Texas CAV Task Force 2020 Annual Report

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June 3, 2021

Executive Summary of 2020 Annual Report

Texas CAV Task Force 2020 Annual Report

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Acknowledgments

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

The goal of the Texas CAV Task Force is to be a single point of information and coordination for all CAV activities in Texas. Activities the Texas CAV Task Force may undertake include hosting industry meetings, developing white papers, creating a knowledge base for best practices, and collaborating and reporting on lessons learned. The Texas CAV Task Force will serve as a clearinghouse of information for those seeking to pursue innovative CAV technology in Texas. The Texas CAV Task Force will be an incubating hub for any CAV policy recommendations that may need to be brought before the Texas Legislature and governor.

The Texas CAV Task Force is charged with providing a website as a single portal for CAV activities in Texas to inform the public, industry, and others. The Texas CAV Task Force is also charged with providing white papers on the most pertinent topics related to connected and automated vehicle technologies and development. This document describes the topics addressed in 2020 by the Texas CAV Task Force.

White Paper Executive Summaries

As a part of its initial efforts, the Texas CAV Task Force was asked to provide white papers across several topics related to connected, automated, and autonomous vehicle technologies. The Texas CAV Task Force focused on five areas and limited the scope of the white papers to discussing key concepts to understand the current situation and identifying issues and opportunities for ways forward among topics in those areas. The white papers were developed by five related subcommittees.

Connected and Automated Vehicle Terminology
A White Paper from All Subcommittees

During discussions, the subcommittees identified the need for the public to understand common terms. This white paper contains a broad set of terms applicable to the industry and technology and serves as a basis for developing a mutual understanding and common foundation.

This white paper is found in Appendix A of the Texas CAV Task Force 2020 Annual Report.

Automated Vehicle Safety Validation, Data, and Metrics
A White Paper from the Subcommittee on Safety, Liability, and Responsibility

CAVs are expected to increase the safety of motor vehicles, with the potential to greatly reduce the number of annual vehicle crashes and fatalities. A key public concern is the safety of fully autonomous vehicles and advanced automation technologies.

This white paper discusses state and federal roles and the state of the practice. The U.S. Department of Transportation has developed guidance, and the National Highway and Traffic Safety Administration (NHTSA) and Federal Motor Carrier Safety Association have made initial efforts to address rules updates. NHTSA has guidelines on voluntary safety self-assessments and is reviewing the Federal Motor Vehicle Safety Standards. States have varied in their approaches to facilitate safe testing and operations, and the paper reviews states' safety standards and policy development. The paper covers the work of standards bodies and data initiatives related to vehicle safety, examines NHTSA's Model Minimum Uniform Crash Criteria, and discusses the potential for reporting crash factors related to automated vehicles (AVs).

State of Texas safety and liability opportunities include:

- Promote ongoing and open public-private stakeholder dialogue and collaboration efforts on safety information and transparency.
- Discuss data sharing with AV companies, focusing on what data can be shared, cannot be shared, and are open for discussion.
- Encourage discussion between operators and developers and law enforcement to explore how to incorporate AV and automated driving function crash factors into state crash report forms (CR-3).
- Design an AV public education campaign developed with national partners, with distribution carried out by local officials and first responders.
- Continue to work with AV developers to create a website showing a map of AV testing and deployments within Texas.

This white paper is found in Appendix B of the Texas CAV Task Force 2020 Annual Report.

Understanding Perceptions and Opinions about Connected and Automated Vehicle Technology: Advancing the Dialogue

A White Paper from the Subcommittee on Education, Communication, and User Needs

Advances in connected and automated technology, both in vehicles and infrastructure, are changing how systems are operated, managed, and maintained. The rate of advancement will continue to increase. Potential safety and other benefits will be affected by the rate of public acceptance and adoption. Effective education and outreach are needed to build awareness, encourage engagement, increase public understanding, and inform adoption.

This white paper begins by addressing the need for common terms the public understands. The paper discusses gaining public perceptions of CAVs. It closes with an approach and strategies for successful education and outreach.

State of Texas CAV education and communication opportunities include:

- Tailor outreach and education to specific communities and audiences, supported by research, appropriate multimedia, and measures of effectiveness. Use a stakeholder engagement strategy and a complementary public outreach plan informed by:
    - Audience identification.
    - Market research.
    - Message design.
    - Consistent and continual message delivery.
- Achieve and educate about common terminology.
- Continue development and update of the Texas CAV Task Force website.
- Continue pilots and demonstrations supported by research and community surveys.
- Develop information on emergent issues including impacts on workforce, education, equity and inclusion, land use and environment, economic development, freight, etc.

This white paper is found in Appendix C of the Texas CAV Task Force 2020 Annual Report.

Connected and Automated Vehicle Data Issues and Opportunities
A White Paper from the Subcommittee on Data, Connectivity, Cybersecurity, and Privacy

Connected vehicles (CVs) and AVs use an array of sensors and other technologies to collect vast amounts of data from their own vehicles and the environment around them, as well as rely on volumes of different types of data from various sources to operate safely. A safe and successful integration of both CVs and AVs into the state's transportation ecosystem depends on understanding and addressing an array of critical policy and planning issues related to vehicle data.

This white paper is intended to build community knowledge about CAV data that informs safety, policy, stakeholder engagement, and technology practices. The paper provides an overview of CAV technologies and federal and state policies to frame the understanding of the related data concepts. It addresses CV and AV data privacy, security, and cybersecurity challenges. The paper also examines CV and AV data use, generation, and ownership concepts. The paper closes with the opportunities and challenges for data sharing and data exchange. These issues require ongoing collaboration among public- and private-sector stakeholders.

State of Texas CAV data opportunities include:

- Continue working as public-private partners to deal with issues such as data ownership, access, use, sharing, exchange, privacy, and cybersecurity protection. One exercise to inform these issues is answering the following questions:
    - Which entities are collecting, storing, and using CV and AV data—how, for what purposes, and with what protections?
    - What data gaps exist that hinder innovation and furthering the public interest?
    - What data can be shared or exchanged to facilitate the safe and successful integration of CVs and AVs into the transportation ecosystem?
- Address the ownership, technical, and policy issues surrounding these high-priority data categories. This will accelerate the safe deployment of CVs and AVs in Texas, providing information on work zones, real-time traffic and road conditions, roadway inventories, signal phase and timing, cybersecurity, and safety performance.
- Examine CV and AV data management challenges and solutions for both public- and private-sector agencies including collection, transmission, storage, and analytics.

This white paper is found in Appendix D of the Texas CAV Task Force 2020 Annual Report.

Connected and Automated Vehicle Infrastructure Needs for Automated Freight
A White Paper from the Subcommittee on Freight and Delivery

The freight network is at the heart of the Texas economy. The freight industry is moving toward a more connected and automated future. By investing in smart infrastructure, maintaining an attractive regulatory environment, and taking a proactive approach to workforce development, Texas will improve roadway safety, optimize freight operations, and grow the Texas economy.

This white paper provides an overview of the ground-based freight ecosystem, highlighting challenges and opportunities in three environments:

- Long-haul.
- Warehouses, distribution centers, and intermodal facilities.
- Last-mile delivery.

The paper identifies applicable federal and state policies. It describes several connected and automated freight vehicle types under development. Each vehicle is designed to operate in at least one of the following infrastructure environments: highway, local street, and sidewalk. In addition, this paper examines shifts in the Texas freight workforce as the trucking industry evolves from a driver-based profession to a skills-based labor market. Finally, the paper describes the infrastructure needs to enable connected freight capabilities and the potential safety benefits.

State of Texas freight CAV opportunities include:

- Prioritize roadway maintenance along CAV corridors, focusing on lane striping, pavement quality, and signage.
- Sponsor research into gaps in common infrastructure challenges such as work zone, forced merges, and transfer points.
- Expand the Texas connected freight network to include local roads, using the Texas Connected Freight Corridors project as an opportunity to develop critical applications, gain experience in CV technology, and formulate best practices for deployment.
- Continue to examine the potential needs for infrastructure enhancement and/or refinement, including items such as transfer points, changes to sidewalk design, and ways multiple vehicle types can travel safety and cooperatively on the same infrastructure at different speeds.
- Continue to discuss information-sharing opportunities with the private sector, including items related to geometry, signage, and safety.
- Work with the private sector to identify opportunities for increased CV connectivity and technology, and work with partners to identify high-priority applications and locations for future efforts.
- Provide information on executed and planned CV deployments to the public, and educate them on the benefits of adopting the technology.
- Invest in workforce development programs that upskill workers and create new educational pathways.

