmentfs.cfm

technically neutral manner, and in interviews with both the majority and minority staffs of the Senate Committee on Commerce, Science, and Transportation, they indicated their support for this proposition as well. However, based on our interviews, it appears that there is a strong desire for a single connected vehicle solution (DSRC or CV2X, but not both). Both the OEMs and the owner/operators are concerned about the cost and complexity of supporting multiple connectivity solutions. Because PC5 will not run on their networks, the carriers are somewhat ambivalent. While there may be some long-term cost savings and easier transition to 5G for the carriers, it is not yet clear how vehicle connectivity will play out in a 5G environment.

If U.S. DOT promulgates a performance-based rule, it should consider including a default provision that drives the industry towards a common solution. Either the industry agrees on a solution which could be one of the existing technology solutions, a new technology solution, or a combined solution within one year, or the rule will default to one of the currently available technologies. Doing so would minimize delay and allow OEMs and infrastructure owners and operators to plan. While the industry could rely on market forces to drive a common solution, the absence of a rule will likely result in delays and in many thousands of lives being unnecessarily lost.

If U.S. DOT does not promulgate a rule requiring CV technology these important safety enhancements will be delayed even if industry participants utilize their participation in standards development organizations to bring forth the appropriate standards to ensure interoperability.

U.S. DOT SHOULD FINANCIALLY SUPPORT THE DEPLOYMENT OF V2X TECHNOLOGY

U.S. DOT should make Infrastructure for Rebuilding America (INFRA) Grant Program funds, Better Utilizing Investments to Leverage Development (BUILD) grants, as well as other FAST Act[53] funds available to seed the deployment of CV technology. This could come in two forms. First, funds should be made available to support the deployment of roadside equipment at both the state and local level. Second, funds should also be made available for the strategic deployment of aftermarket devices in government owned or operated fleet vehicles. For example, CDOT has applied for a $23M BUILD grant to provide the remaining funding for their $117M CV build out which is to be completed by 2021. CDOT is located in a very progressive state with a progressive governor and DOT director, but most states are not so lucky. Moreover, over 75% of the nation's traffic signals are owned and operated by cities and counties that face even more financial and technical constraints than do state DOTs. For this program to be successful, it will be key to get funds and technical support to the cities and counties. Doing so would build the market while the manufacturers develop and install in-vehicle technology. Finally, it would also help generate public acceptance.

---

[53] https://www.fhwa.dot.gov/fastact/factsheets/apportionmentfs.cfm

As operators upgrade their infrastructure, they should also update their technology. Michigan, Arizona, Utah, and other states are deploying DSRC radios as they upgrade their traffic signals. Operators should also look to the private sector for help in funding this upgrade. As carriers look to roll out small cells, they should also be looking for willing partners. AT&T and Verizon recently entered into agreements with San Jose to upgrade its network in return for data and access. Panasonic entered into an agreement with Colorado. Crown Castle has agreements with Utah and Colorado. Others will be looking for access to data or real estate and may be willing to reach valuable cost or revenue sharing agreements. Operators concerned about the current debate around which CV technology to deploy can now install both radios at a very low cost and hedge their bets.

Operators should also be looking to deploy fiber whenever possible. Utah DOT has rolled fiber out throughout their entire network and now sees that it can easily meet the looming data transfer needs. Other DOTs should look to partner with existing fiber providers to sell their fiber, to enter into fiber maintenance agreements, or to lease fiber rather than build it themselves. Depending on the specific characteristics of the location, these are all options that can save an operator resources or generate revenue for new technology.

8 POTENTIAL CONNECTED VEHICLE ROLL-OUT SCENARIO

Roll-out scenarios for V2V, V2I, and V2X vary dramatically based upon the different assumptions used. The goal of this roll-out scenario is to save lives by deploying as much technology on the roadway as possible, quickly and cost effectively.

The first assumption is that deploying connected vehicle technology will save lives and is desirable. Most individuals believe that if deployed, this technology has substantial safety benefits. Some believe that current Advanced Driver Assistance Systems (ADAS) equipment accomplishes such a high percentage of the safety benefits associated with connected vehicle technology that its deployment is not warranted. A detailed cost benefit analysis of the V2V proposal is contained in the NPRM.[54]

The second assumption is that V2X is a desirable goal. While deploying V2V technology will provide very significant benefits if deployed properly, it will be largely invisible to the driver, and therefore difficult for the OEMs to monetize.[55] As V2X is deployed more extensively, drivers will benefit from enhanced safety and mobility applications. Manufacturers and other commercial operators will have the ability to create

---

[54] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

[55] It is anticipated that costs will drop as deployment expands, enabling OEMs to compete on safety benefits.

new safety and mobility services. Operators will have the ability to leverage V2V data along with current TMC data to provide enhanced safety and mobility services to their customers and new business opportunities.

The third assumption is that the industry will coalesce around one technology. This could be done through the existing NPRM or the NPRM could be revised to be completely technology neutral.[56] Alternatively, NHTSA could establish a performance-based mandate that would permit the market to decide between DSRC and C-V2X. In this case the market and open standards development organizations would determine the technology winners, but it would likely result in a deployment delay of three to five years. If the NPRM were revised, we suggest that it include a provision that if the industry cannot coalesce around a specific technology, that U.S. DOT default to one by a certain date.

If one assumes consensus, then they can defer to the NPRM for a roll-out schedule for new model vehicles. U.S. DOT concluded that to obtain benefits from the technology there must be a high penetration rate. As such, the agency proposes an aggressive phase-in schedule after conclusion of the lead period as follows:

- End of Year 1—50% of all new light vehicles must comply with the rule.
- End of Year 2—75% of all new light vehicles must comply with the rule.
- End of Year 3—100% of all new light vehicles must comply with the rule.[57]

This proposed schedule allows a total of five years until all new vehicles would be required to comply with the final rule. This time frame is consistent with Toyota's intention to deploy DSRC technology in all new model Toyota and Lexus vehicles in the United States by 2021. If the rule is not completed by the end of 2019 or if a default provision is triggered because consensus around a specific technology is not reached, this schedule will slip accordingly.

The fourth assumption is that the product aftermarket will supplement OEM installation to obtain early penetration and to show early results. In the NPRM, U.S. DOT assumes that aftermarket installation will follow quickly with devices that support safety, mobility, and environmental applications.[58] NHTSA concludes that "while safety is important to consumers, the other applications offered by these devices may be potentially more attractive to the consumer."[59] NHTSA further states that deployment will be driven by the large market (the existing vehicle fleet) and the short market opportunity (the fleet

---

[56] The current NPRM seeks comment on a technology neutral option.

[57] https://www.federalregister.gov/documents/2017/01/12/2016-31059/federal-motor-vehicle-safety-standards-v2v-communications

[58] Id.

[59] Id.

transition period). NHTSA anticipates that the vast majority of the light vehicle fleet in the United States will be completely replaced in less than 20 years.

To build market demand and create early benefits for the transportation infrastructure operators, we recommend that the U.S. DOT seed the market by providing grant funding to state and local governments that are deploying V2I infrastructure, and be willing to outfit government or regulated fleet vehicles with aftermarket devices.

Fleet vehicles, whether they are transit vehicles, taxicabs, or government owned, tend to operate on fairly regular routes and are operated at fairly high usage rates. Similar incentives could be provided to toll facilities or commercial fleet operators, again, those with regular routes. If this were to be done over the next five years as the OEMs are rolling out new model vehicles with connected vehicle technology, safety benefits could be shown, and commercial applications developed to drive adoption.

Finally, in order to use the complete bandwidth available in the 5.9 GHz spectrum, multiple radio interfaces may be needed, regardless of whether DSRC or CV2X (PC5) is used. Beyond V2V safety, additional radio interfaces may be needed in vehicles for V2X in the 5.9 GHz band to grow into more than just a V2V safety system with a few limited V2I applications.

9   AUTONOMOUS VEHICLE BACKGROUND AND STATUS

According to the World Health Organization, more than 1.2 million lives were lost to traffic fatalities in 2010, the vast majority of which were preventable. More than 94% of the associated crashes were the result of human error. Self-driving cars have the ability to reduce the number of resulting injuries and fatalities. Self-driving cars also have the ability to reduce congestion, improve mobility for the disabled and aged, allow passengers to use their time better, reduce emissions, and to otherwise improve life. It is no wonder that these opportunities are creating a trillion-dollar industry.

To produce self-driving cars, manufacturers are using different combinations of cameras, lidar, radar, sensors, radios, computer vision, and GPS to provide the vehicle with 360-degree awareness at all times. This sensor data is combined with high-definition 3-D map data to localize the vehicle and to provide real time information on what is happening around the vehicle (e.g., location, speed, heading). The vehicle's operating system then predicts what is likely to happen with the surrounding vehicles, pedestrians, bikes, etc. With this understanding of space and time, the data is then compared with the desired vehicle behavior and information regarding road rules, plan routes, traffic controls, etc.[60] This data is then converted into commands to actuators that control the steering, brakes, drive unit, etc. In lower levels of automation (i.e., 1-3) the vehicles are designed to have a driver in the vehicle that can take over when and if necessary. At level 4, the vehicles are designed to be operated with or without a driver but to have

---

[60] The vehicle operating system has been developed over time with input from simulation, real testing, machine learning and other forms of artificial intelligence.

some type of safety control where the vehicle will automatically stop, a passenger can stop the vehicle, or a remote operator can take over if necessary. At this time, all AVs are designed to operate in geofenced areas under specific conditions. At level 5, the vehicle will be designed to operate without any human intervention and at any location.

