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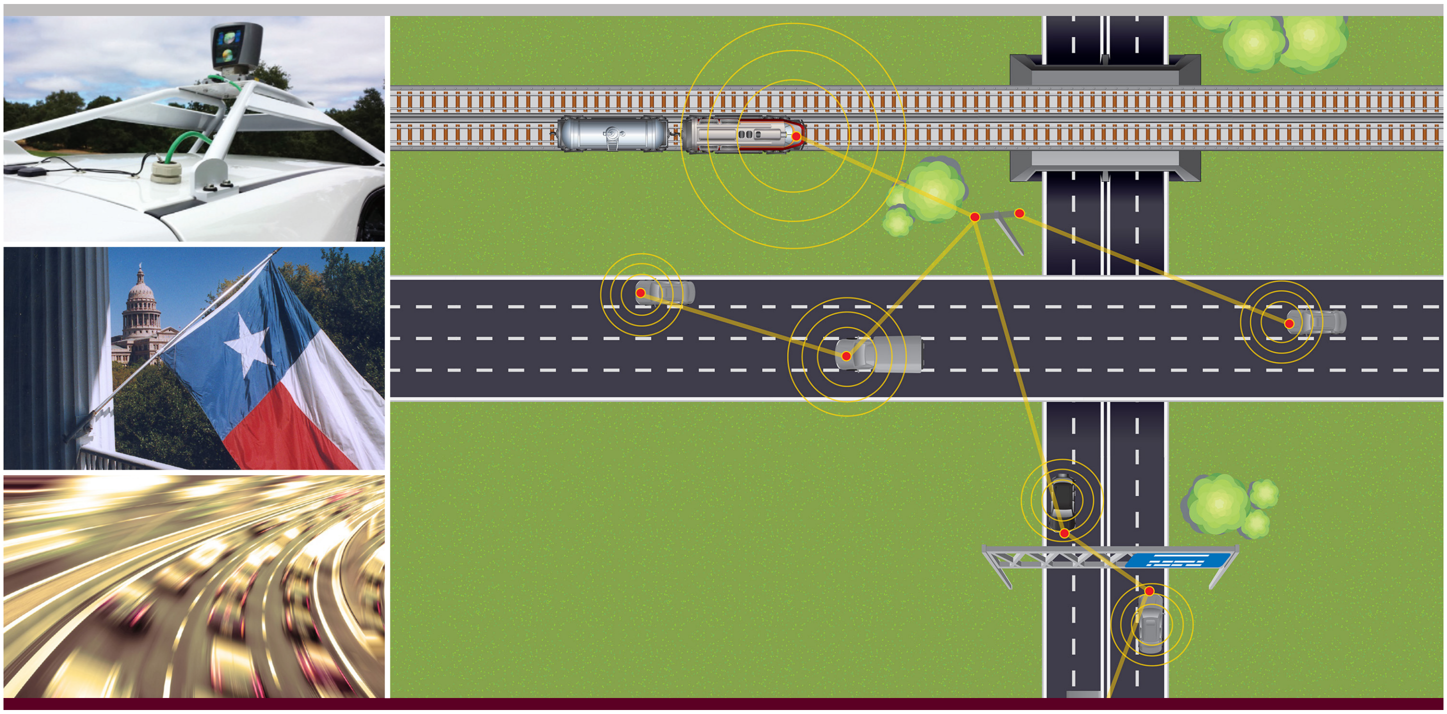
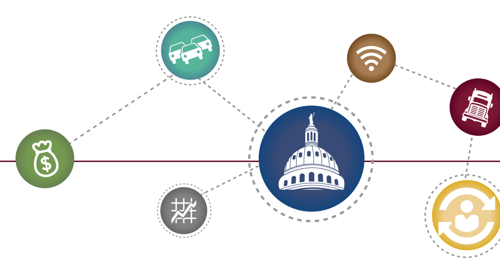


Revolutionizing Our Roadways

The Challenges and Benefits of Making Automated Vehicles a Reality



TRANSPORTATION
Policy Research CENTER

Revolutionizing Our Roadways

The Challenges and Benefits of Making Automated Vehicles a Reality

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Automated Vehicles: The Future Is Near

Automated vehicles (AVs)—a combination of technologies and sensors that enable vehicles to operate with limited or no driver input—are rapidly moving from science fiction to real-world application. Low-level, limited function AV technologies are already available on new vehicles today, and high-level AVs may be just around the corner. On-road vehicle testing is currently underway and legal in several states, and some industry experts expect high-level AVs to be available as soon as 2020.

While the technological advancement is impressive, many unknowns surround the widespread deployment of AVs. How can we safely test AVs on public roads? Will consumers readily accept automation? How can we ensure the security of transmitted data between vehicles and the roadside when major corporations struggle to ensure users' data privacy and security? Will consumers or vehicle manufacturers bear the liability of an AV crash? What are the implications for the roadway infrastructure? What are the societal benefits and costs of implementation (e.g., upgrading infrastructure vs. cost savings accrued from improved safety)? These are a few of the big-picture questions that Texas A&M Transportation Institute (TTI) researchers investigated in this study.

Technology Moves Us Forward

It's no longer a matter of *if* AV deployment will happen but *when*. Low-level automated features, like adaptive cruise control or electronic stability control, are already available on existing vehicle models. As they prove themselves reliable and cost-effective, automated technologies will continue to achieve greater levels of market penetration. Optimistic estimates for high-level automation put availability as early as 2020.

AVs can help usher in a future marked by improved safety, enhanced mobility, and reduced congestion. For example, AVs can help reduce the number of crashes since they will not make common human mistakes like failing to check a blind spot or texting while driving. High-level AVs could improve mobility for populations that struggle with the driving task (e.g., the elderly, the handicapped). Congestion—mitigated by more efficient throughput on roadways—could decrease, improving everyone's quality of driving life and minimizing time and dollars currently lost to gridlock.

Miles to Go Before We're Ready

The reality of widespread, high-level AV deployment, however, is many years away. Even considering Google's innovative and highly-publicized self-driving car, high-level AVs are not yet commercially available. Once they are available, it will take many years for the vehicles to become commonplace. While the private sector is responsible for developing AVs, public agencies must ensure that AVs safely function in a roadway environment designed specifically for human drivers, where automated and human-driven vehicles can seamlessly interact.

However, state and local transportation agencies are unsure how to prepare for automation. Because so many questions about AVs have yet to be answered, transportation agency officials are often excited about automation's promises, but unsure how to prepare and adapt. The federal government has taken a cautious stance, not yet regulating automation, but providing recommendations for states that are considering regulations. Four states and the District of Columbia have already passed laws regulating AVs, focusing largely on testing vehicles on public roads.