This white paper is found in Appendix E of the Texas CAV Task Force 2020 Annual Report.

Connected and Automated Vehicle Licensing and Registration
A White Paper from the Subcommittee on Licensing and Registration

State of Texas laws have led to a recent wave of CAV innovation and experimentation—on roads and streets and sidewalks, in cities, and on rural highways—operating within a range of public- and private-sector agencies and operators with state regulations that focus on regulating drivers, operators, and vehicles. As these technologies continue to advance and be adopted by the public, it is important to understand their impacts on federal and state authorities and what areas may need future policy clarity.

This white paper identifies current federal and State of Texas agencies' roles and responsibilities, as well as the roles and responsibilities of other individuals and organizations that can also impact AV policy. The paper covers current licensing, certification, registration, titling, vehicle sales, and operations requirements. The paper addresses some expectations of CAVs in Texas, as well as gaps in driver/operator and vehicle regulation requirements for AVs. It provides some case studies of other states' licensing and registration requirements.

State of Texas opportunities for future CAV operational clarity include:

- AV developers and the Texas Department of Public Safety could collaboratively discuss compliance with state motor vehicle equipment standards and current AV configurations, particularly for personal delivery devices and zero-occupant vehicles.
- AV developers and manufacturers, the Texas Department of Motor Vehicles, and the Texas Automobile Dealers Association could discuss how current dealer licensing/sales laws and registration rules affect the range of commercial relationships between original equipment manufacturers and AV developers.
- If some AV developers are considering alternatives that include AV operation entirely by remote operators (rather than by onboard software that controls vehicle driving tasks), the AV industry may want to interact with applicable state agencies to determine how the current regulatory structure addresses such operations.
- The AV industry and national associations of state transportation and motor vehicle agencies can develop guidelines for best practices for identifying AV vehicles and responsible parties for meeting licensing and operating requirements of state law.

This white paper is found in Appendix F of the Texas CAV Task Force 2020 Annual Report.

APPENDIX A

Connected and Automated Vehicle Terminology

Texas CAV Task Force White Paper

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Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's

performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. This white paper includes a full listing of terms and definitions used in this developing technology ecosystem.

# #

4G: the short name for fourth-generation wireless broadband mobile communications. According to the International Telecommunication Union, a 4G network requires a mobile device to be able to exchange data at 100 Mbps although some technologies branded as 4G do not offer this level of performance (1).

4G LTE: the short name for the fourth-generation long-term evolution designed to exchange data 10 times the speed of 3G, at approximately 150 Mbps download and 50 Mbps upload. 4G LTE was created to bridge the gap between the 3G and 4G mobile communication networks (2).

5G: the short name for fifth-generation wireless broadband mobile networks, with performance loads between 100 and 1,000 times that of existing 4G networks (1). 5G is expected to be able to deliver 10 Gbps and be able to process a high volume of data without delay (3).

A

Access Control: mechanisms and policies that restrict access to computer resources. An access control list, for example, specifies what operations different users can perform on specific files and directories (1).

Access Management (AM): the proactive management of vehicular access points to land parcels adjacent to all manner of roadways. Good AM promotes safe and efficient use of the transportation network. AM encompasses a set of techniques that state and local governments can use to control access to highways, major arterials, and other roadways (4).

Adaptive Cruise Control: a driver assistance system that automatically adjusts a vehicle's speed to maintain a set following distance from the vehicle in front (as defined by the National Highway Traffic Safety Administration) (5).

Advanced Collision Avoidance Technologies (ACAT): a National Highway Traffic Safety Administration program designed to develop a standardized process for evaluating the performance and effectiveness of the technologies that prevent and mitigate vehicle crashes (6).

Advanced Driver Assistance System (ADAS): a system designed to help drivers with certain driving tasks (e.g., staying in the lane, parking, avoiding collisions, reducing blind spots, and maintaining a safe headway). ADASs are generally designed to improve safety or reduce the workload on the driver. With respect to automation, some ADAS features could be considered SAE Level 1 or 2, but many are Level 0 and may provide alerts to the driver with little or no automation (5).

Aerial Easement: see *Avigation Easement*.

Aftermarket: equipment installed on a vehicle after purchase and not involving the original equipment manufacturer (6).

Aftermarket Safety Device (ASD): a connected device in a vehicle that operates while the vehicle is mobile but is not connected to the data bus of the vehicle (1). The connected device is capable of sending and receiving messages installed on a vehicle after purchase (6).

Anonymity: lacking individuality, distinction, and recognizability within message exchanges (1).

Antilock Braking System (ABS): a system that automatically controls the brakes to prevent the vehicle wheels from locking up (6).

Artificial Intelligence: the intelligence that is learned, exhibited, and executed by a machine (3).

Assured Position, Navigation, and Timing (A-PNT): a form of position, navigation, and timing that is accurate and always available (7).

Automated Delivery System: any vehicle equipped with an automated driving system that delivers goods.

Automated Driving System (ADS): hardware and software that are collectively capable of performing the entire dynamic driving task on a sustained basis, regardless of whether the task is limited to a specific operational design domain. This term is used specifically to describe a Level 3, 4, or 5 driving automation system (as defined by SAE J3016) (5). ADS is defined in Title 7 §545.451 of the Texas Transportation Code as "hardware and software that, when installed on a motor vehicle and engaged, are collectively capable of performing, without any intervention or supervision by a human operator: (a) all aspects of the entire dynamic driving task for the vehicle on a sustained basis; and (b) any fallback maneuvers necessary to respond to a failure of the system" (8).

***Automated Driving Systems: A Vision for Safety 2.0* (ADS 2.0)**: the U.S. Department of Transportation's cornerstone voluntary guidance document for automated driving systems (9).

Automated Emergency Braking (AEB): a system that can detect an impending forward crash with another vehicle in time to avoid or mitigate the crash. The system first alerts the driver to take corrective action and supplements the driver's braking to avoid the crash. If the driver does not respond, the AEB system may automatically apply the brakes to assist in preventing or reducing the severity of a crash (10).

Automated Highway System (AHS): an intelligent transportation system facility with predetermined routes intended mainly for autonomous vehicles (6).

Automated Motor Vehicle: see *Automated Vehicle*.

Automated Vehicle: any vehicle equipped with automated driving system technologies (as defined by SAE J3016). This term can refer to a vehicle fitted with any form of driving automation (SAE Level 1 through 5) (5).

Automated Vehicle/Connected Vehicle (AV/CV) Bandwidth Requirements: see *Radio Spectrum*.

Automatic License Plate Recognition (ALPR): an identification method that uses optical character recognition on images to read license plates on vehicles (11).

Automation: the use of electronic or mechanical devices to operate one or more functions of a vehicle without direct human input (5).

Autonomous Aerial System: see *Unmanned Aircraft System (UAS)*.

Autonomous Delivery Vehicle: any vehicle that delivers goods without the need for a human driver.

Autonomous Vehicle: a vehicle in which no driver is needed in a particular operational design domain. All driving functions are controlled by the vehicle itself, and the vehicle is able to sense its environment (6).

Autonomy: the quality or state of being self-governing.

Avigation Easement: a grant of a property interest in land over which a right of unobstructed flight in the airspace is established (12).

B

Bandwidth: see *Radio Spectrum*.

Basic Safety Message (BSM): the set of location and vehicle information transmitted between connected vehicles and connected infrastructure (13).

Beacon: a radio transmitter that produces guiding signals (14).

Bicycle: a vehicle having two tandem wheels, propelled solely by human power, upon which any person or persons may ride (Title 23 §217 of the U.S. Code of Federal Regulations) (15).

Bicycle Data: data pertaining to bicyclists.

Bit (b): a binary digit of computer information that has a value of zero or one (16).

Bus Signal Priority (BSP): see *Transit Signal Priority (TSP)*.

Byte (B): a sequence of 8 bits (16).

C

Carsharing: a program where individuals have temporary access to a vehicle without the costs and responsibilities of ownership. Individuals typically access vehicles by joining an organization that maintains a fleet of cars and light trucks deployed in lots located within neighborhoods, public transit stations, employment centers, and colleges/universities. Typically, the carsharing operator provides insurance, gasoline, parking, and maintenance. Generally, participants pay a fee each time they use a vehicle (17).

Cellular Communication Technology: the systems that operate mobile phones. See *4G, 4G LTE,* and *5G*.

Cellular Vehicle to Everything (C-V2X): the cellular technology that enables the communication between vehicles and other objects and services (18).

Cloud Computing: data storage and services accessed through the internet (6).

Collision Avoidance System: see *Collision Prevention System*.