Some view CV and AV technology as completely indistinguishable and others view the incorporation of CV technology in the AV space as unnecessary. Based upon our interviews with industry experts, the authors recommend the combination of the two. Minimally, manufacturers will need vehicle connectivity to move mapping data and other real time traffic data; optimally, they will have active safety connectivity as another form of redundant safety technology.

Self-driving vehicles will be connected to the internet through a carrier's network for a variety of operational needs or for moving data from the vehicle to the cloud or the edge in either real-time or at designated times during the day. To provide this support, the carriers will need to provide a reliable wireless connection. Doing so will require a sufficient number of proximal small cells. Depending upon the needs of the real-time data analysis, the carriers will likely have to provide an edge solution where the data can be triaged (e.g., acted upon immediately, sent to the edge or cloud for action, sent to the cloud for analysis, or discarded).[61] Finally, the carriers will need to provide appropriate priority for time-sensitive applications.

This data transfer will require sufficient fiber backhaul. This will be the case whether the data is transferred wirelessly to a small cell, a tower, or the edge. It will also be the case if the data is transferred at the end of the day from a maintenance facility. Some manufacturers are contemplating their own fiber networks for this purpose. It seems that such an approach will not be cost effective when we arrive at broad penetration.

9.1   AUTONOMOUS VEHICLE BACKGROUND

Self-driving cars have been of interest to researchers as far back as the 1920s with the first radio-controlled vehicle. Over subsequent decades research ebbed and flowed with new approaches for self-driving vehicles ranging from cables, wires, and magnets in the roadways to cameras and radios in the vehicle or on the roadside. It was not until the 1980s that modern prototype vehicles began to surface, and projects funded by organizations like the Defense Advanced Research Project (DARPA) and Bundeswehr University Munich's EUREKA Prometheus Project. These projects and research from other academic institutions like Carnegie Mellon University produced vision-guided vehicles and neural networks that are the predecessors to today's vehicles.

---

[61] For a more detailed discussion see Automotive Edge Computing Consortium, General Principle and Vision, White Paper, Version 1.0.0, December 1, 2017.

In 1991, Congress passed the Intermodal Surface Transportation Efficiency Act of 1991, which allocated $650M for research on the National Automated Highway System and instructed U.S. DOT to "demonstrate an automated vehicle and highway system by 1997."[62] To accomplish this, FHWA established the National Automated Highway System Consortium, a consortium of public and private entities that culminated its research with a successful demonstration of more than 20 automated vehicles in San Diego. The National Automated Highway System and DARPA also partially funded the Carnegie Mellon University Navlab pilot that drove 2,848 miles across America in 1995, 98% of it autonomously.[63] Over the next decade there were a number of other significant demonstrations of self-driving vehicles around the world.

In the 2000s, the U.S. government began investing more in military research efforts to construct unmanned vehicles that could maneuver in difficult off-road terrain. These research efforts culminated in three autonomous vehicle challenges sponsored by DARPA (the Grand Challenges). The first two of these challenges were held in the desert and the third in an urban setting. In the urban challenge, six vehicles completed the course. These challenges put out millions of dollars in prize money and spurred AV research.

9.2   U.S. DOT AUTONOMOUS VEHICLE RESEARCH

With all of this private sector activity, U.S. DOT's current role in research has been limited. The U.S. DOT's Intelligent Transportation System Joint Program Office (ITS JPO) established an automation program within the overall ITS program a number of years ago. This program was developed as a 2015-2019 Multimodal Program Plan for Vehicle Automation (Program Plan).[64] The Program Plan clarifies U.S. DOT's role to:

- Facilitate development and deployment of automated transportation systems that enhance safety, mobility, and sustainability.
- Identify benefit opportunities in automated vehicle technology.
- Invest in research areas that further industry investments and support realization of benefit opportunities.
- Establish Federal Motor Vehicle Safety Standards and infrastructure guidance.[65]

It further outlines the goals of the Department's automation program as:

- Develop estimates of the potential benefits and challenges of automated vehicles.

---

[62] https://www.fhwa.dot.gov/publications/publicroads/94summer/p94su1.cfm

[63] https://www.cmu.edu/homepage/environment/2014/fall/from-0-70-in-30.shtml

[64] https://www.its.dot.gov/automated_vehicle/avr_plan.htm

[65] Id.

- Evaluate and promote enabling technologies.
- Develop prototype applications.
- Identify needed standards and appropriate methods for development.
- Identify technical, policy, institutional, and regulatory barriers to deployment and possible solutions.
- Generate design guidelines for automated vehicles.
- Collaborate with a broad range of public and private stakeholders.[66]

To date, U.S. DOT has sponsored a number of important research projects in the AV space, including:

- Developing functional descriptions and test methods for emerging automated vehicle applications.
- Developing platform technology for automated vehicle research.
- Sponsoring a transportation system benefit study of highly automated vehicles.
- Conducting human factors evaluation of level 2 and 3 automated driving concepts.
- Developing simulation tool for research on automated longitudinal vehicle control.
- Developing high performance vehicle streams simulation.
- Supporting research on partial automation for truck platooning.
- Conducting lane changing/merge foundational research.[67]

9.3   NHTSA AUTONOMOUS VEHICLE GUIDANCE

The most valuable role that the U.S. DOT has played recently has been to provide guidance to the various actors on testing and certification. In September 2016, NHTSA and U.S. DOT issued a Federal Automated Vehicle Policy (AV Policy) that provided model state guidance in an attempt to prevent a chaotic patchwork of conflicting state regulation of autonomous vehicles and "vehicle performance guidance" for companies involved in the manufacture, designing, testing, and sale of automated vehicle systems.[68] The AV Policy provides an overall framework for assessing the safety of automated vehicles during design, testing, and deployment. The AV Policy calls for manufacturers to submit a "Safety Assessment" to NHTSA showing how the guidance is being followed.

Building on the details of the AV Policy and incorporating feedback received through public comments and congressional hearings, NHTSA issued an update to the AV Policy in September 2017, A Vision for

---

[66] Id.

[67] https://www.its.dot.gov/automated_vehicle/index.htm

[68] https://www.transportation.gov/AV/federal-automated-vehicles-policy-september-2016

Safety 2.0 (Vision 2.0).[69] Vision 2.0 provided voluntary guidance to the manufacturers that encourages best practices and prioritized safety. It also provided guidance for manufacturers who opt in to conduct their own 12-point Voluntary Safety Self-Assessments, which could then be published for NHTSA and the general public to review.[70] To date, two manufacturers have published Voluntary Safety Assessments, but U.S. DOT has reported that others are under review. Finally, Vision 2.0 also provided further technical assistance to states and best practices for policymakers[71]

NHTSA is currently working on updating the AV Policy and Vision 2.0 (Guidance 3.0). Guidance 3.0 is slated to be released in the fall of 2018. Guidance 3.0 is expected to be multimodal in nature. In describing U.S. DOT's efforts to develop the Guidance 3.0, Secretary Elaine Chao stated that the department will coordinate across multiple agencies to identify and address regulatory barriers to AV deployment and execute pilot programs to close research gaps. During the U.S. DOT AV Summit earlier this year, Secretary Chao identified six department-wide principles that will guide U.S. DOT's work on AV policy:

- Safety will always be the top priority.
- Policies will be "flexible and tech-neutral, not "top-down, command and control."" U.S. DOT will not pick winners and losers but will instead allow the market to pick the best solutions and technologies.
- Regulations will be as non-prescriptive and performance-based as possible. In all future regulatory actions, U.S. DOT will not automatically assume that a "driver" of a vehicle is a human.
- U.S. DOT will work with states and other authorities to avoid a patchwork of regulations that could make it difficult for AVs to cross state lines.
- Provide support to stakeholders through guidance, best practices, pilot programs, and other assistance needed to safely integrate AVs.
- Recognize that there will always be a mixed fleet where AVs operate side-by-side with traditional, human-driven vehicles.[72]

9.4   CURRENT EFFORTS TO UPDATE THE FEDERAL MOTOR VEHICLE SAFETY STANDARDS

NHTSA has not yet set federal standards around AVs. Historically, the Federal Motor Vehicle Safety Standards (FMVSS) have been a prescriptive set of standards around the physical components of vehicles and how their controls respond to human drivers. This framework has worked well for human-driven

---

[69] https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf

[70] Id.

[71] Id.

[72] https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/314091/usdot-public-listening-summit-automated-vehicle-policy-summary-report.pdf

vehicles but is inadequate (at least in its current form) when it comes to regulating the safety of AVs, which are driven by a complex mix of sensors, computers, software, and physical components.

Since AV technology is still developing and manufacturers are taking many different approaches to designing them, NHTSA has held off on setting standards until the technology matures.