For AVs to safely and optimally function, the transportation infrastructure may need to change or be maintained at a higher level than the current standards require. These changes could result in significant costs for state and local governments. Meanwhile, publicly-funded agencies are already stretching limited resources to meet the ever-growing demands on today's transportation system. In that context, planning for fundamental enhancements to infrastructure can seem like a luxury. Yet, high-level automation is coming.

There are still many unknowns surrounding vehicle automation and its effects. As higher-level AVs become available, our understanding of how humans react to and behave in a world with automation will improve. In the meantime, additional research will help us plan for and adapt to a driving environment that may be a little safer, less congested, and more worry-free.

Figure 1. Lidar and GPS Hardware on one of Google's Self-Driving Cars.

An Overview of Automated Vehicles

Implementing AVs is a complex undertaking. The AV industry is developing the next generation of autonomous vehicles, and the public sector is responsible for maintaining the nation's transportation infrastructure and ensuring the safety of its drivers. Since AV implementation is still in its formative stages, better understanding the issues surrounding vehicle automation is essential to making good decisions regarding the adoption of AVs on our roadways. This section provides answers to questions to promote that dialogue.

What Is an Automated Vehicle?

An AV operates partially or fully — through steering, accelerating, and/or braking — independently of a driver. Vehicle automation is an emerging technology, so market penetration is currently limited. Some vehicles on the road today have automated features (e.g., adaptive cruise control, parking assist, traffic jam assist). These features are mostly limited to high-end vehicles and still require constant monitoring by a driver. As automated technologies advance, it is likely that these vehicles will eventually control the driving task completely. High-level automation, which could drive some of the most dramatic changes, will not reach significant U.S. market penetration in the near future.

How Do AVs Function?

A variety of sensors enable an AV to detect and react to the world around it. Computers receive and interpret the sensor information and direct electronic vehicle controls to respond to the roadway environment. This process enables the vehicle to accelerate, brake, and steer in a dynamic driving environment. A few of the sensors commonly used in AVs include:

- **radar** — used in range and object detection;
- **lidar** — a laser-based ranging and imaging system, functionally similar to radar;
- **computer imaging** — the process by which computers interpret images of the world to better understand its elements, like detecting road striping, stop signs, or traffic signals;
- **global positioning systems (GPS)** — a satellite-based navigational aid;
- **ultrasonic sensors** — functionally similar to radar, but used in shorter-range situations; and
- **dedicated short-range communications (DSRC)** — enables radio communication between vehicles, the infrastructure, and other transportation modes (e.g. pedestrians, bicycles, etc.) to share information about vehicle position, movement, and the general roadway environment.

Table 1. NHTSA AV Classification Structure

NHTSA Automation Level		Description
0	No Automation	Vehicles function without any automation.
1	Function-Specific	One of the vehicle's functions is automated, but the motorist must constantly monitor the vehicle and the road should he need to take over.
2	Combined Function	Multiple functions are automated concurrently, but the motorist must constantly monitor the vehicle and the road should she need to take over.
3	Limited Self-Driving	The vehicle is sufficiently automated so that it can operate without the driver constantly monitoring the road, but the driver may need to intervene in rare circumstances.
4	Full Self-Driving	The vehicle can drive itself without a human driver present.

These technologies enable currently automated functions—like electronic stability control, adaptive cruise control, park assist, and collision prevention systems—and also serve as the technological underpinnings of future, high-level AVs.

How Do We Classify Levels of Automation?

Automation is not an either-or, binary technology; it exists as a series of technological levels. When applied to AVs, *automation* can refer to different levels of technology assistance. The National Highway Traffic Safety Administration (NHTSA) developed a key for classifying AVs, which includes five distinct levels of automation.

A few vehicle models currently on the market, for example, are equipped with adaptive cruise control. This feature enables an equipped vehicle to drive at a pre-set speed (like cruise control) but is also able to dynamically adjust the vehicle's speed to maintain a safety cushion behind a vehicle ahead. This is an example of a level 1 technology, since only one function of the vehicle (acceleration) is automated.

Table 2. AV Development Timeline

NHTSA Automation Level		Forecasted Range
1	Function-Specific	Now
2	Combined Function	Now to 3 years away
3	Limited Self-Driving	3 to 10+ years away
4	Full Self-Driving	7 to 12+ years away

Continuing the example, *if* the vehicle could also maintain its position within the lane, it would be classified as a level 2 AV. This is because both the acceleration and steering functions are automated simultaneously and collaboratively. To reach a level 3 automated technology, the vehicle would need to control all "safety-critical functions under certain traffic or environmental conditions." It would also have to be sufficiently robust to allow the driver to disengage from actively monitoring the road.

When Will AVs Become Available?

TTI researchers posed this question to AV manufacturers, developers, and suppliers. While their opinions varied, the following table provides a glimpse into the AV industry's expectations for time ranges of when AVs of certain levels will reach the market.
Low-level automated features, such as adaptive cruise control, already exist on some vehicles. Higher-level AV development and proliferation seem guaranteed, with the most pressing question rapidly shifting from *if* self-driving cars will be a reality to *when*.

Despite the relatively near-term horizon for introducing AVs into the market, it will likely be many years before AVs represent a significant portion of the private automotive fleet. This is due in part to the lengthy turnover period for private vehicles (in 2013, the average U.S. vehicle age was 11.4 years)[i]. This suggests that

non-automated and low-level AVs will dominate the U.S. vehicle fleet long after high-level AVs have been introduced.

How Will AVs Affect Society?

Unfortunately, the technologies are not yet fully developed and data on the effects of automation is very limited. However, AVs have the potential to fundamentally change the dynamics of our transportation system. How that will happen is uncertain, but early evidence indicates AVs hold the potential to:

- improve driving safety;
- enhance convenience, comfort, and productivity;
- improve mobility and reduce congestion; and
- alter urban development patterns.

Improvements to Driving Safety

According to a recent analysis by NHTSA, some standard AV technologies are already reducing crashes[ii]. It seems likely that as technologies improve and proliferate, crashes will continue to decrease. Current automated technologies — like electronic stability control, lane departure warnings, crash imminent braking, and other collision avoidance systems — are already helping to reduce vehicle crashes. A recent U.S. Department of Transportation (DOT) report to Congress estimated that 95 percent of crashes are attributable to human error when, for example, drivers divert their attention from the roadway to check a text message or take a phone call[iii]. It's logical to assume that technologies automating tasks prone to human error will help make roads safer. They will not be infallible, however, and some percentage of crashes will likely persist.