Collision Prevention System: the set of features that detect, prevent, mitigate, and/or warn drivers of potential front, rear, and side collisions (13).

Commercial Driver License (CDL): defined in Title 7 §522.003 of the Texas Transportation Code as "a license issued to an individual that authorizes the individual to drive a class of commercial motor vehicle" (8).

Commercial Motor Vehicle: defined in Title 7 §522.003 of the Texas Transportation Code as "a motor vehicle or combination of motor vehicles used to transport passengers or property that: (a) has a gross combination weight or a gross combination weight rating of 26,001 or more pounds, including a towed unit with a gross vehicle weight or a gross vehicle weight rating of more than 10,000 pounds; (b) has a gross vehicle weight or a gross vehicle weight rating of 26,001 or more pounds; (c) is designed to transport 16 or more passengers, including the driver; or (d) is transporting hazardous materials and is required to be placarded under 49 CFR Part 172, Subpart F" (8).

Conditional Automation (Level 3): the SAE definition for the automation driving level where a vehicle is equipped with an automated driving system for all dynamic driving tasks, but the human driver is expected to remain engaged in order to be able to take back control of the driving task (5).

Connected Device: any device used to transmit to or receive messages from another device (1).

Connected Freight: commercial motor vehicles that interact with each other, the roadside, and beyond via wireless communications.

Connected Vehicle: vehicles that interact with each other, roadside equipment, and beyond via wireless communications (19).

Connected Vehicle Reference Implementation Architecture (CVRIA): a set of system architecture views that describe the functions, physical and logical interfaces, enterprise/institutional relationships, and communications protocol dependencies within the connected vehicle environment. The CVRIA defines functionality and information exchanges needed to provide connected vehicle applications (20).

Cooperative Adaptive Cruise Control (CACC): vehicle-to-vehicle communication technology combined with adaptive cruise control that allows vehicles to synchronize acceleration and braking, and decrease the following distance to improve traffic stability (13).

Cooperative Automated Transportation (CAT) Coalition: the collaboration of federal, state, and local officials to address the technical issues associated with connected and automated vehicles (21).

Cooperative Automation: the ability of automated vehicles to communicate with each other and with infrastructure to coordinate their movements (5).

Cooperative Lane Change and Merge: a dynamic driving task for automated vehicles that uses communications to enable negotiations between vehicles to provide safe gaps for a manual or automated lane change or merge maneuver on a roadway (as defined by the Federal Highway Administration) (5).

Crash Avoidance Technology: see *Collision Prevention System*.

Curve Speed Warning (CSW) System: the use of the global positioning system and digital mapping that warns a driver of an upcoming curve that is approaching too quickly (22).

Cybersecurity: the practice of protecting computers, data, networks, programs, and software from an attack, damage, theft, or unauthorized access (6). Cybersecurity includes the prevention of damage to, protection of, and restoration of computers, electronic communications systems, electronic communications services, wire communication, and electronic communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation (16).

D

Data: distinct pieces of digital information that have been formatted in a specific way (16). Figure 1 defines some data measurements.

Abbreviation	Unit	Value	Size (in bytes)
b	bit	0 or 1	1/8 of a byte
B	bytes	8 bits	1 byte
KB	kilobytes	1,000 bytes	1,000 bytes
MB	megabyte	$1{,}000^2$ bytes	1,000,000 bytes
GB	gigabyte	$1{,}000^3$ bytes	1,000,000,000 bytes
TB	terabyte	$1{,}000^4$ bytes	1,000,000,000,000 bytes
PB	petabyte	$1{,}000^5$ bytes	1,000,000,000,000,000 bytes
EB	exabyte	$1{,}000^6$ bytes	1,000,000,000,000,000,000 bytes
ZB	zettabyte	$1{,}000^7$ bytes	1,000,000,000,000,000,000,000 bytes
YB	yottabyte	$1{,}000^8$ bytes	1,000,000,000,000,000,000,000,000 bytes

Figure 1. Data Measurement Definitions.

Data Governance: the collection of procedures that encompass the official management of an organization's data assets (23).

Data Lake: see *Data Store*.

Data Store: a reservoir in which data can be held for an indefinite period. Data stores are shown on data flow diagrams where data repositories are required to support data aggregation or archival services (1).

Data Warehouse: a data storage facility that supports the input (deposit) and retrieval (delivery) of clearly defined data objects. This can be designed and implemented in a variety of ways, including publish/subscribe and a traditional query-based database, also known as a data distribution system (1).

Dedicated Short-Range Communication (DSRC): a two-way short- to medium-range wireless communications capability that permits very high data transmission critical in communications-based active safety applications (19). According to the Federal Communications Commission (FCC) (Dedicated Short Range Communications of Intelligent Transportation Services—Final Rule, *Federal Register* Doc. No. 99-30591), DSRC is "the use of non-voice radio techniques to transfer data over short distances between roadside and mobile radio units, between mobile units, and between portable and mobile units to perform operations related to the improvement of traffic flow, traffic safety and other intelligent transportation service applications in a variety of public and commercial environments." DSRC is a technology designed for the transmission of information between multiple vehicles and between vehicles and the transportation infrastructure using wireless technologies (20). FCC has issued a ruling to reallocate the spectrum that is dedicated to transportation safety. While there was a 75-MHz allocation for DSRC, FCC has made the lower 45 MHz of the 5.9-GHz band available for unlicensed operations such as Wi-Fi and allocated the upper 30 MHz for cellular-vehicle-to-everything operations (24). Existing DSRC licenses are able to continue operating in the upper 30 MHz; however, existing operations in the lower 45 MHz are required to cease operations after the one-year transition period.

Demand Scheduling: see *Just-in-Time (JIT) Delivery.*

Digital Mapping: the process of formatting a series of data into a virtual image (13).

Driver: a person who operates a motorized vehicle. If more than one person drives on a single trip, the person who drives the most miles is classified as the principal driver. It also means an occupant of a vehicle who is in physical control of a motor vehicle in transport (15).

Driver Assistance (Level 1): the SAE definition for the automation driving level where the vehicle is equipped with driver assistance technologies that execute either steering or acceleration and deceleration but requires human interaction for the remaining driving tasks (5).

Driver Assistance Technologies: cameras and sensors in vehicles that help drivers see more than they can with the naked eye and warn of a possible collision. Driver assistance technologies can help drivers with backing up and parking, maintaining safe distances from other vehicles, preventing forward collisions, and navigating lanes safely (as defined by the National Highway Traffic Safety Administration) (5).

Driver License: a license issued by a state or other jurisdiction to an individual that authorizes the individual to operate a motor vehicle on highways (Title 49 §383 of the U.S. Code of Federal Regulations) (15).

Driverless Carsharing: a driverless vehicle that can be shared or rented for individual use (6).

Driverless Operation: a vehicle that is able to navigate to destinations without input from a human (6).

Dynamic Driving Task (DDT): all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and the selection of destinations and waypoints (as defined by SAE J3016) (5).

Dynamic Driving Task (DDT) Fallback: the response by the user or by an automated driving system to either perform the DDT or achieve a minimal risk condition after occurrence of a DDT performance-relevant system failure(s) or upon operational design domain exit (as defined by SAE J3016) (5).

E

Edge Computing: the process of using computer servers and data analytics to prioritize information on demand (18, 25).

Electronic Control Unit (ECU): a unit that is embedded in the vehicle that controls one or more electrical systems, such as the human-machine interface or engine control unit (3).

***Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0* (AV 4.0)**: a U.S. Department of Transportation guidance document that builds upon *Preparing for the Future of Transportation: Automated Vehicles 3.0* and expands the scope to 38 relevant U.S. Government (USG) components that have direct or tangential equities in the safe development and integration of automated vehicle technologies. AV 4.0 seeks to ensure a consistent USG approach to automated vehicle technologies, and to detail the authorities, research, and investments being made across the USG so that the United States can continue to lead automated vehicle technology research, development, and integration (26).

Entire Dynamic Driving Task: defined in Title 7 §545.451 of the Texas Transportation Code as the "operational and tactical aspects of operating a vehicle. The term: (a) includes: (i) operational aspects, including steering, braking, accelerating, and monitoring the vehicle and the roadway; and (ii) tactical aspects, including responding to events, determining when to change lanes, turning, using signals, and other related actions; and (b) does not include strategic aspects, including determining destinations or waypoints" (8).

Exabyte (EB): 1,000 petabytes.

Extremely High Frequency (EHF): the highest band of radio frequency, between 30 and 300 GHz (14).