Nevertheless, NHTSA is currently undertaking an exhaustive review of the FMVSS to determine those provisions that are currently applicable to AVs, those provisions that can easily be made applicable to AVs through an administrative change, those provisions that will require a regulatory change, and those areas that will require new provisions all together.[73]

9.5 DRAFT GUIDING PRINCIPLES ON DATA FOR AUTOMATED VEHICLE INTEGRATION AND DRAFT FRAMEWORK FOR DATA FOR AUTONOMOUS VEHICLE INTEGRATION[74]

While refraining from issuing any regulatory requirements, U.S. DOT has taken a leadership role on data exchange issues related to AVs, recognizing that data exchange will be an important component in accelerating the safe integration of AVs into the US transportation system. As U.S. DOT notes, the data exchange issues range from "the data that comes off the vehicles, between private sector entities, with infrastructure operators, and with policy-makers at different levels of government."[75] As a result, U.S. DOT has published both Draft Guiding Principles on Data for Automated Vehicle Integration and a Draft Framework for Data for AV Integration (Draft Framework).[76]

The Draft Framework establishes a "common language for identifying and prioritizing data exchange needs across traditional silos" by defining categories of data exchange, their purposes, and identifying participants in the data exchange loop. U.S. DOT believes that the provision of a common nomenclature will result in a number of faster improvements with respect to policies, costs, and results.

9.6 ROLE OF FEDERAL/STATE REGULATION OF AUTONOMOUS VEHICLES

There is a division of responsibilities with respect to the operation of motor vehicles between federal and state governments. At the federal level, NHTSA establishes the FMVSS that cover virtually everything about automobile safety from the original FMVSS adopted in 1967, FMVSS No. 209 governing seat belts,

---

[73] https://www.federalregister.gov/documents/2018/01/18/2018-00671/removing-regulatory-barriers-for-vehicles-with-automated-driving-systems

[74] https://www.transportation.gov/av/data

[75] Id.

[76] Id.

to FMVSS 141, establishing sound requirements for hybrid and electric vehicles, beginning September 1, 2018. The limited NHTSA regulatory action on AVs to date has focused on granting exemptions and waivers from the FMVSS in order to enable testing of AVs.
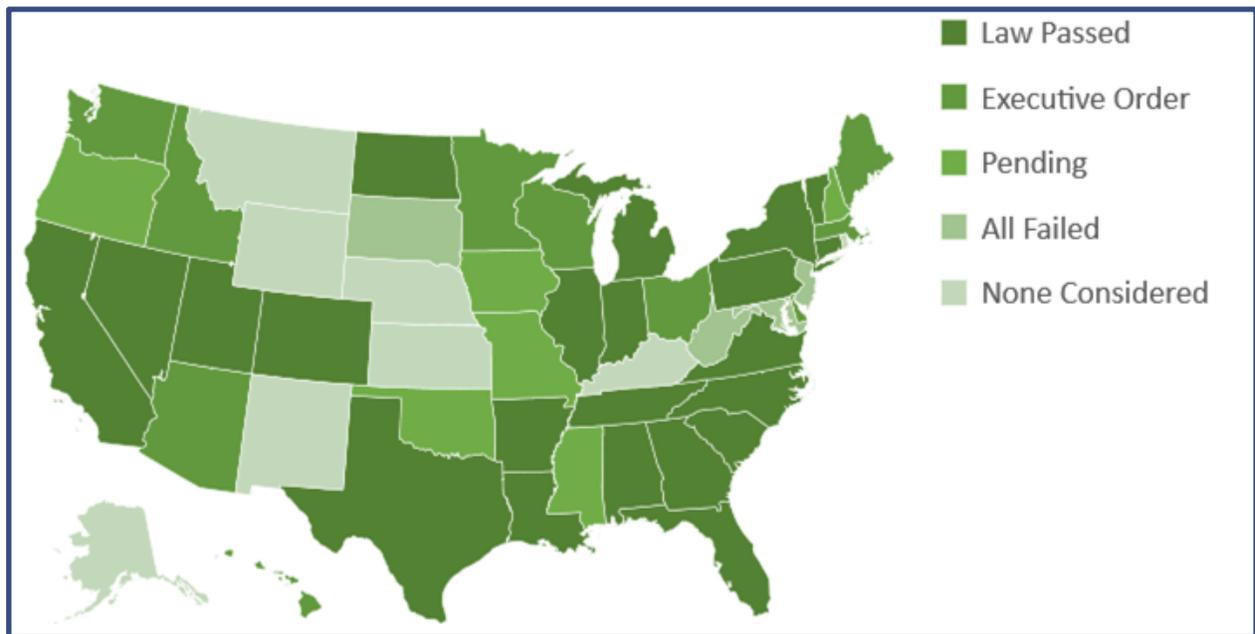
States establish driver safety requirements such as the issuance of drivers' licenses and sets the rules of the road (e.g., speed limits, reckless driving, and vehicle inspection requirements).

The vacuum created by the absence of any significant federal regulatory action, other than waivers, has provided an opportunity for states to occupy the vehicle safety space. State action is all the more likely in light of the necessity for manufacturers and other market participants (e.g., ride share ventures or delivery companies) to experiment, to test, and to perfect their AV offerings.

Many states have considered, or are considering, the enactment of permissive regulations for autonomous vehicles in the hope of convincing high-level companies to launch testing programs within their borders. Twenty-one states and Washington, D.C., have passed legislation related to autonomous vehicles.[77] In 2017, 33 states had introduced legislation related to autonomous vehicles, up from 20 states in 2016. The U.S. Senate is considering legislation to preempt states from adopting a stricter standard than the federal government for self-driving cars. If they do so, there could be further confusion about which rules apply.

---

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

Figure 7. State Regulation of Autonomous Vehicles.

Source: National Conference of State Legislatures

9.7   FEDERAL LEGISLATIVE INITIATIVES TO REGULATE AUTONOMOUS VEHICLES

Legislation has been introduced in both the U.S. House of Representatives and the U.S. Senate to address issues involving autonomous vehicles.

9.7.1   HOUSE OF REPRESENTATIVES

The House of Representatives has passed, and sent to the Senate for its consideration, H.R. 3388, the Safely Ensuring Lives Future Deployment and Research in Vehicle Evolution Act (SELF-DRIVE Act).[78] The legislation is designed to clarify the role of states and localities in supporting and promoting the testing, development, and deployment of highly automated vehicles as well as requiring NHTSA to complete several rulemakings, to establish an advisory council on Highly Automated Vehicles (HAVs) and to create a publicly available database about manufacturers that receive exemptions from current law to pursue development and testing of HAVs. In effect, the bill preserves the respective and separate roles and responsibilities of states and localities vis-à-vis the federal government in the vehicle operation and safety space.

---

[78] https://www.congress.gov/bill/115th-congress/house-bill/3388

Additionally, the bill requires U.S. DOT to initiate and complete several rulemakings regarding standards and testing of HAVs and manufacturers of HAVs to develop cybersecurity plans and processes before introducing HAVs into commerce.

9.7.2   SENATE

The comparable legislation pending in the Senate has been approved by the Senate Committee on Commerce, Science and Transportation. S. 1885, the American Vision for Safer Transportation through Advancement of Revolutionary Technologies (AV-START) Act[79] is designed to advance the development and deployment of HAVs.

Among other things, the AV-START Act would address the following areas with respect to HAVs:

- Provide enhanced safety oversight by DOT
- Reinforce traditional federal, state, and local safety and enforcement roles
- Reduce barriers to deployment
- Provide DOT with expertise needed to set new and update legacy safety regulations
- Strengthen cybersecurity protections
- Promote consumer education

As of the date of publication of this report, S. 1885 has not been scheduled for full Senate consideration. If S. 1885 does pass the Senate, a conference between both houses of Congress will be needed to reconcile the differences between the Senate and House passed bills before it can be signed into law.

---

[79] https://www.congress.gov/bill/115th-congress/senate-bill/1885

9.8 U.S. DOT DESIGNATED AUTONOMOUS VEHICLE PROVING GROUNDS

In an effort to accelerate autonomous vehicle testing and information sharing, U.S. DOT designated ten sites around the country as AV Proving Grounds.[80] The designees were selected from a pool of 60 applicants. The program was intended to create a community of experience that would create and share best practices and lessons learned. The sites selected were:

- City of Pittsburgh and the Thomas D. Larson Pennsylvania Transportation Institute
- Texas AV Proving Grounds Partnership
- U.S. Army Aberdeen Test Center
- American Center for Mobility (ACM) at Willow Run
- Contra Costa Transportation Authority (CCTA) & GoMentum Station
- San Diego Association of Governments (SANDAG)
- Iowa City Area Development Group
- University of Wisconsin-Madison
- Central Florida Automated Vehicle Partners
- North Carolina Turnpike Authority

The designations are spread around the country and have differing "facilities that can be used to gauge safety, manage various roadways and conditions, and handle various types of vehicles."[81] There were, however, a number of notable areas/facilities that were not on the list. Among the notable locations not included were Arizona, where Waymo and Uber have been doing a significant amount of on-road testing; Virginia Tech Transportation Institute, the second largest university-led transportation Institute in the U.S.; Mcity, the country's first autonomous vehicle test facility; and the Transportation Research Center, the largest independent vehicle test facility in the U.S. While the designations came with no funding they came with branding rights and other soft benefits. The designations have become controversial because in the Consolidated Appropriations Act, 2018, Congress provided $20M in funding to designated proving grounds.[82] U.S. DOT is currently revisiting the designations.