Enhancements to Convenience, Comfort, and Productivity

Navigating congested traffic is a stressful and time-consuming chore endured by millions of Americans every day. AVs could alleviate this burden by enabling drivers to concentrate on other things. The AV industry anticipates that this will be the first area in which motorists notice automation making their lives easier. At lower levels of automation, the vehicle will still require the driver's partial attention. At higher levels, the motorist would very rarely (if ever) need to attend to the vehicle.

Improvements to Mobility and Reduction of Congestion

Understanding and predicting how automation will affect mobility and congestion is difficult because we do not yet know how AV technologies will specifically affect the real-world roadway environment. However, it's possible to discuss a few potential effects.

First, level 4 fully autonomous vehicles (unavailable for many years) could improve mobility for populations that currently cannot drive (e.g., the elderly, the blind, and other disabled populations), enabling them to safely travel.

The extent to which AVs might alleviate congestion is less certain. AVs could decrease congestion through improved vehicle control and more efficient roadway use. For example, AVs will likely have highly-precise controls enabling them to safely drive in situations where a human driver could not. This ability, in combination with other vehicle technologies, could allow these vehicles to drive more closely together in high-speed platoons, increasing vehicle throughput along a corridor. Also — as automation matures and proliferates — departments of transportation could potentially alter road designs to suit the capabilities of AVs, increasing the capacity of existing roads by narrowing lanes, minimizing shoulder usage, and removing other infrastructure elements designed to accommodate a driver's limitations. Finally, congestion resulting from traffic slow-downs due to crashes would likely decrease as vehicles become safer and crash frequency decreases.

However, there is some evidence that automation could actually *increase* congestion. AVs will likely decrease the costs of driving, incentivizing more frequent and longer trips and thereby potentially increasing vehicle miles traveled and worsening congestion on roadways. Some of the congestion-mitigating benefits partially depend on the availability of vehicle-to-vehicle (V2V) communication, which NHTSA recently announced would be required on future light-duty vehicle models. NHTSA did not state the year the mandate would take effect.

Alterations to Urban Development Patterns

Evidence shows that AVs could change urban form by allowing commuters to live further away from their places of work. When selecting housing, individuals make tradeoffs between wages, commute times, and living costs. High-level AVs could decrease the costs of commuting by reducing stress, decreasing commute time, and enabling motorists to use their commute time more productively (e.g., prepare for a meeting while the car does the driving). A high-level AV would allow a person to work in urban areas while living in suburban or exurban areas and incurring minimal cost from an AV-enabled commute. Combining these factors, the net result could be individuals choosing to live further away from work than they do currently.

Though not available in the near future, high-level automation could also enable cities to plan developments more efficiently, resulting in increased density. Fully autonomous vehicles could drop off passengers at desired locations, park in an off-site parking facility, and return to pick up passengers upon command. As a result, cities could consolidate parking facilities into a few locations, achieving increased density through more efficient urban design.

What Have State Governments Done about AVs?

Many states are currently considering legislation. Thus far, California, Nevada, Florida, Michigan, and Washington, D.C., have all passed laws regarding automated vehicles.

California

The California Legislature passed Senate Bill (SB) 1298, establishing rules for AVs. The legislation permits the operation of AVs for testing on public roads *if* there is a driver present to operate the vehicle in an emergency. The law requires that AVs without a driver comply with certain rules to be developed by the state's department of motor vehicles (CADMV) by 2015. The CADMV released the draft regulations as part of the public review process in January 2014.

District of Columbia

Washington, D.C.'s, Autonomous Vehicle Act of 2012 directed the D.C. DMV to create an AV designation and develop "safe operating protocols." The legislation created definitions for AVs and established rules for their operation. The rules hold that the vehicle must:

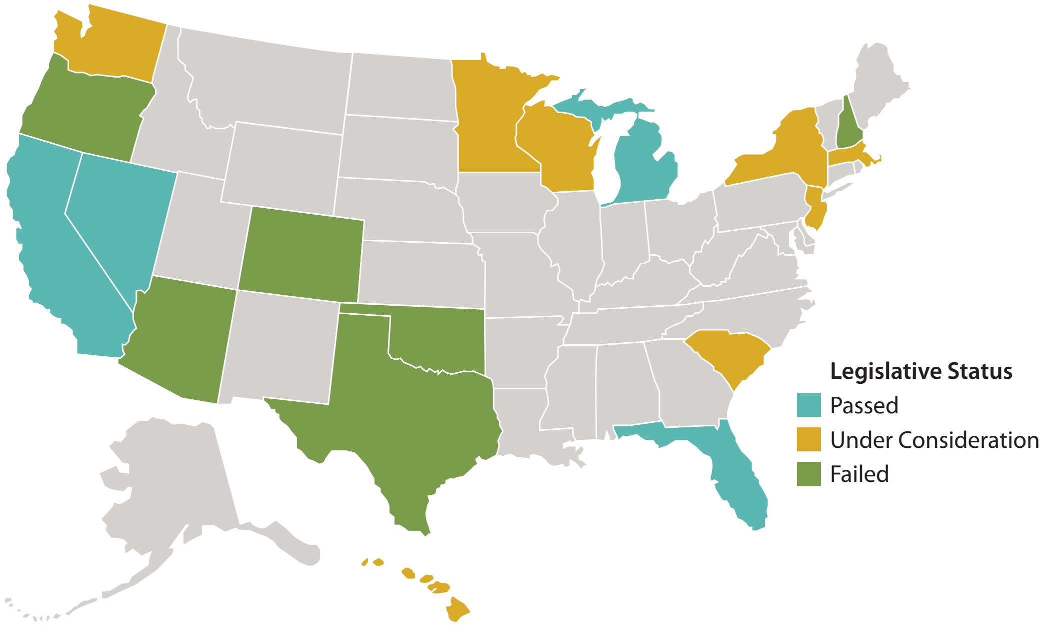
- have a manual override;
- have a driver in the driver's seat ready to take over at any time; and
- operate in compliance with all of the district's other normal traffic laws and regulations.

The law also set rules for converting vehicles to autonomous operation and limits AV industry liability for any vehicle converted to autonomous driving purposes.

Florida

Florida's autonomous vehicle legislation — passed in 2012 — specifies that a "person who possesses a valid driver license may operate an autonomous vehicle in autonomous mode." Similar to other state legislation, the law establishes that AVs must:

- comply with federal motor vehicle standards;
- have a function that enables and disables the autonomous functions;
- support a device inside the vehicle that indicates when the vehicle is in autonomous mode; and
- include a feature that alerts the operator if the technology should fail.