F

Far Infrared Sensor (FIRS): a piece of equipment used at night or times of poor visibility that senses heat to detect pedestrians or living objects on or near a roadway (6).

Federal Aviation Administration (FAA): a federal agency charged with regulating air commerce to promote its safety and development; encouraging and developing civil aviation, air traffic control, and air navigation; and promoting the development of a national system of airports (12).

Federal Aviation Regulations (FAR): the set of regulatory obligations contained in Title 14 of the U.S. Code of Federal Regulations, which the Federal Aviation Administration is charged to enforce in order to promote the safety of civil aviation both domestically and internationally (15).

Federal Communications Commission (FCC): an independent regulatory agency overseen by Congress that administers the spectrum and has primary authority for communications law (27).

Federal Communications Commission (FCC) Spectrum: see *Radio Spectrum*.

Federal Highway Administration (FHWA): an agency of the U.S. Department of Transportation. FHWA administers the Federal-Aid Highway Program, which provides financial assistance to states to construct and improve highways, urban and rural roads, and bridges. FHWA also administers the Federal Lands Highway Program, which provides access to and within national forests, national parks, Indian Tribal lands, and other public lands (1).

Federal Motor Carrier Safety Administration (FMCSA): the agency of the U.S. Department of Transportation that is responsible for regulating and providing safety oversight of commercial motor vehicles (CMVs). FMCSA's mission is to reduce crashes, injuries, and fatalities involving large trucks and buses. FMCSA partners with industry, safety advocates, and state and local governments to keep the nation's roadways safe and improve CMV safety through regulation, education, enforcement, research, and technology (28).

Federal Motor Carrier Safety Regulation (FMCSR): defined in Title 7 §644.001 of the Texas Transportation Code as "a federal regulation in Subtitle A, Title 49, or Subchapter B, Chapter III, Subtitle B, Title 49, Code of Federal Regulations" (8).

Federal Motor Vehicle Safety Standard (FMVSS): the minimum specifications issued by the National Highway Traffic Safety Administration to comply with Federal Motor Vehicle Safety Regulations (29).

Federal Transit Administration (FTA): an agency of the U.S. Department of Transportation. FTA is the principal source of federal financial assistance to America's communities for the planning, development, and improvement of public or mass transportation systems. FTA provides leadership, technical assistance, and financial resources for safe, technologically advanced public transportation that enhances mobility and accessibility, improves the nation's communities and natural environment, and strengthens the national economy (1).

First Mile: the initial movement of goods along a transportation system.

First-Mile/Last-Mile Problem: the challenges with not having adequate access to transportation at the beginning or end location of a trip, which increases the time needed for transportation, such as walking from a bus stop to an end location.

Freight: defined in Title 2 §7.001 of the Texas Transportation Code as "baggage and other property transported by a common carrier" (8).

Freight Signal Priority (FSP): an operational strategy that grants freight vehicles the right of way with the goal of improving travel time and reliability (6).

Full Automation (Level 5): the SAE definition for the automation driving level where a vehicle is equipped with an automated driving system and completes all dynamic driving tasks under all conditions without the need for human intervention (5).

Fully Autonomous Vehicle: a vehicle that can perform all driving tasks on a sustained basis.

Fusion: see *Sensor Fusion (Fuse).*

G

Geofence: an electronic set of geographic reference points that form a bounded geographic region (1).

Geofencing: the practice of using the global positioning system or radio frequency identification to define an area or location (30).

Gigabyte (GB): 1 billion bytes.

Global Positioning System (GPS): the satellite-based navigation system that uses location and time information to triangulate position (13). The system determines position by comparing radio signals from several satellites (16).

Graphics Processing Unit (GPU): a specialized electronic circuit designed to accelerate image and graphics processing. GPUs excel at parallel processing (3).

Gross Vehicle Weight Rating (GVWR): the maximum rated capacity of a vehicle, including the weight of the base vehicle, all added equipment, driver and passengers, and all cargo (15).

H

High Automation (Level 4): the SAE definition for the automation driving level where a vehicle is equipped with an automated driving system for all dynamic driving tasks, but the human driver does not need to respond to a request to intervene in a driving task (5).

High-Definition Mapping: maps that use extremely high precision, at the centimeter level, for use in self-driving vehicles (31).

Host Vehicle: a connected vehicle that receives messages from a remote vehicle. Sometimes, the host vehicle is also used to describe the originator of a vehicular transmission of information to the roadside unit (1).

Human-Machine Interface (HMI): an interface that is responsible for two-way communication between a vehicle and the occupants. The HMI may include touchscreen displays, voice recognition, or integration with mobile devices (3). See *Natural Language Processing (NLP).*

Human Operator: defined in Title 7 §545.451 of the Texas Transportation Code as "a natural person in an automated motor vehicle who controls the entire dynamic driving task" (8).

I

In-Vehicle Fallback Test Driver (IFTD): a human operator that provides oversight of a fully autonomous vehicle that can intervene if needed.

Incident Scene Pre-arrival Staging Guidance for Emergency Responders (RESP-STG): an application that safely and efficiently guides public safety responders to an incident scene (6).

Inertial Measurement Unit (IMU): a device that tracks the position of unmanned aerial vehicles and other aircraft, and records the orientation, velocity, and gravitational forces (32).

Infrared Camera: a camera that detects and converts surface temperature into an electronic image (33).

Intelligent Transportation System (ITS): the system composed of the electronics, communications, or information processing in transportation infrastructure and in vehicles used singly or integrated to improve transportation safety and mobility and enhance productivity. ITS encompasses a broad range of wireless and wire line communications-based information and electronics technologies (1). These technologies are used by different modes of transport and traffic management (11).

Intelligent Transportation System (ITS) Architecture: an architecture of interrelated systems that work together to deliver transportation services. An ITS architecture defines how systems functionally operate and the interconnection of information exchanges that must take place between these systems to accomplish transportation services (1).

Intelligent Transportation System (ITS) Standards: the documented technical specifications sponsored by a standards development organization to be used consistently as rules, guidelines, or definitions of characteristics for the interchange of data (1).

Internet of Things (IoT): a concept that built infrastructure is linked and dynamic, often displaying intelligence via integrated sensors and adaptive controls (19).

Interoperability: the ability of two systems to work together (14).

J

Just in Time (JIT): cargo or components that must be at a destination at the exact time needed. The container or vehicle is the movable warehouse (15).

Just-in-Time (JIT) Delivery: a logistics management strategy intended to increase efficiency and reduce waste that involves the coordination between producers and suppliers so that suppliers only order the components they need to meet the current demand.

K

Kilobyte (KB): 1,000 bytes.

L

Last Mile: the final movement of goods to their designated destination.

Last-Mile Connectivity to Transportation Management Centers: connectivity solutions to address the first-mile/last-mile data exchange problems and provide real-time data on the availability of platforms. Examples include micro-mobility applications, transit-oriented development, and just-in-time delivery.

Latency: a measure of time delay experienced in a system, the precise definition of which depends on the system and the time being measured. For a data element in this context, latency is the time difference between the time that data value is acquired by the source and the time the message is transmitted (15).

Liability: the quality of being obligated by law (14).

License Plate Recognition (LPR): see *Automatic License Plate Recognition (ALPR)*.

Light Imaging, Detection, and Ranging (LiDAR): an extremely precise laser-based form of radar used in autonomous vehicles, usually located on the top of a vehicle to provide a 360-degree view of the area around the vehicle (6).

Location Beacons: see *Beacon*.

Locationing: the process of locating an object. See *Position, Navigation, and Timing (PNT)*.

Logistics: all activities involved in the management of product movement: delivering the right product from the right origin to the right destination, with the right quality and quantity, at the right schedule and price (15).

Logistics Management System: see *Logistics*.

Long-Range Radar (LRR): a system that uses a transmitter and receiver, operating at 77 GHz with a detection range of 0.36 to 250 meters, with six fixed radar antennae for use in detecting objects. LRR is often used in driver assistance technologies, such as adaptive cruise control (34).

M

Machine Learning: a subset of artificial intelligence that gives machines the capability to learn on their own, resulting in algorithms that make data-driven decisions (3).

Machine Vision: the process of using image-based inspection and analysis tools to complete automated applications (6).

Manufacturer: see *Original Equipment Manufacturer (OEM)*.

Map Data Message (MAP): provides the road geometry at an intersection (1).

Megabyte (MB): 1 million bytes.

Memorandum of Understanding (MOU): a document providing a general description of the responsibilities that are to be assumed by two or more parties in their pursuit of some goal(s). More specific information may be provided in an associated statement of work (15).