9.9 AUTONOMOUS VEHICLE TESTING ON PUBLIC STREETS

A number of cities around the country are rolling out slow-moving shuttles that operate in geofenced areas. Gleaning more attention, however, are companies like Waymo, Tesla, GM, Ford, Apple, Uber, and Lyft that have been testing level 3 and 4 AVs on public streets in more that 20 cities around the U.S. At the end of 2017, Bloomberg Philanthropies and the Aspen Institute launched an interactive website on

---

[80] https://www.transportation.gov/briefing-room/dot1717

[81] Id.

[82] https://www.gpo.gov/fdsys/pkg/BILLS-115hr1625enr/html/BILLS-115hr1625enr.htm

Cities and Autonomous Vehicles. As of July 2018, it was tracking 106 cities worldwide that had launched or were planning to launch AV testing. Of these, 76 cities were hosting AV tests or had committed to do so in the near future. (25 are U.S. cities.) The balance of the cities are undertaking long-range surveys of the regulatory, planning, and governance issues raised by AVs, but have not yet started piloting.[83] In a statement launching this initiative, James Anderson, the head of Bloomberg Philanthropies' Government Innovation program said that "this map will serve as an important knowledge-sharing tool, providing cities with what's needed to not only have a seat at the table during this transformation but be leaders of it."

When launched, the project also included a survey of 38 cities that had launched AV testing at that time that provided some interesting insights. Importantly, city planning for AVs is generally in the early stages across the board with more than 25% of those surveyed only engaging on the issue in the past year.

## Figure 8. When Cities Identified Autonomous Vehicles as a Concern

Source: Bloomberg Philanthropies

---

[83] https://avsincities.bloomberg.org/
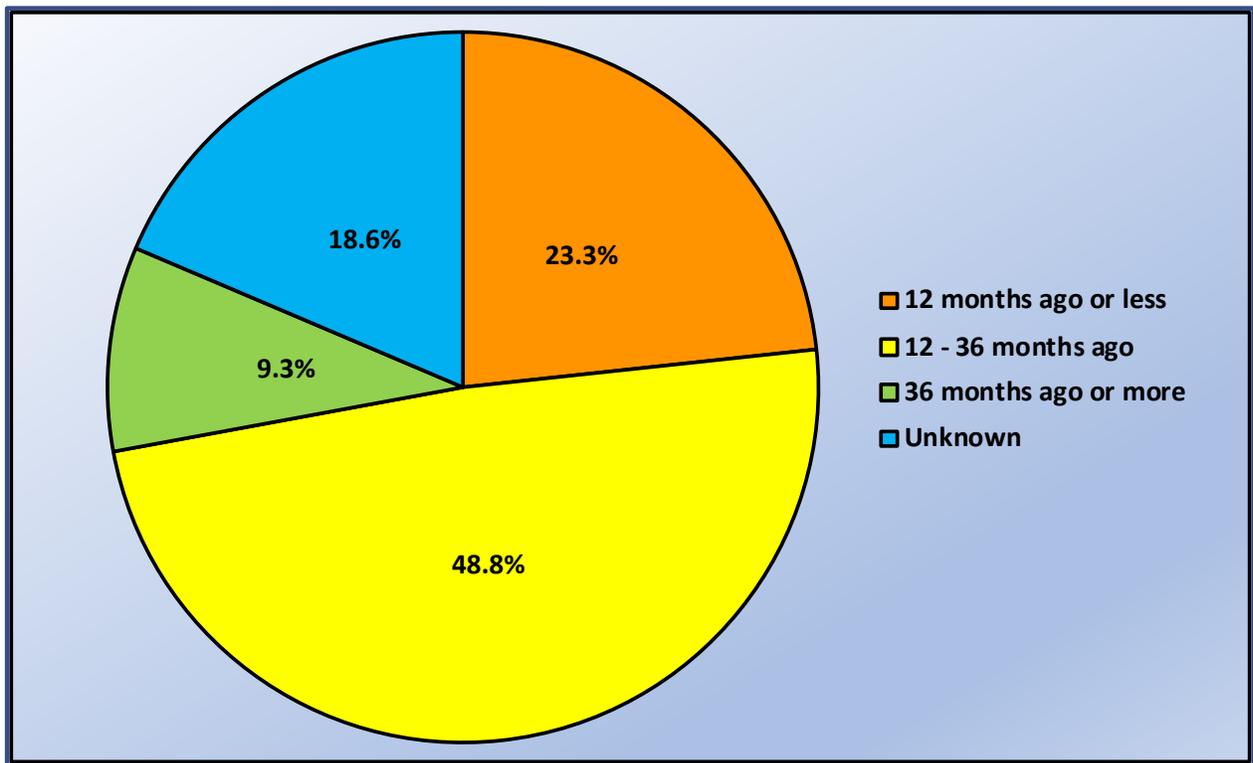
The first/last mile gap is cities' main reason for gravitating toward the technology. The website states that "more than half of the 36 cities with ongoing or committed pilots are testing AVs in last-mile applications ranging from connectors between rail stations and employment centers, to shuttles circulating within large campuses." [84]

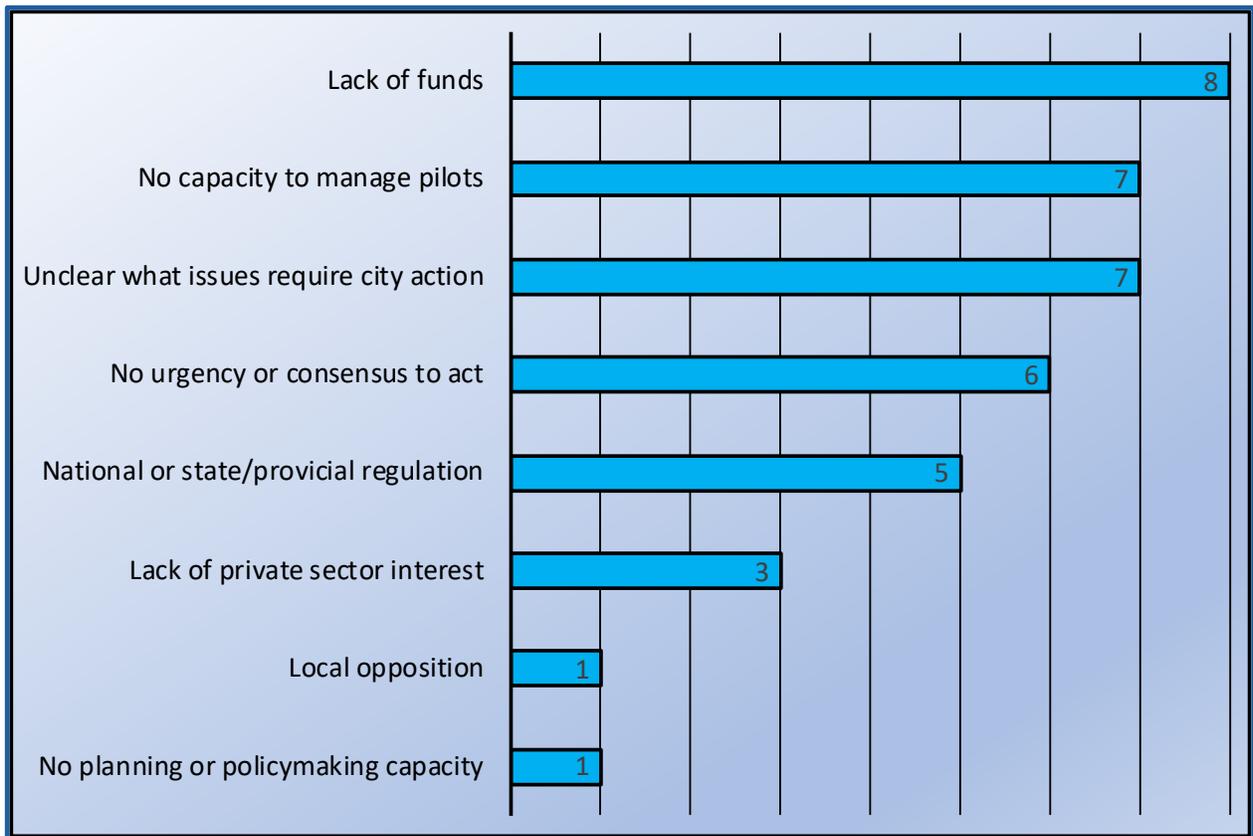## Figure 9. Anticipated Uses by Cities of Autonomous Vehicles
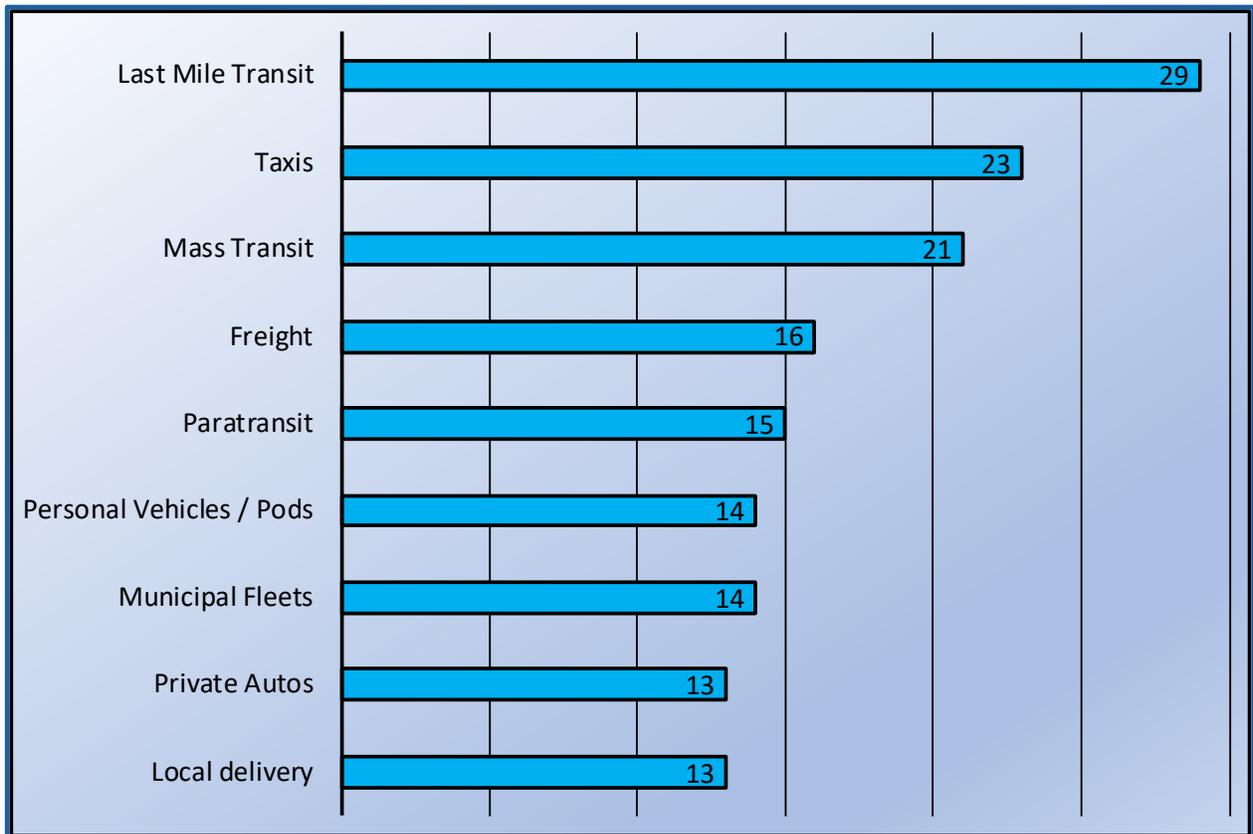
Source: Bloomberg Philanthropies