Action taken on automated vehicle legislation	Number of states
Have passed legislation	4 states and Washington, D.C.
Are currently considering legislation	8 states
Attempted but failed to pass legislation	6 states, including Texas

Figure 2. AV Legislative Actions in the United States[iv].

The law limits liability for the AV industry regarding converted vehicles, requires testing companies to carry insurance, and directs the Florida Department of Highway Safety and Motor Vehicles to advise the legislature on recommended regulatory actions.

Nevada

Nevada passed Assembly Bill 511 in 2011 and then amended the legislation in 2013 in SB 313. As in other states, this legislation establishes definitions for AVs, directs the DMV to develop regulations for AVs, limits liability of the AV industry regarding autonomous test vehicles, and states that "a person is not required to actively drive an autonomous vehicle."

Michigan

Michigan passed two bills — SB 169 and SB 663 — in December 2013. This legislation establishes definitions for AVs; allows for testing by the AV industry, suppliers, and others on public roads; requires a qualified operator be present when a vehicle is operated; and directs the Michigan Department of Transportation to report on progress in three years. Both laws limit liability for the AV industry and suppliers.

What Has the Federal Government Done about AVs?

In summer 2013, the National Highway Traffic Safety Administration (NHTSA) published formal recommendations for states considering regulating the testing of AVs on public roads[v]. The document provides:

- a review of NHTSA's research activities in relation to automated driving;
- definitions of the various levels of automation; and
- "recommended principles" for states to consider regarding "driverless vehicle operation, especially with respect to testing and licensing."

AVs are still a nascent technology. At this point, NHTSA does not currently have a rulemaking action to formally regulate AVs. However, the agency does provide guidance for states attempting to pass regulations. The guidance does not cover vehicle levels 0 through 2, or any operation by private individuals. Instead, it focuses on "the licensing, testing, and operation of [level 3 and 4] self-driving vehicles on public roads."

Given the developmental nature of AVs, NHTSA recommends that states strike a balance between ensuring safety and providing businesses the flexibility to innovate. First, the agency recommends that states do not regulate a vehicle's technical performance. Second, they recommend against "states attempt[ing] to establish safety standards." Finally, NHTSA recommends that states not authorize self-driving vehicles for any purposes other than testing.

The recommendations are explained in complete detail in their Preliminary Statement of Policy Concerning AVs.[vi] As an overview, the recommendations cover four main areas:

1. Licensing drivers to operate self-driving vehicles for testing.
   a. Ensure the driver understands how to operate a self-driving vehicle.
2. Regulating the testing of self-driving vehicles.
   a. Ensure on-road testing minimizes risks to other road users.
   b. Limit testing operations to conditions suitable for the capabilities of tested self-driving vehicles.
   c. Establish reporting requirements to monitor testing.
3. Establishing basic principles for testing self-driving vehicles.
   a. The transition process from self-driving mode to driver control is safe, simple, and timely.
   b. Self-driving test vehicles should have the capability of detecting, recording, and informing the driver that the system of automated technologies has malfunctioned.
   c. The installation and operation of any self-driving vehicle technologies does not disable any federally required safety features or systems.
   d. Self-driving test vehicles record information about the status of the automated control technologies in the event of a crash or loss of vehicle control.
4. Regulating the operation of self-driving vehicles for purposes other than testing.

Connected Vehicles

"Connected vehicle" is a term that describes a related, but independent technology.[1] This technology allows vehicles to communicate with each other, the infrastructure, and other transportation modes through dedicated short-range radio communications (DSRC). The USDOT has largely spearheaded connected vehicle research, and has recently announced plans to move forward with implementing connected vehicle applications on light-duty vehicles.[vii]

Connected vehicle technologies were primarily developed for their safety benefits, but when applied to AVs, could also enhance performance and operations. Current AVs do not require this form of connectivity, but the additional sensors and information could improve safety and provide benefits beyond the capabilities of AVs alone, like facilitating high-speed vehicle platoons.

[1]Connected vehicle is often also known by its various acronyms, including V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure), and V2X (vehicle-to-other)

Asking the Experts

Interview Approach

Based on the research findings presented in Section 2.0, the TTI team conducted interviews with two groups vital to successful implementation of AVs. Interviews lasted approximately one hour and respondents' anonymity was ensured. The appendix of the technical report, "Automated Vehicles: Policy Implications Scoping Study," lists the questions asked of both groups.[viii] As noted earlier, researchers used the NHTSA automated level definitions in discussions with respondents.

First understanding the private-sector perspective gave researchers the opportunity to explore issues pertinent to the public sector during the second set of interviews. For example, most industry representatives felt that a patchwork of conflicting state legislation and regulation would impede AV development. Using both perspectives, researchers identified questions that future research must answer prior to attempting widespread AV deployment.

The groups interviewed were:

1. **AV manufacturers, suppliers, and developers (referred to collectively as original equipment manufacturers, or OEMs)**. Researchers sought OEM perspectives on the development and societal impact of AVs, as well as insights into how state and local transportation agencies will need to adapt infrastructure and daily operations to facilitate implementation. Ten individuals were interviewed.
2. **State and local transportation agency employees (including state DOT members, DMVs, and local government representatives)**. Researchers sought reactions to the issues raised in the OEM interviews and provided those on the front line of AV implementation the opportunity to discuss how their agencies could better prepare to meet the needs of a road network with AVs. Nine individuals were interviewed.

A summary of responses for each topic is provided in the following two sections. In-depth response summaries and analyses are available in the technical report.

Group 1 Results: Private-Sector OEMs

Researchers asked OEMs 11 questions covering the following topics related to AV implementation:

- timeline;
- standardized technologies;
- role of V2X communications in AV deployment;
- roadway and infrastructure changes;
- managed lanes;
- state legislation and regulations;
- role of federal, state, and local governments;
- economic benefits;
- cybersecurity;
- vehicular data usage; and
- product liability.

Table 3. AV Development Timeline

NHTSA Automation Level		Forecasted Range
1	Function-Specific	Now
2	Combined Function	Now to 3 years away
3	Limited Self-Driving	3 to 10+ years away
4	Full Self-Driving	7 to 12+ years away

How long will it take to implement AV capabilities consistent with NHTSA automation levels 2 and 3?