Metadata: a set of data that describe and give information about other data (19).

Microwave: a short electromagnetic wave between 1 millimeter and 1 meter in wavelength (14).

Middle Mile: the segment of the transportation system that connects the origin of goods, or first mile, to the final destination, or last mile.

Mid-range Radar (MRR): a system that uses a transmitter and receiver, operating at 77 GHz with a detection range of 0.36 to 160 meters, with four independent channels and digital beam forming for use in detecting objects. MRR is often used in driver assistance technologies, such as side view assist (35).

Millimeter Wave: see *Extremely High Frequency (EHF)*.

Minimal Risk Condition: a condition to which a user or an automated driving system may bring a vehicle after performing the dynamic driving task fallback in order to reduce the risk of a crash when a given trip cannot or should not be completed (as defined by SAE J3016) (5).

Mobile Carrying Device: defined in Title 7 §552A.0001 of the Texas Transportation Code as "a device that: (a) transports cargo while remaining within 25 feet of a human operator; and (b) is equipped with technology that allows the operator to actively monitor the device" (8).

Mobility: the ability to move or be moved from place to place (15).

Mobility as a Service (MaaS): the movement away from personal vehicle ownership to on-demand transportation services, often using app-based subscription technologies (6, 36).

Mobility on Demand: the innovative transportation concept for the ability to access transportation services on an as-needed basis, often using an app-based shared service (36).

Motor Carrier: defined in Title 7 §643.001 of the Texas Transportation Code as "an individual, association, corporation, or other legal entity that controls, operates, or directs the operation of one or more vehicles that transport persons or cargo over a road or highway in this state" (8).

N

National Highway Traffic Safety Administration (NHTSA): an agency of the U.S. Department of Transportation established to:

- Carry out a congressional mandate to reduce the mounting number of deaths, injuries, and economic losses resulting from motor vehicle crashes on the nation's highways.

- Provide motor vehicle damage susceptibility and ease of repair information, motor vehicle inspection demonstrations, and protection of purchasers of motor vehicles having altered odometers.
- Provide average standards for greater vehicle mileage per gallon of fuel for vehicles under 10,000 pounds (gross vehicle weight) (15).

National Intelligent Transportation System (ITS) Architecture: a systems framework to guide the planning and deployment of ITS infrastructure. The national ITS architecture is a blueprint for the coordinated development of ITS technologies in the United States. It is unlikely that any single metropolitan area or state would plan to implement the entire national ITS architecture (15).

Natural Language Processing (NLP): a form of artificial intelligence that enables a vehicle to understand and respond to natural human speech (3).

No Automation (Level 0): the SAE definition for the driving level that requires complete human interaction for all driving tasks (5).

O

Object Event Detection and Response (OEDR): the subtasks of the dynamic driving task (DDT) that include monitoring the driving environment (i.e., detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events (i.e., as needed to complete the DDT and/or DDT fallback) (as defined by SAE J3016) (5).

Obstacle Detection: an advanced driver assistance system feature that detects slow-moving or stationary objects in front of a vehicle and alerts the driver to use the brakes (6).

On-Demand Scheduling: see *Just-in-Time (JIT) Delivery*.

Onboard Equipment (OBE): computer modules, display, and a dedicated short-range communications radio, which are installed and embedded into vehicles and provide an interface to vehicular sensors and a wireless communication interface to the roadside and back-office environment (1). The Federal Communications Commission (FCC) has issued a ruling to reallocate the spectrum that is dedicated to transportation safety. While there was a 75-MHz allocation for DSRC, FCC has made the lower 45 MHz of the 5.9-GHz band available for unlicensed operations such as Wi-Fi and allocated the upper 30 MHz for cellular-vehicle-to-everything operations (24). Existing DSRC licenses are able to continue operating in the upper 30 MHz; however, existing operations in the lower 45 MHz are required to cease operations after the one-year transition period.

Onboard Unit (OBU): a vehicle-mounted device used to transmit and receive a variety of message traffic to and from other connected devices (other OBUs and roadside units). Among the message types and applications supported by this device are vehicle safety messages used to exchange information on each vehicle’s dynamic movements for coordination and safety (1).

Operational Design Domain (ODD): the specific conditions under which a given driving automation system or feature thereof is designed to function, including but not limited to driving modes. This can incorporate a variety of limitations, such as those from geography, traffic, speed, and roadways (as defined by SAE J3016) (5).

Operator: defined in Title 7 §642.001 of the Texas Transportation Code as "the person who is in actual physical control of a motor vehicle" (8).

Original Equipment Manufacturer (OEM): a company that designs and produces a product (6).

Over-Size/Overweight Warning: a system that detects if vehicles are over-size or overweight, typically using weigh in motion, lasers, global positioning system, and connected devices to inform drivers (37).

Over-the-Air (OTA) Update: software or firmware updates for a vehicle that are downloaded from the cloud (3).

Owner: the person or entity having administrative and fiscal responsibility for the owned element and the right to exclusively control and use it for one's own purposes. Ownership is the state or fact of having exclusive possession or control of some object, facility, intellectual property, or some other kind of property (1). The Texas Transportation Code has the following definitions of owner:

- Title 7 §541.001 defines the owner as "a person who has a property interest in or title to a vehicle. The term: (a) includes a person entitled to use and possess a vehicle subject to a security interest; and (b) excludes a lienholder and a lessee whose lease is not intended as security."
- Title 7 §501.001 defines the owner as "a person, other than a manufacturer, importer, distributor, or dealer, claiming title to or having a right to operate under a lien a motor vehicle that has been subject to a first sale."
- Title 7 §502.001 defines the owner as "a person who: (a) holds the legal title of a vehicle; (b) has the legal right of possession of a vehicle; or (c) has the legal right of control of a vehicle" (8).

P

Partial Automation (Level 2): the SAE definition for the automation driving level where the vehicle is equipped with one or more driver assistance technologies that execute both steering or acceleration and deceleration, but requires human interaction for the remaining driving tasks (5).

Pedestrian: any person not in or on a motor vehicle or other vehicle, excluding people in buildings or sitting at a sidewalk cafe. The National Highway Traffic Safety Administration also uses another pedestrian category to refer to pedestrians using conveyances and people in buildings. Examples of pedestrian conveyances include skateboards, nonmotorized wheelchairs, roller skates, sleds, and transport devices used as equipment (15).

Pedestrian Data: data about and pertaining to pedestrians.

Pedestrian Walkway: a continuous way designated for pedestrians and separated from the through lanes for motor vehicles by space or barrier (Title 23 §217 of the U.S. Code of Federal Regulations) (15).

Personal Delivery Device: defined in Title 7 §552A.0001 of the Texas Transportation Code as "a device that: (a) is manufactured primarily for transporting cargo in a pedestrian area or on the side or shoulder of a highway; and (b) is equipped with automated driving technology, including software and hardware, that enables the operation of the device with the remote support and supervision of a human" (8).

Personal Vehicle Sharing (PVS): the sharing of privately owned vehicles where companies broker transactions among car owners and renters by providing the organizational resources needed to make the exchange possible (e.g., online platform, customer support, driver and motor vehicle safety certification, auto insurance, and technology) (17).

Personally Identifiable Information (PII): information about a human being, living or deceased, regardless of nationality, that permits identification of that individual to be reasonably inferred by either direct or indirect means (38).

Petabyte (PB): 1,000 terabytes.

Platooning: the method of grouping vehicles together through artificial intelligence, which enables vehicles to accelerate and brake simultaneously (6).

Position, Navigation, and Timing (PNT): a combination of three distinct, constituent capabilities:

- Positioning, the ability to accurately and precisely determine one's location and orientation two-dimensionally (or three-dimensionally when required) referenced to a standard geodetic system (e.g., World Geodetic System 1984).
- Navigation, the ability to determine the current and desired position (relative or absolute) and apply corrections to course, orientation, and speed to attain a desired position anywhere around the world, from subsurface to surface and from surface to space.
- Timing, the ability to acquire and maintain accurate and precise time from a standard (e.g., Coordinated Universal Time), anywhere in the world and within user-defined timeliness parameters (39).

Preparing for the Future of Transportation: Automated Vehicles 3.0 **(AV 3.0)**: a U.S. Department of Transportation (USDOT) guidance document that builds upon *Automated Driving Systems: A Vision for Safety 2.0* and expands the scope to provide a USDOT framework and multimodal approach to the safe integration of automated vehicles into the nation's broader surface transportation system (5).

Privacy: the ability of individuals to seclude information about themselves and thereby reveal information about themselves selectively (1).