Not surprisingly, the survey found that lack of funding and lack of capacity to manage the projects were the major impediments faced. City leaders also appear to be unsure of what requires city action and where they are constrained by state or federal regulations.

---

[84] Id.

Figure 10. Barriers to Cities' Autonomous Vehicle Efforts

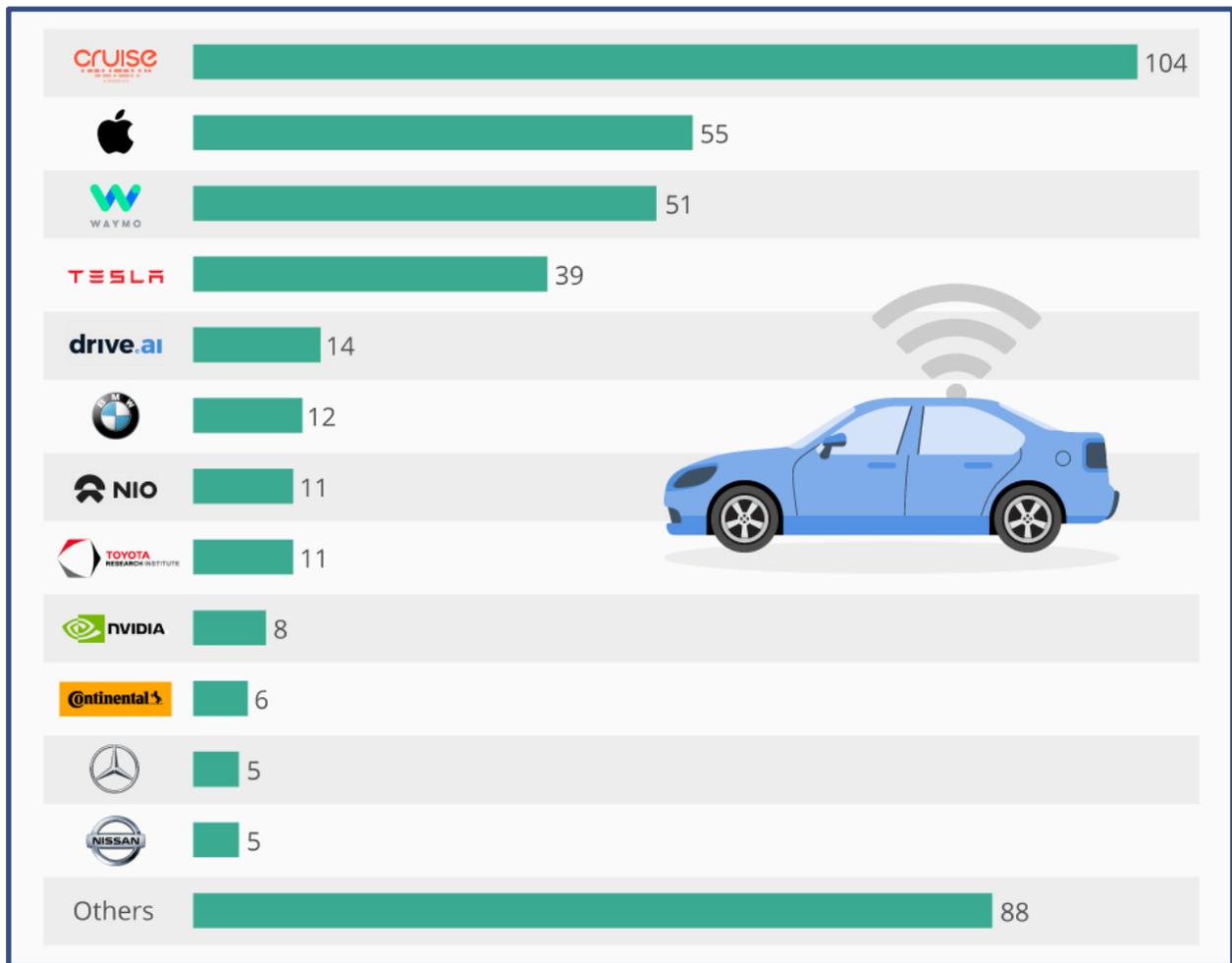| Barrier	Count
Lack of funds	8
No capacity to manage pilots	7
Unclear what issues require city action	7
No urgency or consensus to act	6
National or state/provicial regulation	5
Lack of private sector interest	3
Local opposition	1
No planning or policymaking capacity	1

Source: Bloomberg Philanthropies

OEMS have been testing self-driving technology since the mid-2000s. Virtually all major OEMs are now testing self-driving vehicles. There are also non-legacy players playing leading roles in the developing of self-driving vehicles. Waymo, formerly Google's self-driving vehicle project, states that it is testing its vehicles in 25 U.S. cities, logging over 25,000 miles per day, and having logged more than eight million miles on city streets.[85] Other technology firms like Apple, Aurora, Zoox, Uber, Tesla, and MobileEye have also entered the space. In California alone, 55 companies have registered to test their vehicles on California streets.

---

[85] https://techcrunch.com/2018/07/20/waymos-autonomous-vehicles-are-driving-25000-miles-every-day/

Figure 11. Companies Testing Self-Driving Cars in California.*

*As of May 9, 2018

Source: StatistaCharts / California DMV / Business Insider

Testing on city streets slowed for a period at the beginning of 2018, as a number of AV crashes were reported. The first death associated with AV testing occurred on March 19, 2018, when an Uber test vehicle struck a pedestrian crossing the street late in the evening. It was later learned that the safety driver was watching her phone at the time of the accident and that accident was "entirely avoidable."[86] Another death occurred that same month when a Tesla owner operating a Model X in autopilot mode crashed into a concrete barrier. The driver was found to have not touched the steering wheel in the

---

[86] https://www.cnet.com/news/was-ubers-driverless-car-crash-avoidable-some-experts-say-the-self-driving-car-should-have-braked/

previous five seconds and had received multiple visual and audible alerts. This crash followed another Tesla autopilot fatality in 2016.

9.10 INTERNATIONAL STANDARDS HARMONIZATION

During the course of our interviews, several stakeholders noted the need for international standards harmonization with respect to AVs. For example, a data acquisition system designed to work on streets in Japan may not work in the United States. Being able to port AV technology from one country to another will significantly reduce the cost of development and deployment of connected and automated vehicle technology. International standards could alleviate some of the complexity associated with deploying AVs. One respondent said that there would be great cost savings if the manufacturers managed their updates collectively.