Responses were relatively consistent for level 2, but varied dramatically for higher levels of automation. Note: the researchers only specifically asked about levels 2 and 3, but some respondents addressed level 4 as well. Several respondents noted the significant technical distance between a 99.9 and a 100 percent-reliable vehicle; this difference accounts for the significant time needed to transition from level 3 to level 4 vehicles. Others felt institutional issues like liability, licensing, regulations, and inconsistent legislation would create a greater delay than technology. Some, however, felt that level 3 AVs could be on the market in the next three years, with level 4 vehicles available in less than 10 years.

Will AVs use a standard technology set? If so, which one?

The industry is in the early stages of developing enabling sensory technologies. As these technologies mature, OEMs will slowly converge on some combination of similar solutions. One respondent emphasized that setting standards for the industry too early in the development process would stifle innovation.

How important will connected vehicle communications be in AV development?

Some cited the benefits of V2X technologies, which include the ability for vehicles to "see around corners" (especially beneficial in high-speed environments), and the benefits associated with connectedness related to traffic management and vehicle platooning. Others cited barriers that limit DSRC—the V2X enabling technology—including privacy, security, and funding issues. The most frequently cited barrier was lack of availability, since DSRC sensors are not currently mandated in vehicles and are not installed along the roadside. One respondent even dubbed DSRC an "obsolete technology."

How will roadway infrastructure, digital infrastructure, maps, or other associated data need to change to accommodate AVs? Also, what changes to roadway infrastructure or DOT operations are necessary to facilitate AV development?

Additional public-sector services might aid AV deployment, but respondents expressed concerns that infrastructure couldn't evolve quickly enough to keep up with AV developments. Well-maintained infrastructure, such as pavement striping and roadside vegetation control, is vital for safe AV operation. High-quality digital maps can aid AV navigation, and one respondent noted the benefits of a sensory system capable of detecting animals in the roadway.

Can managed lanes facilitate the early implementation of AVs?
Respondents were split down the middle on this question. Some of those in favor of the idea raised the following points. Managed lanes (MLs) could:

- facilitate AV adoption by providing access to expedited lanes;
- encourage consumer acceptance of the technology;
- accelerate the availability of high-functioning automated systems; and
- increase efficiency via vehicle platooning.

Opponents raised the following points:

- Infrastructure changes cannot keep up with AV developments. Waiting for dedicated lanes would mean society would not be making adequate use of the technology.
- There is a "chicken and egg" problem: companies would not build vehicles with the necessary V2X sensors unless consumer demand existed; consumers would not buy vehicles with V2X sensors unless the infrastructure already existed; transportation agencies—already strapped for maintenance and development dollars—would not build the infrastructure to make use of V2X sensors not yet in vehicles.
- Using managed lanes for this purpose is "a waste of infrastructure."

What effect will state legislation have on OEM's ability to test vehicles?
Current state legislation has had little impact on operations. As long as manufacturers remain involved with the process, noted one respondent, "these laws pose minimal concerns to OEMs." In general, OEMs expressed trepidation about unqualified individuals/organizations testing unsafe vehicles, since a crash could potentially result in negative press for the industry as a whole, as well as liability for the producer. States licensing companies that test AVs on public roads would reduce the likelihood of this occurring by tightening and clarifying regulations.

What role, if any, will governments play in developing and deploying AVs?
Frequently raised issues included developing consistent regulations and definitions. Respondents generally felt innovation would flourish if states refrain from passing "a tapestry of regulations" with significant variations between states. Government agencies should consult more closely with the industry than they have to date. Technology requirements and definitions should be set at a national or international level; development should occur in consultation with relevant industry stakeholders. Some individuals expressed displeasure with NHTSA's definitions, saying they lacked sufficient industry feedback prior to being codified and released.

Federal regulations on AV testing and certification would be helpful, although one respondent felt robust testing method for AVs is impossible. This individual credited the difficulty of developing a robust testing method to the high threshold for safety needed with an AV: an AV must be capable of safely handling nearly any situations that might occur while driving, which are essentially infinite. Successfully testing a vehicle's ability to handle literally any situation is a very daunting proposition.

What economic benefits could result from AVs (assuming automation levels 2 and 3)?
Respondents identified the following benefits:

1. **Safety**. Many crashes result from human error. Automating the driving task will likely reduce crashes. At lower automation levels, sensors will reduce low-speed, property damage crashes.
2. **Convenience, comfort, and productivity**. As automation matures and AVs take on additional responsibility for the driving task, motorists will have the option to free themselves from the mundane, stressful tasks of navigating traffic. Drivers can use this time more productively.
3. **Congestion reduction**. AVs may reduce congestion, especially when platooning, by reducing headways and improving overall system efficiency.
4. **Increased mobility**. High-level AVs can potentially grant greater mobility to handicapped or other traditionally driving-impaired individuals.

What role do governments have in addressing cybersecurity? Are cyberthreats a risk to AVs?
Respondents were evenly split on this issue. Half believed the federal government should take a leading role in setting cybersecurity standards and minimum requirements. The other half felt that cybersecurity is either not a concern or their organization was adequately prepared to address it. In either case, connected vehicles transmitting data will require authentication, firewalls, and safety protocols ensuring that unauthorized entities can never access vehicle data.

What issues exist regarding the use/ownership of AV data?
Many respondents characterized this issue as a choice between two competing goals: *safety* and *privacy*. Most felt companies will use data to improve AV system safety, fine-tune technical aspects of the system, and determine liability when a crash occurs. One OEM felt that AVs need driver-monitoring sensors to ensure the driver is awake and unimpaired and can take control if needed.

Several respondents expressed concerns about the need to ensure privacy. One person noted that the United States needs stronger federal regulations to safeguard privacy. Another stated that finding "an appropriate balance of vehicular data and safety" could occur "through a national discussion and appropriate regulation." Regulations developed must be "robust and clear."

Table 4. A Summary of Insights from Industry Respondents

Topic	Industry Perspective
Timeline	• Some level of AVs will be on the road in the next 3-10 years. • The time needed to design/deploy safe vehicles combined with addressing the legal, liability, and regulatory issues will determine the actual time to market for AVs.
Standardized technology	• OEMs will eventually converge to using some combination of similar technologies to achieve robust automation. • Standards set too early will stifle innovation.
V2X communications	• It is vital to promote safety and system efficiency. • Barriers include infrastructure technology keeping pace with AV technology.
Managed Lanes for AVs	• Possible benefits include safety, mobility, reduced congestion, and increased productivity. • Who will risk investing capital in development first—private sector or public sector?
Public policy issues	• Private-sector (experts) must remain involved in the policy development process. • States should establish licensing/regulatory requirements for vehicle testing. • Governments should develop consistent standards, regulations, and definitions, including cybersecurity. • A balance between safety and privacy must be struck when collecting/establishing ownership of collected data. • Clarification of liability: who's responsible and under what circumstances?
Economic benefits	• Improved safety: fewer human error-related crashes can be expected. • Enhanced convenience/productivity: AVs drive/navigate while passengers work, etc. • Reduced congestion: platooning and AVs can increase system efficiencies. • Increased mobility: driving-impaired individuals will have more options.
Liability	• This is the largest issue for the AV industry that can potentially stifle innovation and pace of deployment.