Private Carrier: a carrier that provides transportation service to the firm that owns or leases the vehicles and does not charge a fee (15).

Privately Owned Vehicle (POV): a privately owned vehicle or privately operated vehicle (15).

Proprietary Information: information owned by an individual or organization that is protected by copyright, patent, trademark, or trade secret laws (40).

Public Liability: defined in Title 49 §387 of the U.S. Code of Federal Regulations as “liability for bodily injury or property damage and includes liability for environmental restoration” (15).

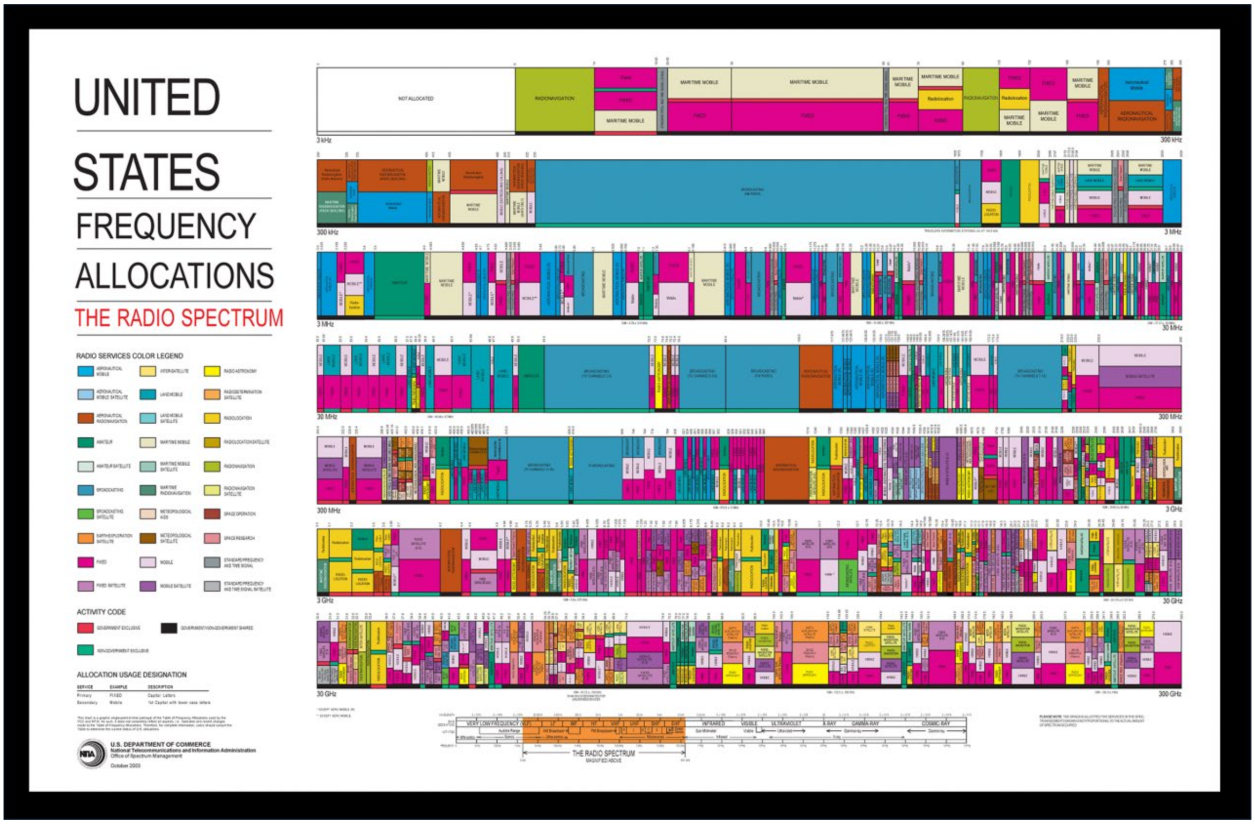
Q

No terms.

R

Radar: a system that emits radio waves and processes the reflections to detect and locate objects (14).

Radio Spectrum: the radio frequency portion of the electromagnetic spectrum, specifically the part ranging from 1 Hz to 3,000 GHz (3 THz). Currently, only frequency bands between 9 kHz and 275 GHz have been allocated (i.e., designated for use under specified conditions) (27). The spectrum is divided into different frequency bands, and each band has been allocated for a specific application, ranging from aeronautical and maritime communication to AM and FM radio stations (41). Figure 2 shows the frequency allocations on the radio spectrum.



Source: U.S. Department of Transportation

Figure 2. U.S. Frequency Allocations on the Radio Spectrum.

Real-Time Data (RTD): immediately available data that are collected continuously (6).

Real-Time Kinematics (RTK): a navigation positioning technique using carrier measurements and the transmission of corrections from the base station that provides a precise position location (6).

Real-Time Traffic Information (RTTI): a service that provides current information about the roadway to drivers (6).

Regional Intelligent Transportation System (ITS) Architecture: a specific, tailored framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects in a particular region. The architecture functionally defines what pieces of the system are linked to others and what information is exchanged between them (1).

Registered Owner: see *Owner*.

Reliability: the degree of certainty and predictability in travel times on the transportation system. Reliable transportation systems offer some assurance of attaining a given destination within a reasonable range of an expected time. An unreliable transportation system is subject to unexpected delays, increasing costs for system users (15).

Remote Driver: a driver who is not seated in a position to manually exercise in-vehicle braking, acceleration, steering, and transmission gear selection of input devices (if any) but is able to operate the vehicle (as defined by SAE J3016) (5).

Remote Vehicle: a connected vehicle that periodically and dynamically broadcasts a message about its general situation to a host vehicle (1).

Responsibility: the state of being morally, legally, or mentally accountable (14).

Retrofit Device: a piece of equipment installed on a vehicle after the purchase (6).

Ride Hailing: see *Transportation Network Company (TNC)*.

Ride Share Service: see *Transportation Network Company (TNC)*.

Ridesourcing: see *Transportation Network Company (TNC)*.

Right of Way: defined in Title 7 §541.001 of the Texas Transportation Code as "the right of one vehicle or pedestrian to proceed in a lawful manner in preference to another vehicle or pedestrian that is approaching from a direction, at a speed, and within a proximity that could cause a collision unless one grants precedence to the other" (8). This is the land (usually a strip) acquired for or devoted to highway transportation purposes (15).

Risk: defined in Title 23 §515.5 of the U.S. Code of Federal Regulations as "the positive or negative effects of uncertainty or variability upon agency objectives" (42). Risk is the potential for positive or negative effects based on actions taken.

Risk Management: defined in Title 23 §515.5 of the U.S. Code of Federal Regulations as "the processes and framework for managing potential risks, including identifying, analyzing, evaluating, and addressing the risks to assets and system performance" (42).

Road: an open way for the passage of vehicles, persons, or animals on land (15).

Roadside: the strip of land along the side of the roadway (14).

Roadside Equipment (RSE): the complement of equipment to be located at the roadside. The RSE prepares and transmits messages to the vehicles and receives messages from the vehicles for the purpose of supporting vehicle-to-infrastructure applications (20).

Roadside Unit (RSU): a connected device that is only allowed to operate from a fixed position (which may in fact be a permanent installation or temporary equipment brought on site for a period of time associated with an incident, road construction, or other event). Some RSUs may have connectivity to other nodes or the internet (1, 19).