10 RECOMMENDATIONS FOR AUTONOMOUS VEHICLES

The potential benefits associated with driverless cars are many. While it is still too early to fully understand how autonomous vehicles will impact society, there are numerous potential benefits. Our recommendations are intended to help expedite the deployment of AVs and are as follows:

U.S. DOT SHOULD REQUIRE THAT AVS ARE CONNECTED

V2V and V2I is the foundation of what will be the bedrock of autonomous driving. Jim Doyle, President of Panasonic Enterprise Solutions Co., stated at the 2017 Consumer Electronics Show that "if you don't have those in place, you really cannot achieve true autonomous driving in a way that the public will feel confident and safe. This (RoadX) will be the project that gets us to a point where we understand how it works."[87]

Interviewees all agreed that vehicle connectivity is desirable for autonomous vehicles and many thought it was essential. One interviewee from a major auto OEM stated that achieving full automation without connectivity and cooperative sensor data sharing between vehicles and infrastructure was not possible. Another university respondent echoed that sentiment, stating that complete automation of the U.S. surface transportation infrastructure absolutely requires connectivity. Connectivity would enable cooperative coordination among vehicles and among vehicle and infrastructure, thereby filling the gaps between autonomous vehicles and a fully automated surface transportation system.

---

[87] https://www.denverpost.com/2017/01/04/panasonic-colorado-autonomous-vehicles-interstate-70/

Figure 12. Is Vehicle to Vehicle Connectivity Needed for Autonomous Vehicles?
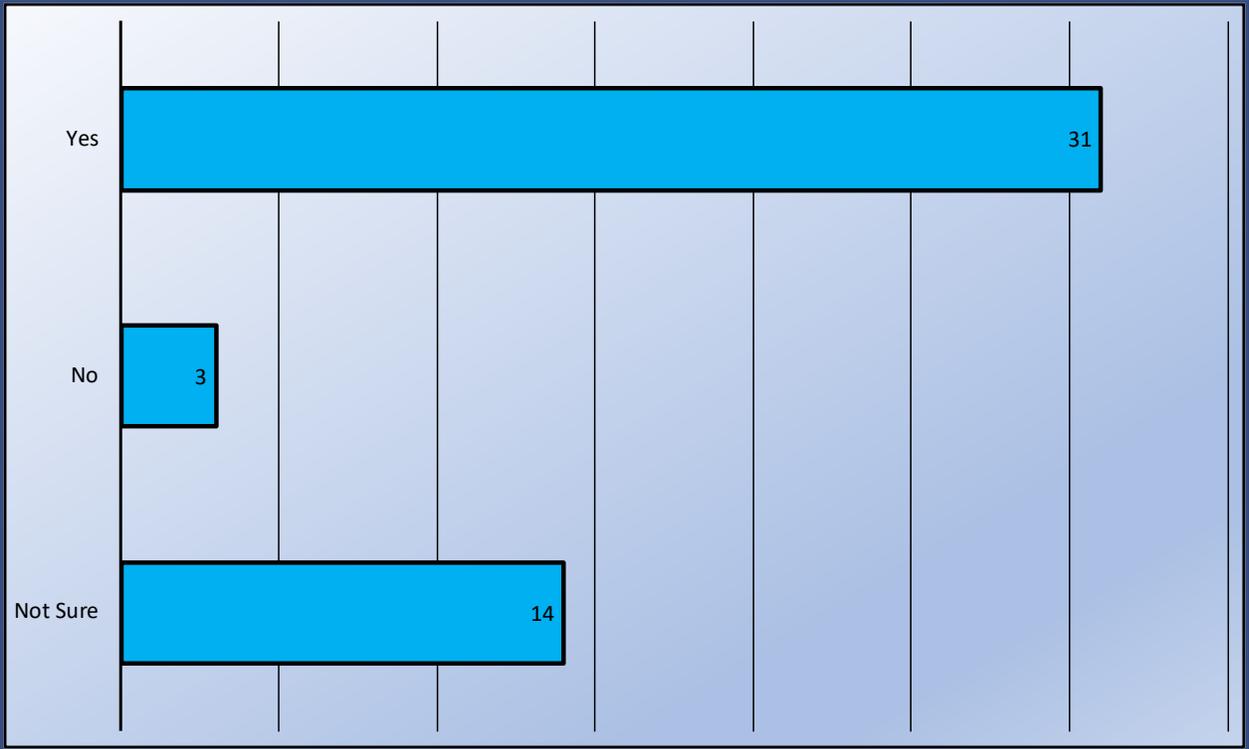
Source: Interviews

A number of technology companies stated that their solutions do not require vehicle connectivity because they do not want to rely on third party data, infrastructure that might not be maintained, and a technology that was not ubiquitous. One company representative said that by the time the connected vehicle program was rolled out, they will have leaped-frogged the technology. Having said this, all agreed that it if it were available, they would use it.

A number of OEMs and universities believe that there are a number of use cases for connectivity. First, it is unclear that there will ever be a time when the roads are only occupied by autonomous vehicles. If vehicle connectivity is deployed in vehicles driven by humans, it will need to be rolled out in autonomous vehicles to optimize penetration and manage traffic. A number of individuals stated that self-driving vehicles would benefit from information about extreme whether situations like fog, sandstorms, snow, etc. Others voiced concerns about road conditions and noted that only 50% of the nation's roads have road striping. Finally, others raised issues about vehicles out of the line of sight and situations where vehicles arrive at the same destination at the same time. Clearly, many of these concerns will be addressed with further research and technology. But again, all agreed that the deployment of this redundant safety application would save lives.

CONGRESS SHOULD EXPAND FEDERAL FUNDING FOR AUTONOMOUS VEHICLE RESEARCH

Earlier this year, Congress allocated an additional $100M to U.S. DOT for AV research.[88] The new funding includes $60M for grants "to fund demonstration projects that test the feasibility and safety" of self-driving vehicles. $20M will go to automated vehicle proving grounds, local governments, or academic institutions but not to private companies. $38M will go to U.S. agencies to conduct research into self-driving cars, including cybersecurity issues. U.S. DOT is "expected to prioritize research topics that fill gaps in research being conducted by the private sector" and that "have the strongest potential to advance the safe deployment" of autonomous vehicles. Finally, $1.5M will go to conduct a comprehensive analysis of the impact of self-driving vehicles on U.S. employment, including the potential pace of job losses among truck, taxi, and other commercial drivers, as well as the potential safety risks surrounding commercial autonomous vehicles.[89]

The AV proving grounds and other qualified test facilities will continue to require funding. The recent AV accidents will likely result in more testing in controlled test facilities. Many of the AV Proving Grounds have yet to be developed and doing so will cost millions of dollars. As we have seen with traditional vehicle testing and certification, manufacturers need independent test facilities in addition to their own. Many existing test facilities are well equipped to take on some of this work, while others will need to be built from the ground up. Finding private sector sponsorship is challenging and beyond the ken of those locations or institutions that are new to this area.

Congress was prescient in requesting research on the impact on U.S. employment. Vehicle automation is a megatrend that will impact multiple segments of our economy. In addition to truck and taxi drivers, it is not hard to imagine its impact on the insurance industry, the car repair industry, and the parking industry. Anticipating these important changes and considering policies that will help to mitigate them is essential. As the industry continues to move to deployment, additional issues are sure to arise and require additional research.

---

[88] https://www.gpo.gov/fdsys/pkg/BILLS-115hr1625enr/html/BILLS-115hr1625enr.htm

[89] Id.

Figure 13. Lonely Parking Lot Attendant

Source: Tom M. Johnson, http://fence.photoville.com/artist/pittsburgh-parking-lot-booths-and-their-attendants/

There are important non-technical issues, such as data ownership, that must be studied as well as they have the potential to inhibit the progress of this important technology. Data is the lifeblood of CVs and AVs. It will also be one of the major financial engines driving deployment. Based on our interviews, data ownership is confused at best. In fact, a number of respondents suggested that the only way this will be resolved is through the courts. Obviously, early federal intervention could save significant time and resources.

Data protection and privacy are also significant issues that warrant review. In light of the EU's recent passage of the General Data Protection Act, recent news reports of technology companies abusing personal data, California's new data privacy law, and congressional efforts to create a national data protection scheme, the issue of data ownership could have a profound impact on CVs and AVs.

Another important issue will be how to ensure that those in rural areas, as well as those that are less fortunate economically, have access to this important technology. As we have seen with the rollout of

2G, 3G, and 4G, rural areas are connected much later than urban areas and their connectivity may be less robust. This reality is even more important in the transportation safety space. While rural areas cover 97% of the nation's land, only 19% of the nation's population lives in rural areas.[90] In 2016, these 19% accounted for roughly 49% of the traffic fatalities in the United States.[91] This disparity in fatalities per 100,000 population will only increase if safety becomes increasingly reliant on connectivity or usage fees. Congress and the FCC have sought to address this digital divide through rural broadband initiatives, but additional study is necessary to assess its impact on transportation.