How does liability affect your organization's approach to AVs?
Many respondents identified liability as one of the largest issues facing the industry. One respondent even characterized liability as an issue that would likely "dictate how AV development proceeds." As AV capabilities increase, the responsibility for driving will gradually shift from the human to the vehicle itself. As the vehicle increasingly bears the burden of the driving task, the vehicle manufacturer will also bear a greater share of crash liability. As an example, if a motorist engages an auto-drive function and the vehicle crashes erroneously, it seems unusual to assign the liability to a human driver who was not engaged in the driving task.

This shift in liability is very disconcerting to the automobile industry. One respondent stated that concerns over liability could keep high-level AVs from ever reaching the market. Another felt that existing liability structures are sufficient: vehicles will gather data—which can then be used to assign liability— if a crash occurs.

Group 2 Results: Public-Sector Agencies

Researchers asked agency personnel 10 questions covering the following topics related to AV implementation:

- concerns with AV development;
- benefits of AVs;
- steps taken in preparation for AVs;
- safety incentives;
- NHTSA regulations;
- operations and maintenance;
- infrastructure connectivity;
- cybersecurity;
- commuting; and
- managing the transition.

What are the public-sector concerns related to AV development?
Safety
State DOT personnel in particular feel the onus of ensuring that public roadways are safe; therefore, the reliable testing and safe introduction of AVs is very important. One option is the use of secure manufacturers' plates and other regulatory measures to ensure vehicles are safe, including requiring manufacturers to use reliable engineering practices, meet certain government-mandated guidelines, and have proper insurance. Licensure and regulation could occur via the state's DMV.

Insufficient Coordination between Government and the AV Industry
Though many regulatory requirements occur at the state level, states are generally only responsible for maintaining and operating a portion of the total road network. In some cases, local and regional entities lack detailed knowledge about AVs and their deployment issues, requiring a greater level of coordination and information sharing between states and local agencies.

Inconsistencies in State Licensing and Regulation Efforts Could Stifle AV Industry Innovation
State regulations can significantly impact the AV industry itself. Any regulations imposed should ensure the safe testing of AV technologies. States should avoid prescribing preferred technology solutions.

No Business Case for Investment by the Public Sector in V2X Infrastructure Exists
Many interviewees recognized that V2I communication technologies like DSRC are needed to maximize the potential benefits of AV technologies. However, outside the potential safety benefits, a strong case has not been made for investing in V2I equipment. More research on the effects of connected and automated vehicle technologies on local and regional planning, commuting patterns, and congestion could help make this business case.

What are the benefits of AVs?
Safety and efficiency were the most commonly cited benefits. AVs can reduce crashes and improve overall roadway safety. Likewise, system efficiencies can improve via AV innovations like platooning, which can enhance system throughput.

Has your agency taken any steps to prepare for AVs?
Most recent state actions involve licensing and regulation development regarding testing vehicles on public roadways (as opposed to regulating AV introduction into the general vehicle fleet). Some states are involved—or are considering involvement—in the incubation of AV technologies or directly testing AV systems. For example, one state is considering reactivating a test bed for evaluating roadside equipment at intersections that might benefit from AV applications. Another is looking at using V2V communications in commercial vehicle operations.

Some states want to examine the institutional changes necessary for the testing and eventual deployment of AVs. For example, terminology, vehicular codes, and operational processes and procedures will likely need significant revisions to accommodate AVs. Similarly, AV requirements when interacting with roadside safety elements (e.g., lane markings) were a concern, as were determining how AVs perceive them and whether they might need alteration or enhanced maintenance to ensure the safe operation of AVs. Several respondents acknowledged that, until they have a better idea of the technologies involved, they cannot answer many of these questions.

Respondents noted other areas of research interest that would help their states prepare for AV deployment, including:

- scenario planning and testing to better quantify the potential penetration of AV applications in the vehicle fleet;
- examination of potential AV applications for commercial vehicle operations;
- human factors research, specifically on how the transition from human to automated control of the vehicle will occur; and
- assessment of the potential impact of AV technologies on car ownership patterns.

Has your state evaluated implementing policies that encourage the use of AVs for safety-related purposes?
At the time of the interviews, no state had yet taken formal actions to encourage the accelerated development of AV systems. Most activities involved meeting with other transportation entities or AV system developers to discuss how to address safety issues. One respondent said they are waiting to see the national agenda before considering incentivizing policies. One regional representative stated they would most likely advocate for these technologies due to their potential safety benefits but was unsure about enacting any specific policies aimed at encouraging their adoption.

What feedback do you have on the existing NHTSA regulations?
There is disagreement regarding the adequacy of NHTSA's current AV definitions. As one respondent from a state with a strong OEM presence noted, the private sector has been developing AVs for decades. This person feared that current NHTSA definitions might impede further progress in this field, a sentiment echoed by others. Another interviewee felt that definitions should have been issued ten years ago, noting the federal government is far behind the industry.
Most agreed that, at the state level, entities responsible for licensing drivers should be the most engaged in rulemaking. In some states, licensing drivers is handled by the DOT, while in others, the DMV or department of public safety (DPS) handles that function.

How will AV deployment affect your agency's approach to asset management? Any concerns related to funding?
Non-DOT entities (such as DMVs) deferred this question to their respective DOTs. DOT representatives noted that funding shortages are already impacting their states' ability to maintain and operate their infrastructure. Heightened levels of maintenance will require finding new funding sources or increasing existing revenue sources. Respondents repeatedly raised the question of who would bear these costs—the federal government or the state and local authorities?
Cost-benefit analyses and comprehensive asset inventories would help states and local entities determine what costs they could bear when implementing programs or maintaining assets to support AV development. Some DOTs are already

evaluating new methods of asset management that, while not directly encouraging AV development, would likely benefit the industry. Similarly, some agencies are looking at a more flexible decision-making process for employees (allowing them to use their discretion based on agency values rather than adhering lock-step to a process manual). This same flexibility would allow the agency to become more nimble and responsive to dynamic situations than was possible before.