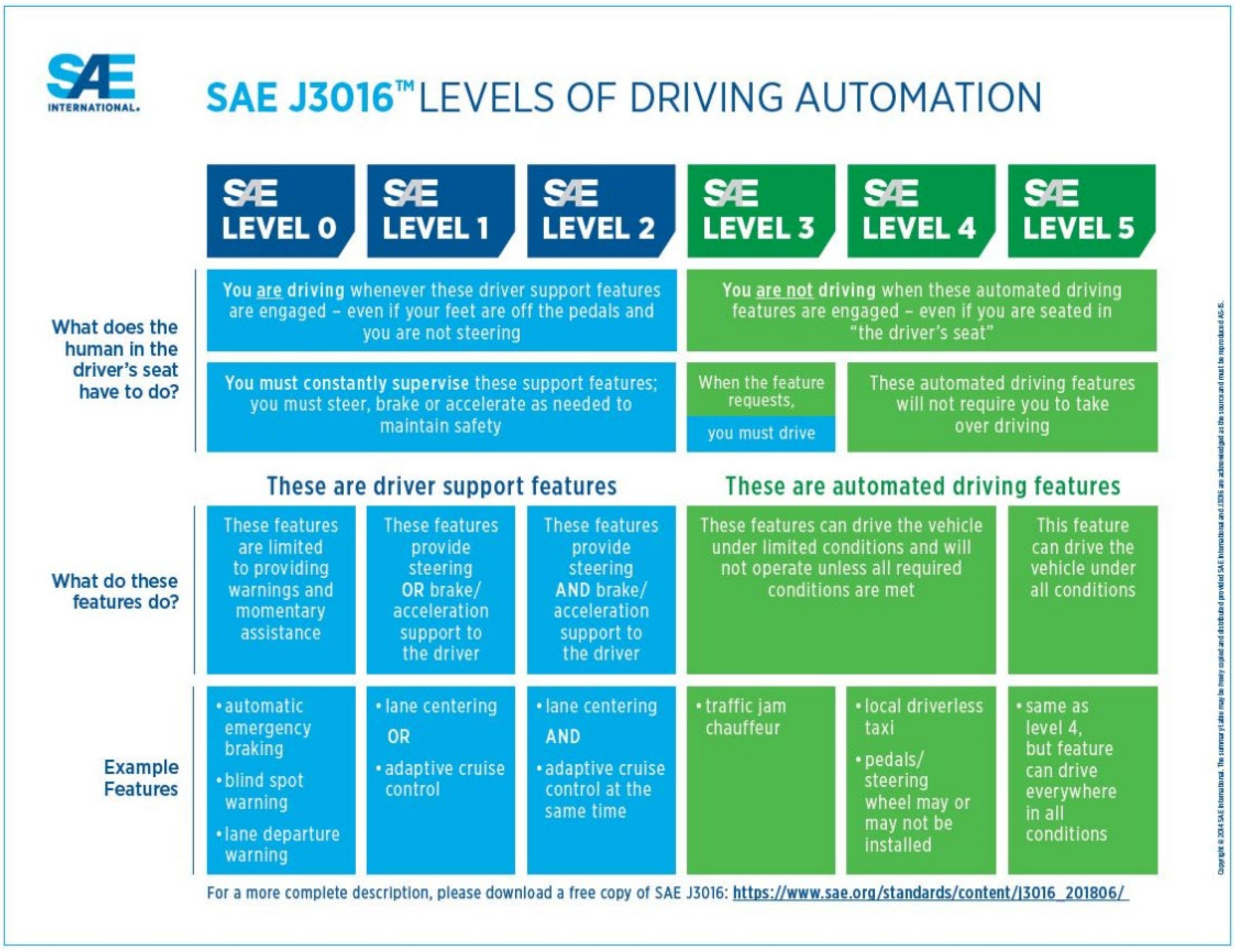
Roadway: defined in Title 7 §541.001 of the Texas Transportation Code as "the portion of a highway, other than the berm or shoulder, that is improved, designed, or ordinarily used for vehicular travel. If a highway includes at least two separate roadways, the term applies to each roadway separately" (8).

Roadway User: an individual that has access to and operates on a roadway.

Robotaxi: any vehicle that delivers people without the need for a human driver.

S

SAE Level of Automation: see *No Automation (Level 0), Driver Assistance (Level 1), Partial Automation (Level 2), Conditional Automation (Level 3), High Automation (Level 4),* and *Full Automation (Level 5).* Figure 3 illustrates the different levels of automation.



Source: SAE International

Figure 3. SAE-Defined Levels of Automation.

Safety: the state of being free from hurt, injury, or loss (14).

Safety Operator: see *In-Vehicle Fallback Test Driver (IFTD)*.

Security: the state of being free from danger, fear, or anxiety (14).

Security Credential Management System (SCMS): a message security solution for vehicle-to-vehicle and vehicle-to-infrastructure communication that uses a public-key infrastructure-based approach that employs highly innovative methods of encryption and certificate management to facilitate trusted communication (43).

Self-Driving Vehicle: a vehicle that is able to drive by itself using onboard sensors and is equivalent to high automation (Level 4) (6).

Sensor Fusion (Fuse): the second of the three stages of in-vehicle computing that is used for autonomous driving. The vehicle compares and combines sensor data to build a model of its environment (3).

Shared Mobility: the shared use of a motor vehicle, bicycle, or other low-speed transportation mode (17).

Shared Service: see *Shared Mobility*.

Short-Range Radar (SRR): a high-performance sensor, operating at 77 GHz, that is used in forward and backward applications (44).

Short-Range Wireless Communications: a wireless communications channel used for close-proximity communications between vehicles, mobile/personal devices, and the immediate infrastructure. Short-range wireless communications supports location-specific communications for intelligent transportation system capabilities such as vehicle safety, transit vehicle management, driver information, roadway payments, and automated commercial vehicle operations (1).

Sign: defined in Title 6 §393.001 of the Texas Transportation Code as "an outdoor sign, display, light, device, figure, painting, drawing, message, plaque, poster, or other thing designed, intended, or used to advertise or inform" (8).

Signal: an object used to convey information (14).

Signal Phase and Timing (SPaT): a message type that describes the current state of a signal system and its phases and relates this to the specific lanes (and therefore to movements and approaches) in the intersection. SPaT is used along with Map Data Message (MAP) messages to describe an intersection and its currently allowed movements (1).

Signal Priority: see *Bus Signal Priority (BSP), Freight Signal Priority (FSP),* and *Transit Signal Priority (TSP).*

Signalized Intersection Approach and Departure: an automated vehicle application that communicates with infrastructure using signal phase and timing and Map Data Message (MAP) messages to automate the movement of single or multiple automated vehicles through intersections to increase traffic flow and safety (as defined by the Federal Highway Administration) (5).

Smart Parking Facilities for Connected and Autonomous Vehicles: a facility used to contain fully autonomous vehicles while not in use. The vehicles could park very close together because no humans would need to enter or exit the vehicle at the parking location, so the spacing between vehicles would not need to be large.

Smart Work Zone System: the application of computers, communications, and sensor technology designed to improve the safety of highway workers and the traveling public by predicting travel time, delay, or speed on a freeway work zone in real time (45).

Social Equity: equal access for all people to the use of technologies and products (6).

Software Development Kit (SDK): the set of tools that decrease the time developers need to build software (6).

Speed Harmonization: a strategy to increase traffic flow enabled by communications between an automated vehicle and infrastructure to change the traffic speed on roads that approach areas of traffic congestion, bottlenecks, incidents, special events, and other conditions that affect flow (as defined by the Federal Highway Administration) (5).

T

Tele-assist: see *Telematics*.

Telematics: the process of sending, receiving, and storing information through communication technologies that enables the monitoring, management, and potentially control of objects remotely (6).

Teleoperated Driving System: see *Autonomous Delivery Vehicle, Remote Driver*, and *Zero-Occupancy Vehicle*.

Teleoperations: the operation of an object or device from a distance.

Terabyte (TB): 1,000 gigabytes.

Traffic Management: the management of the movement of all types of vehicles, travelers, and pedestrians throughout the transportation network. Traffic management deals with information collection, dissemination, and processing for the surface transportation system. Traffic management covers automated monitoring and control activities, decision-making processes (both automated and manual) that address real-time incidents and other disturbances on the transportation network, and management of travel demand as needed to maintain overall mobility (1).

Transfer Hub: see *Transport Hub*.

Transit Signal Priority (TSP): an operational strategy that grants transit vehicles the right of way at signalized intersections with the goal of improving travel time and reliability (46).

Transport as a Service (TaaS): see *Mobility as a Service (MaaS)*.

Transport Hub: the location where multiple modes of transportation connect to allow passengers and cargo to change transportation modes or services (e.g., bus stops, parking lots, or truck terminals).

Transportation Demand Management (TDM): programs designed to reduce demand for transportation through various means, such as the use of public transit and alternative work hours (1).

Transportation Management Center (TMC): a center that provides real-time highway monitoring, incident detection, response coordination/support, and distribution of traveler information. Normally, TMCs are open 24 hours a day and 7 days a week but are at least open during peak periods (11).

Transportation Network Company (TNC): a ridesourcing service (also known as ride hailing) that provides prearranged and on-demand transportation services for compensation, connecting drivers of personal vehicles with passengers. Smartphone mobile applications are used for bookings, ratings (for both drivers and passengers), and electronic payment. TNCs can offer a variety of vehicle types including sedans, sport utility vehicles, vehicles with car seats, wheelchair-accessible vehicles, and vehicles where the driver can assist older or disabled passengers (17).

Transportation System Management and Operations (TSMO): a set of strategies that focus on operational improvements that can maintain and even restore the performance of the existing transportation system before extra capacity is needed (47).