Figure 14. Rural Areas Have 19% of the Population Yet Account for 50% of the Fatalities

Source: NHTSA / FARS 2007 – 2015 Final File, 2016 Annual Report File (ARF)

Similarly, there are a number of researchers expressing concern that self-driving vehicles and a shared use economy may result in greater congestion and emissions rather than less. While this may be a minority view, it has validity. A recent study by Schaller Consulting entitled "The New Automobility: Lyft, Uber and the Future of American Cities," found that together with taxicabs, the for-hire sector (e.g., Uber, Lyft) is projected to grow to 4.74 billion trips annually by the end of 2018, a 241% increase over the last six years. This growth has added more than 5.7 billion vehicle miles traveled in nine major metropolitan areas that

---

[90] https://www.census.gov/newsroom/press-releases/2016/cb16-210.html

[91] https://crashstats.nhtsa.dot.gov/#/PublicationList/56

are also seeing growth in car ownership that is greater than the normal population.[92] Clearly, these statistics have huge implications for land use planning, transit, congestion, and the environment, and warrant public policy intervention. As importantly, however, Schaller concludes that without public policy intervention, the likelihood is that the autonomous future mirrors today's reality: more automobility, more traffic, less transit, and less equity and environmental sustainability."[93]

Other important issues, such as the role of artificial intelligence, ethics, liability, insurance, etc. will need to be researched and appropriate policy developed.

CONGRESS SHOULD PASS LEGISLATION TO CLARIFY FEDERAL AND STATE AUTHORITIES' AND RESPONSIBILITIES' FOR REGULATING AUTONOMOUS VEHICLE

The long-standing division of responsibility between federal, state, and local authorities with respect to motor vehicles, discussed in section 9.6, has the potential to inhibit the further deployment of AVs unless Congress clarifies these roles. For example, notwithstanding the traditional right of states related to establishing vehicle inspection, licensing, and "driver" training requirements, NHTSA may have the statutory authority to establish requirements in these areas that conflict with state efforts to promote testing of AVs.

Similarly, although the statutory language is vague, the National Traffic and Motor Vehicle Safety Act appears to grant NHTSA the authority to preempt state common law tort liability if it conflicts with a "significant regulatory objective," although "Compliance with a motor vehicle safety standard prescribed under this chapter does not exempt a person from liability at common law."

In the absence of clarity, Congress can establish the ground rules necessary for testing AVs, unencumbered by the vagueness of the existing statute. One respondent suggested making the Voluntary Safety Assessments mandatory and public.

AUTONOMOUS VEHICLE STAKEHOLDERS SHOULD PROMOTE AND PARTICIPATE IN THE DEVELOPMENT OF INTERNATIONAL STANDARDS

As noted by a Tier 1 auto supplier in the course of our interviews, developing AV technology for each individual country is impractical. The cost of roll-out can be decreased, and the pace of roll-out can be accelerated, if the U.S. DOT, operators, and manufacturers participate in the appropriate standards development organizations and develop international standards for connected autonomous vehicles.

---

[92] http://www.schallerconsult.com/rideservices/automobility.pdf

[93] Id.

Potential subjects of the standards could be infrastructure (e.g., road striping) and connected vehicle technologies.

Initially, development of standards may result in minor deployment delays, but in the long run, the cost and pace of roll-out will be optimized if standards are in place to support implementation of one set of technologies that applies across the globe.

U.S. DOT SHOULD FACILITATE GREATER COLLABORATION AMONG THE PARTIES

One recurring comment from our respondents was the need for greater dialogue and collaboration among the parties. There was recognition that U.S. DOT has made great strides in this area with their NHTSA AV listening sessions and the FHWA National Dialogue on Automation. That national trade associations have also tried to fill this void with groups like the American Association of State Highway Transportation Officials' (AASHTO) Working Group on Connected and Autonomous Vehicles; ITS World Congress; and various committees and standards working groups. Even with these efforts, gaps remain. A major concern was the lack of engagement by local governments that are critical for successful deployment. Another concern was lack of engagement by the technology sector and a potential lack of alignment around safety. A number of respondents commented that the need to get technology on the street as quickly as possible to gain a competitive advantage is often inconsistent with the critical importance of safety. Interestingly, this was raised almost exclusively by the private sector. These and other issues can only be resolved with greater dialogue and collaboration.

MANUFACTURERS SHOULD SUPPORT CAMPAIGNS TO EDUCATE THE PUBLIC ABOUT AUTONOMOUS VEHICLES

Another major issue raised by the respondents was the lack of understanding on the part of the public about connected and autonomous vehicles. There have been a number of articles and surveys recently discussing the waning support for autonomous vehicles and lack of confidence in the technology. As a result, Waymo, Mothers Against Drunk Driving, the National Safety Council, the Foundation for Blind Children, the East Valley Partnership, and the Foundation for Senior Living have launched an education campaign in Arizona called "Let's Talk Self Driving" that will include both digital and outdoor advertising. The plan is to eventually expand this campaign nationally, with exposure to Waymo's self-driving technology for the general public. The program is designed to provide easily accessible information that offers answers to questions including, "Are self-driving cars safe?" and "How do they know what to do?" Other technology providers and local governments should team up to provide this type of education to the public on a nationwide basis.

11 POTENTIAL AUTONOMOUS VEHICLE ROLL-OUT SCENARIO

The AV roll-out schedule will be dictated by technology development and public policy. While the industry is in the early stages, technology is being rolled out at a pace not seen before in the transportation sector. As such, this roll-out scenario reflects the roll-out of technology that we are currently aware of.

OEMs are Currently Rolling Out Level 1 and 2 Systems. Level 1 systems include Adaptive Cruise Control, Lane Keeping Assist and automated parking. The driver must be able to take control at any time. Level 2 systems include Tesla Autopilot, Volvo Pilot Assist, Mercedes-Benz Drive Pilot, Cadillac Super Cruise. Level 2 systems will manage drivers speed and steering under certain conditions, such as highway driving. The driver must still pay attention to driving conditions at all times and take over immediately if the conditions exceed the system's limitations. The cost of these systems will continue to decrease and will make their way into more and more vehicles. There are no special infrastructure or communication needs for this technology.

OEMs Will Likely Bypass Broad Deployment of Level 3 Systems. Level 3 systems allow the driver to divert his attention, but he or she must be prepared to retake control when situations call for an immediate response. The differences between level 2 and level 3 systems can lead to confusion. The 2018 Audi A8 Luxury Sedan was the first commercial car to claim to be capable of level 3 self-driving with their Traffic Jam Pilot. When activated, the car takes full control of all aspects of driving in slow-moving traffic up to 37 mph (e.g., stop and go traffic). The function works only on highways with a physical barrier separating one stream of traffic from oncoming traffic. Again, there are no special communications needs for this technology.

OEMS Have Produced Autonomous Shuttles With Level 4 Systems That are Being Demonstrated in Multiple Locations. Level 4 autonomy assumes that the vehicle will operate on its own in most environments, but that a human must be available to intervene. Low speed shuttles are being demonstrated as part of transit systems on university campuses and in other controlled environments around the country. These systems operate at low speeds (below 35 miles per hour) and in geofenced areas. A number of these demonstrations have vehicles operated without a driver but having a remote operator that can take over if necessary. These systems will continue to be demonstrated in greater numbers as the public and localities become more comfortable with the technology. This technology requires high-quality 3D maps that are accessible in real time. These shuttles would operate better if they have a real time communications interface with the traffic signal infrastructure (e.g., V2I).

Companies are Currently Demonstrating Level 4 Systems in Light Duty Vehicles. For as many as nine years, companies like Waymo, Uber, Lyft, Apple, and GM have been testing vehicles with level 4 systems on city streets around the country. The Bloomberg Philanthropies Cities and Autonomous Vehicles website demonstrates that the number of these cities are still relatively limited in number. We are seeing, however, greater interest on the parts of states and cities to become testbeds and would anticipate that the number of locations and vehicles will increase both as the public comfort level increases and the companies catch up to the current industry leaders.

These demonstrations have led to the deployment of shared use fleets providing a variety of commercial services to the public (e.g., ride share, last mile service, grocery delivery). Shared use fleets will likely be the most common use of self-driving vehicles for the foreseeable future given their current high cost of production, maintenance needs, data offload, and communication needs. Waymo is the first company to obtain a license in California to operate a level 4 system without a driver in the vehicle. As with shuttles, this technology requires high quality 3D maps that are accessible in real-time. These shuttles would

operate better if they had a real-time communications interface with the traffic signal infrastructure (e.g., V2I).

The Timeline for the Deployment of Level 5 Systems is Uncertain. While level 4 systems appear to be in the midst of testing and initial deployment in controlled systems, it is not clear when full autonomy will be available to all consumers. In our interviews, interviewees from the traditional auto industry seemed the most skeptical about the timeline for deployment. Leading edge technology companies were more optimistic. Most respondents, as shown in Figure 15, were uncertain about the timeline for deployment of level 5 AVs. Based on the significant amount of ongoing research and investment, we believe level 5 systems will be available to the general public in 15 to 20 years.