Like their industry counterparts, many agency respondents expressed concern about the slow pace of infrastructure development. This issue implies a greater need for private-sector involvement, since industry will be better able to adapt their in-vehicle components to the needs and expectations of drivers. One interviewee stated that a *Manual on Uniform Traffic Control Devices* (MUTCD) specifically for AV systems would be helpful in evaluating potential changes to asset management, as well as ensuring consistency in AV development and state-to-state regulations.

To what extent will AVs rely on V2I communications? What are the opportunities/challenges for your agency in supporting such infrastructure?

Cost was the number-one concern raised. Budget restrictions make it difficult for states to maintain existing intelligent transportation system (ITS) infrastructure. Many respondents noted the adequate case for increased connectivity has not yet been made to policymakers. A business case for implementing V2I roadside equipment and infrastructure has yet to be fully developed, but this is difficult to establish when AV data needs are, to date, unspecified.

A second concern involves a lack of DOT institutional knowledge regarding the placement of connectivity infrastructure. Experienced personnel are retiring, and many agencies worry they will not have the technical skills required in the future. State and regional entities with a strong tolling presence noted they are positioned to be early adopters of AV-ITS applications, given their experience with ITS systems and existing relationships with drivers. However, they also noted that securing necessary funding to develop this infrastructure would likely be a significant barrier.

What are your agency's specific concerns related to cybersecurity? How do you view your role regarding cybersecurity?

Most cited safety as their primary cybersecurity concern. The security of V2X transmissions is paramount. The lack of institutional knowledge noted earlier is a significant area of concern, since the certification and regulation of transmitted data is not a focus area for most transportation entities. Tolling authorities do have some experience with this, but the type of information transmitted as part of AV operations is significantly different than that transmitted for tolling transactions. The low allowable error rate—among the most attractive aspects of AVs from a governmental perspective—is also one of the most challenging to ensure.

How will AVs affect commuting patterns?

Respondents were either unsure or skeptical regarding claims that AVs will affect commuting patterns. There is not yet data showing how people change their behaviors when they use an AV, which will determine how commuting patterns will change. Other technology developments outside of AV—like developing telecommuting technologies—could also have a large impact on travel and urban development patterns.

How should the transition to AV operations be managed and/or regulated?

Vehicle platooning is one operational application that could lead to wider use of AVs because it has, for example, the potential to double the throughput of a single lane. Most entities interviewed have not yet begun to discuss how they might manage the transition to AVs, primarily because it's still unclear as to what will be required of drivers under the AV model. Driver assistance applications exist in newer vehicles, but these still require the driver to maintain full control of the vehicle. Many respondents were open to the idea of dedicated lanes for AVs, or for allowing AVs into limited access facilities (such as managed lanes). In the long term, AVs will need to be treated like every other vehicle.

Table 5. A Summary of Advice from Public-Sector Respondents

Topic	Governmental Perspective
Public-sector concerns	• Safety: agencies are primarily interested in ensuring AVs operate safely. • Coordinating government and industry: currently insufficient; better education of the public sector regarding AVs is needed. • Licensing and regulatory inconsistencies: should focus on safe testing, not regulating specific technologies. • Lack of a business case for V2X: to allot resources and shape good policies, a business case for V2X needs to be made. • Funding: who will fund infrastructure adaptations/maintenance?
Benefits of AVs	• Safety can be achieved through reduction in human error. • System efficiency can be enhanced via technology innovations (e.g., platooning).
How agencies are preparing for AVs	• Some states have begun developing licensing/regulation requirements, especially with regard to AV testing. • Some are looking at necessary institutional changes (policy, procedure) for implementing AVs. • Agencies need a better definition/understanding of AV technology. • Some are waiting to see the national agenda before issuing policies that incentivize adoption of AVs.
How AV deployment will affect asset management	• Funding shortages exist for the current system. • New or enhanced funding sources are necessary to maintain a new, more advanced system. • Some are considering a more flexible decision-making process for agency employees to improve responsiveness to new technology. • Skepticism exists over whether AV will affect commuting patterns. • Most have not yet begun to discuss transition needs due to lack of specificity about technology-human interaction.
How agencies can facilitate infrastructure/ AV communications	• Who will fund V2X communication infrastructure deployment is the primary question. • Lack of a well-designed business model makes arguing the case for funding to decision-makers difficult. • Lack of institutional knowledge about AV-ITS solutions is problematic. • Safety is the number-one concern about cybersecurity.

Where to go from Here…

The project's interviews yielded general findings potentially useful to policy makers as they consider AV implementation in Texas.

Many Questions Remain Unanswered

The private sector expressed uncertainty about how to deploy AVs in terms of system development, timeline for deployment, and operational issues. Though a window of 3 to 10 years was specified by some for NHTSA level 2 and 3 vehicles, OEMs could not agree on when AVs would become technologically mature and readily available. What standardized components (if any) will eventually attain dominance is also unknown. Since how the technologies will be developed, implemented, and paired with existing infrastructure are open questions, how AVs would affect the transportation system, transportation agencies, and consumers is also unknown.

Public Investment in Infrastructure to Facilitate AV Implementation

The lack of practical knowledge regarding how AVs will be implemented makes it difficult to assess the level of public investment in infrastructure required to accommodate AVs. Will transportation agencies need to invest heavily in implementing, operating, and maintaining roadside communications technologies (e.g., DSRC for V2I communications)? Are current pavement marking design and maintenance practices sufficient for the sensing equipment that AV systems might use? Public entities will need a much clearer idea of how AV technologies work before considering allotting resources to accommodate them.

AV Assimilation into the Driving Environment

Though currently being explored, no clear-cut strategy yet exists for incorporating AV technologies into general-purpose traffic environments. Issues like integrating AVs with general traffic (instead of dedicating lanes to AVs) are still undecided. NHTSA level 1 and 2 AVs already operate on public roadways; it seems probable that automation will slowly increase in maturity and sophistication, eventually integrating AV systems with roadway traffic, but the details as to how are not yet clear.

Driver-AV Interaction

How will drivers ultimately interact with AVs? The issue of responsibility behind the wheel is one example of such concerns. Will certain activities—such as texting or driving while intoxicated—be allowed? If so, new laws (or changes to existing laws) are required. If not, how can society enforce such laws when automation masks evidence of impairment or distraction? Since all states ban certain activities while driving, addressing such conflicts will be a significant public policy challenge.

Will Society Benefit from AV Deployment?