Figure 15. When Will Level 5 AV Systems be Deployed?
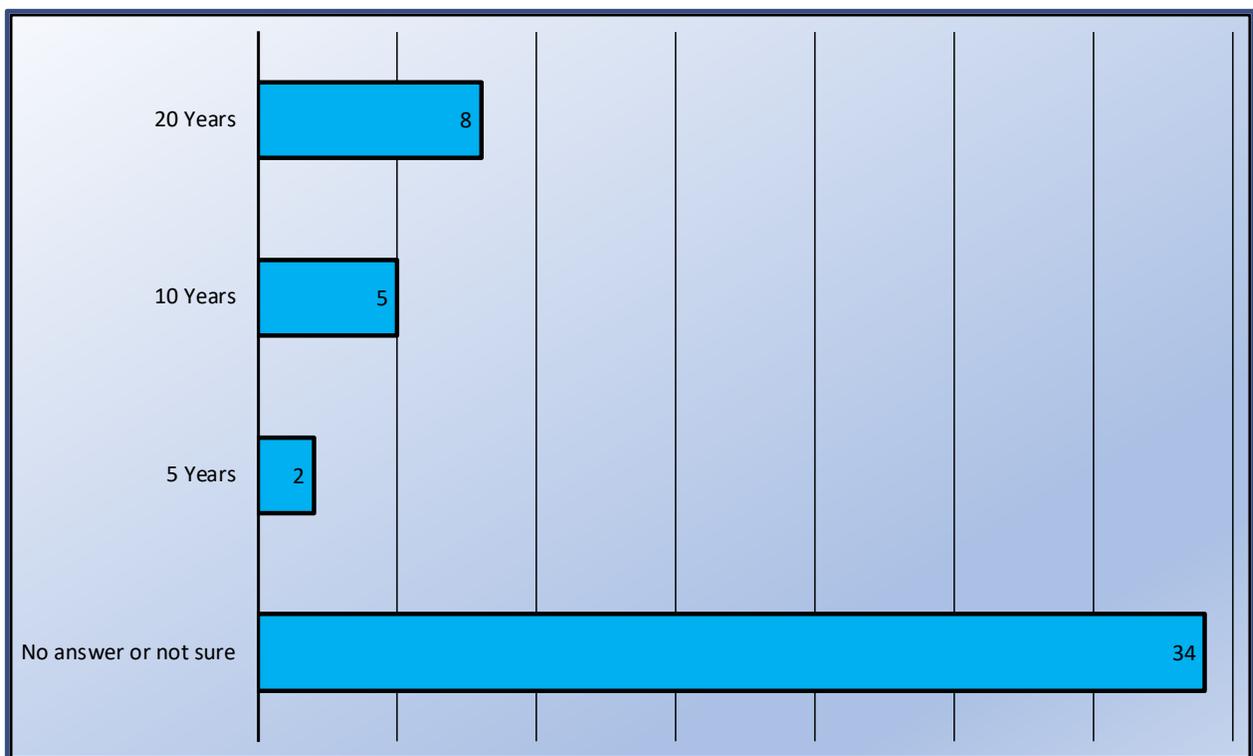
Source: Interviews.

APPENDIX A: ORGANIZATIONS/AFFILIATIONS OF INDIVIDUALS INTERVIEWED

5GAA

AASHTO

Alliance of Automobile Manufacturers

Apple

Association of Global Automakers

AT&T

Auto ISAC

Automotive Edge Consortium

Autotalks

Carnegie Mellon University

Cisco

Colorado Department of Transportation

Contra Costa Transportation Authority

CTIA – The Wireless Association

Denso

Ericsson

Ertico

General Motors

Green Hills Software

HNTB

IBM

Intel

ITS America

ITS Japan/ITS Asia Pacific

Metropolitan Transportation Commission (MTC)

Michigan Department of Transportation

Mobileye

New York City Department of Transportation

Nokia/Bell Labs

OmniAir

On Board Security

Panasonic

Parsons

Qualcomm

Regional Transportation Commission of Southern Nevada

San Diego Association of Governments (SANDAG)

Savari

Senate Committee on Commerce, Science and Transportation (Majority and Minority staffs)

SAE International

Texas A & M Transportation Institute (TTI)

Toyota

Utah Transportation Department

Verizon

Zoox

Note: certain interviewees requested that their company names remain anonymous, including an auto OEM and a systems integrator.

APPENDIX B: ACRONYMS

3GPP – 3rd Generation Partnership Project

5GAA – 5G Automotive Association

ACEA – European Automobile Manufacturers' Association

ADAS – Advanced Driver Assistance System

ANPRM – Advanced Notice of Proposed Rulemaking

AASHTO – American Association of State Highway Transportation Officials

AV – Autonomous Vehicle

CA – Certificate Authority

CAMP – Crash Avoidance Metrics Project

CDOT – Colorado Department of Transportation

CES – Consumer Electronics Show

CRM – Customer Relationship Management

CV – Connected Vehicle

CVP – Connected Vehicle Pilot

C-V2X – Cellular Vehicle to Everything

DARPA – Defense Advanced Research Projects Agency

DSRC – Dedicated Short-Range Communications

ETSI – European Telecommunications Standards Institute

FCC – Federal Communications Commission

IOT – Internet of Things

ISO – International Standards Organization

ITS – Intelligent Transportation Systems

ITS JPO – ITS Joint Program Office

NHTSA – National Highway Traffic Safety Administration

NYC – New York City

LAN – Local Area Network

LTE – Long Term Evolution

MDOT - Michigan Department of Transportation

NIST – National Institute of Standards and Technology

NPRM – Notice of Proposed Rulemaking

OEM – Original Equipment Manufacturer

PII – Personally Identifiable Information

PKI – Public Key Infrastructure

POC – Proof of Concept

PTC – Positive Train Control

SANDAG – San Diego Association of Governments

SCMS – Security Credential Management System

SCOS – Smart Columbus Operating System

SDLC – Software Development Life Cycle

SPaT – Signal Phase and Timing

SPMD – Safety Pilot Model Deployment

TCAS –Traffic Collision Avoidance System

THEA – Tampa-Hillsborough Express Authority

TMS – Traffic Management Center

TRC – Transportation Research Center

TTS – Traffic Technology Services

UMTRI – University of Michigan Transportation Research Institute

U.S. DOT – United States Department of Transportation

V2V – Vehicle to Vehicle

V2I – Vehicle to Infrastructure

V2X – Vehicle to Everything

WYDOT – Wyoming Department of Transportation

APPENDIX C: AIR AND RAIL COLLISION AVOIDANCE SYSTEMS

TRAFFIC COLLISION AVOIDANCE SYSTEM

Efforts to develop automated aviation collision avoidance systems began in earnest following the June 30, 1956 mid-air collision between a United Airlines DC- 7 and a TWA Super Constellation over the Grand Canyon. At the time, each pilot was responsible for his own aircraft's movements and separation from any other aircraft; not unlike the situation today among automobiles on a highway.

The ultimate congressional response to this tragedy, additional mid-air collisions, and numerous near misses was the enactment of the Federal Aviation Act of 1958, which gave complete control of U.S. airspace to the Federal Aviation Administration which ultimately developed air traffic control procedures controlling virtually every movement of commercial aircraft.

Nevertheless, mid-air collisions continued to occur. The June 6, 1971 Southern California collision between Hughes Airwest 706 and a United States Marine Corps F-4 Phantom II, the later flying with an inoperative transponder – rendering it invisible to air traffic controllers – triggered an aggressive effort to develop an airborne collision avoidance system; one independent of air traffic controllers. Over the next fifteen years, extensive research and testing resulted in the development of the Traffic Collision Avoidance System (TCAS) in operation today.

Under the TCAS system, each TCAS equipped aircraft is in constant communication with all other aircraft within a particular range to determine each aircraft's position several times per second. The system creates a three-dimensional map of aircraft in the airspace, including speed, altitude and heading, and projects the anticipated future location of the other aircraft.

If TCAS detects a potential collision, it automatically develops appropriate avoidance maneuvers for the two aircraft that are on a collision course and communicates these maneuvers to the cockpit crew by voice instruction. Since the required installation of TCAS there have been no mid-air collisions anywhere in the world when the TCAS system was operating and the directions given by the TCAS system were being followed by the pilots of aircraft on a collision course.

POSITIVE TRAIN CONTROL

Positive Train Control (PTC) is an advanced train control communications system capable of automatically stopping a train before a variety of different kinds of accidents occur, including:

- Train-to-train collisions
- Derailments caused by excessive train speed
- Train movements through misaligned track switches
- Unauthorized train entry into work zones

PTC will not prevent vehicle-train accidents at railroad crossings, or those due to track and equipment failures.

The Rail Safety Improvement Act of 2008 (PL 110-432) required railroads handling poisonous-inhalation-hazard materials and any railroad with regularly scheduled intercity and commuter rail passenger service to install and implement Positive Train Control (PTC) by December 31, 2015.[94]

While most of the wireless infrastructure being utilized for PTC is in a single frequency near 220 MHz, there is no statutory or regulatory requirement that all PTC systems utilize any particular frequency. Since freight operations often necessitate both the sharing of railroad tracks by multiple railroads, as well as multiple railroads operating their locomotives as a guest on another railroad's tracks, the implementation of PTC is generally being accomplished by using PTC equipment that operates on common radio spectrum.

---

[94] In late 2015, Congress extended the deadline by at least three years to December 31, 2018, with the possibility of an extension to a date no later than December 31, 2020, if a railroad completes certain statutory requirements that are necessary to obtain an extension.