Our research indicates that society could significantly benefit from AVs:

- having fewer crashes due to human error would improve highway safety;
- improved vehicle throughput would enhance overall system efficiency; and
- having fewer driver-reliant vehicles could increase mobility for vulnerable populations.

How specifically can these enhancements benefit society? More research is needed to answer that question. Once better quantified, we could determine the potential effects on planning, congestion, commuting patterns, mobility, and the economy. In an era of fiscally constrained public institutions, pressure is increasingly mounting to justify the expenditure of public dollars. Without being able to quantify the societal benefit of AVs, public agencies will be unlikely to invest in them.

Knowing What We Don't Know

One question that needs answering: how can AVs help reduce congestion? Public- and private-sector stakeholders have differing opinions, and early deployment models are inconsistent. Some fear AVs will operate with longer-than-normal vehicle headways as a way to minimize liability concerns, and this will cause increased congestion. Others feel that investments in AVs could ease congestion and improve safety. Good empirical evidence for either argument remains scarce.

AV systems can potentially benefit people who cannot currently operate a motor vehicle. To accommodate these users, however, AVs must be extremely robust and reliable in a dynamic travel environment. Such technology does not yet exist and will likely not widely penetrate the market for many years. Developing, testing, and deploying level 4 AVs requires research on all aspects of human-vehicular interaction, as well as feasibility testing for V2X communications.

Can the economy benefit? The answer appears to be yes—through crash reduction, decreased congestion, and improved mobility. However, the issue isn't as simple as the answer implies. The ability of AVs to provide these benefits is not well established. Firmly establishing the effect of these changes through robust benefit-cost analyses would provide data upon which good policies, like vehicle equipment mandates, could be based. Such mandates would likely increase vehicle costs in the short-term and require a significant investment of time and resources by the private and public sectors. Any such decision, however, requires a robust and comprehensive benefit-cost analysis and sufficient supporting evidence.

Improved Private- / Public-Sector Communications

Regulating an emerging technology is tricky. Getting it right requires coordination and communication between the AV industry and governmental agencies. Several key areas concern both sectors. The private sector and NHTSA agree: states should focus on regulating OEM testing on public roads, but avoid regulating specific technologies. The industry does not want to see governments bias or constrain innovation; instead, they argue, the optimal vehicle-technology configuration should emerge from the marketplace. They worry about many states passing conflicting regulations. A regulatory "patchwork" approach would make compliance difficult, severely limiting manufacturers' ability to operate in multiple states.

The public sector, of course, has its own concerns. States have an obligation to ensure the safety of their roads. As such, their primary concern lies in ensuring the safe, reliable testing and continued operation of AV systems. Some states want to regulate AV testing to ensure OEMs practice good engineering, have sufficient insurance to cover on-road testing, provide reports on crashes or near crashes, and meet other safety-related requirements. In short, to ensure both public safety and private innovation, both sectors must coordinate, communicate, and work together as partners in a single process, not as adversaries with competing interests.

Regulating Small AV Manufacturers: A Delicate Process

OEMs are also concerned about unqualified AV developers—or those developers without the technical know-how to properly develop and evaluate a self-driving car—testing their vehicles on public roads. One crash could result in bad press that taints an entire industry, undermining public trust in AV technologies. To address this issue, OEMs would like states to certify companies to safely test AV systems on public roadways. While some regulations might be worth considering, states should be careful to avoid unfairly prohibiting small developers and manufacturers from entering the marketplace. Too stringent regulations could unwittingly establish a competitive advantage for established manufacturers. States must carefully and simultaneously promote safety and a competitive marketplace that encourages AV innovation.

Doing More with Less Is More Than a Catch-Phrase

Public agencies today are constantly evaluating how to stretch finite transportation dollars. Add to that the burden of implementing technologies facilitating connected vehicles and AVs, and the need for additional funding resources becomes clear. Though safety and system efficiency benefits from AVs seems likely, the current lack of a compelling business case for connected vehicle infrastructure hurts a public agency's ability to make strategic planning projections or justify increased expenditures to policymakers. Future research examining the different areas potentially improved by connected vehicles—e.g., environment, safety, and congestion/mobility—is necessary to provide the empirical basis for that business case.

A Potential Barrier: The Slow Pace of Infrastructure Development

Though some public-sector personnel officials are eager to plan for incorporating AVs into the transportation system, the industry is reluctant to rely on infrastructure changes to facilitate automation. OEMs are currently designing their vehicles to function under the constraints of the existing roadway system. Several OEMs expressed concern about designing vehicles that rely on infrastructure changes or specific actions by the public sector, given the traditionally glacial pace of infrastructure development. The same principle applies for connected vehicle applications. Some OEMs are interested in the improved functionality that V2I applications and hardware could provide, but are certain their vehicles would function independent of the connectivity. Again, they fear that waiting for V2I enhancements would keep their vehicles from reaching consumers anytime soon.

Cybersecurity Is Crucial

Current AVs function through sensors on the vehicle, but many still require the transmission of data. In the future, vehicles will likely send and receive data to each other, to the infrastructure, and to other entities, like pedestrians. This data that will enable vehicles to form platoons, aid in navigation, and provide other safety benefits. An individual hacking this process or spoofing data transmissions could result in a variety of deleterious effects. The need for a reliably secure and trustworthy information transmission system is obvious. Though opinions differ regarding who should be responsible for securing the system, there exists consensus that the federal government should play a leading role in the development and management of a security certificate system that ensures the secure transfer of data.

Who is Responsible When Things Go Wrong?

If AVs improve safety and decrease vehicular crashes, fewer lives will be lost, fewer injuries will occur, and insurance premiums will decrease. Still, OEMs are concerned about liability when crashes do occur. That concern deters AV manufacturers from bringing innovative technologies to the marketplace, even if overall safety would increase as a result. Thus, policymakers and the public should carefully weigh the costs of liability with the potential benefits the technology could provide. In the past, lawmakers have shifted liability off product manufacturers when their products provide a substantial public benefit. Two apt examples include the vaccine and small aircraft industries in the 1990s and 1980s, respectively. Examining the effects of shifting liability away from these industries and others should be further studied prior to developing policies related to AVs.

Are Current NHTSA Standards Adequate?

Opinions vary about the adequacy of current NHTSA definitions and guidelines on AV systems. OEMs seem split in their support: some felt NHTSA definitions lacked sufficient industry input, while others felt they were adequate. States are unclear regarding whether they should follow NHTSA guidelines for the sake of consistency or create their own standards. Some states object to NHTSA's guidelines due to their own legacy regulatory systems, which they feel are adequate.

Resources

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