Transportation Worker Identification Credential (TWIC): defined by Title 49 §1570.3 of the U.S. Code of Federal Regulations as "a Federal biometric credential, issued to an individual, when TSA [the Transportation Security Administration] determines that the individual does not pose a security threat" (42).

U

Ultrasonic Sensor: a sensor with a frequency above 20,000 Hz (14).

Unmanned Aircraft (UA): any aircraft operated without a pilot on board (48).

Unmanned Aircraft System (UAS): an unmanned aircraft and the equipment that is used to operate it remotely (48).

U.S. Department of Transportation (USDOT): the principal direct federal funding agency for transportation facilities and programs in the United States. USDOT includes the Research and Innovative Technology Administration, the Federal Highway Administration, the Federal Transit Administration, the Federal Railroad Administration, and others (1).

U.S. Department of Transportation Automated Vehicles Activities: see *Automated Driving Systems: A Vision for Safety 2.0 (ADS 2.0)*, *Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0)*, and *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0 (AV 4.0)*.

V

Vehicle Platooning: defined by the Federal Highway Administration as a group of automated vehicles, with and without human drivers, that use communications to enable negotiations between vehicles to support organized behavior and safe close following (5).

Vehicle Safety: addresses vehicle safety for automated, connected, and non-equipped vehicles. The focus of vehicle safety is on the enhancement of safety, security, and efficiency in vehicle operations, by warnings and assistance to users or input to the operation of the vehicle (1).

Vehicle to Cloud (V2C): a communication system designed to wirelessly exchange information between a vehicle and the cloud (49).

Vehicle to Device (V2D): a communication system designed to wirelessly exchange information between a vehicle and any smart device (49).

Vehicle to Everything (V2X): the convergence of automotive and information technology, often using sensors and mobile technology that allows a vehicle to communicate with another device or system (49).

Vehicle to Infrastructure (V2I): a communication system designed to wirelessly exchange information between a vehicle and the infrastructure (20).

Vehicle to Network (V2N): a communication system using dedicated short-range communications and cellular networks to communicate with the vehicle-to-everything management system (49).

Vehicle to Pedestrian (V2P): a communication system designed to wirelessly exchange information between a vehicle and pedestrians (49).

Vehicle to Vehicle (V2V): a communication system designed to transmit basic safety information between vehicles to facilitate warnings to drivers concerning impending crashes (20).

Vision Processing: the technologies used to provide image-based analysis (3). See *Machine Vision*.

Vulnerable Road User: the individuals, such as pedestrians and bicyclists, that are most at risk in traffic operations because they are less protected from injury (50).

W

Wide-Area Wireless Communications: a communications link that provides communication via a wireless device between a user and an infrastructure-based system (1).

Wireless Access for Vehicular Environments (WAVE): a radio communications system intended to provide seamless, interoperable services to transportation (20).

Wireless Local Area Network (WLAN): commonly referred to as Wi-Fi, a local radio network that operates under IEEE-802 (6).

Work Zone: an area of a highway with construction, maintenance, or utility work activities. A work zone is typically marked by signs, channelizing devices, barriers, pavement markings, and/or work vehicles. A work zone extends from the first warning sign or high-intensity rotating, flashing, oscillating, or strobe lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control device (according to the *Manual on Uniform Traffic Control Devices for Streets and Highways* 2009, Section 6C.02) (1).

X

No terms.

Y

Yottabyte (YB): 1,000 zettabytes.

Z

Zero-Occupancy Vehicle: see *Autonomous Delivery Vehicle*.

Zettabyte (ZB): 1,000 exabytes.

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APPENDIX B

Automated Vehicle Safety Validation, Data, and Metrics

Texas CAV Task Force White Paper Subcommittee on Safety, Liability, and Responsibility

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Acknowledgments

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the “CAV Terminology” white paper for a full listing of terms and definitions used in this developing technology ecosystem.

List of Terms and Acronyms

ADS	automated driving system
ADS 2.0	*Automated Driving Systems 2.0: A Vision for Safety*
ASIL	automotive safety integrity levels
AV	autonomous vehicle
AV 4.0	*Automated Vehicles 4.0: Ensuring American Leadership in Automated Vehicle Technologies*
AVSC	Automated Vehicle Safety Consortium
AVT	Autonomous Vehicle Tester
CAV	connected and autonomous vehicle; also, connected and automated vehicle
DAVI	Data for Automated Vehicle Integration
EDR	event data recorder
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
IAM	Institute of Automated Mobility
MMUCC	Model Minimum Uniform Crash Criteria
NAMIC	National Association of Mutual Insurance Companies
NHTSA	National Highway Traffic Safety Administration
NPRM	notice of proposed rulemaking
ODD	operational design domain
OEM	original equipment manufacturer
PennDOT	Pennsylvania Department of Transportation
SOTIF	safety of the intended function
TxDOT	Texas Department of Transportation
USDOT	U.S. Department of Transportation
VSSA	Voluntary Safety Self-Assessment

Executive Summary

Connected and autonomous vehicles (CAVs) are expected to increase the safety of motor vehicles, with the potential to greatly reduce the number of annual vehicle crashes and fatalities. While CAVs are anticipated to increase safety in the future vehicle fleet, ensuring safety during the lengthy development and testing process is a priority.

Because more than 36,000 fatalities occur in the United States each year, motor vehicle safety remains a prime concern. The National Highway Traffic Safety Administration (NHTSA) states that 94 percent of serious crashes are due to dangerous choices or errors people make behind the wheel. It is expected that the introduction of autonomous vehicles (AVs) can largely eliminate human error from the traffic safety equation. However, high-profile crashes involving AVs and other road users have caused concerns regarding safety during the development and testing process. In the push for continuing the integration of safety into every aspect of the development of AVs, AV developers are taking steps to show their due diligence during the testing process and demonstrate transparency in their operations. They are filing Voluntary Safety Self-Assessments (VSSAs) with NHTSA to document how they incorporate safety into the development process. Other efforts proactively taken by AV developers include beginning to use safety cases, releasing information outlining their layered safety approach and number of miles driven with the number of contact events involving their vehicle, and developing a mathematical formula to prove the safety of AVs.

Real-world testing on public roads is the necessary next step in deployment after extensive simulation and closed-track testing have validated system safety. International standards bodies, federal regulators, and other safety organizations are developing safety standards that reflect and harmonize best practices as the technologies mature. According to guidance from the U.S. Department of Transportation (USDOT), states' responsibilities for AV regulation continue to include licensing human drivers, registering motor vehicles in their jurisdictions, enacting and enforcing traffic laws and regulations, conducting safety inspections (if they so choose), and regulating motor vehicle insurance and liability.

As states such as Texas continue to embrace AV testing in the private sector, it is important to understand several aspects of this dynamic and continually developing ecosystem. These features include the following:

- Federal guidelines on VSSAs, state and federal roles, and federal agencies responsible for safety.
- Initial efforts by NHTSA and the Federal Motor Carrier Safety Administration to address rules updates.
- Varied approaches by states to facilitate safe testing and operations.
- International and other standards being used and adopted as the technology advances.
- USDOT initiatives on data development and sharing to improve safety.
- AV-related information that may be required for future Model Minimum Uniform Crash Criteria.

Specific to Texas, opportunities for future policy considerations include:

- **AV education**—Design an AV public education campaign developed with national partners, with distribution carried out by local officials and first responders, and through other avenues such as the Texas CAV Task Force website and social media campaigns.
- **Deployment highlights**—Work with AV developers to create a website showing a map of AV testing and deployments within Texas, with highlights of each deployment.
- **Collaboration**—Promote ongoing and open public-private stakeholder dialogue and collaboration efforts on safety information and transparency.
- **Data-sharing discussions**—Initiate conversations on data sharing (including security and privacy considerations) with AV companies that focus on which data can be shared, which data cannot be shared, and which data are open for discussion.
- **Crash factors**—Encourage discussion between operators and developers and law enforcement to explore how to incorporate AV and automated driving function crash factors into state crash report forms (CR-3).

Introduction

Texas is committed to facilitating a state-of-the art, efficient, and safe transportation system that serves and connects all communities. Texas is also committed to holding its position as a forward-thinking leader in enabling technology and innovation advancements, especially as it relates to connected and autonomous vehicle (CAV) technology. State agencies serve as conveners and facilitators, through the Texas CAV Task Force, by working with stakeholders from industry, research, local, and regional public agencies that have interest and expertise in the safe development, testing, and integration of these technologies. Ensuring the safe deployment of autonomous vehicles (AVs) in Texas remains paramount for all agencies, decision makers, and partners involved in AV development. Safety protocols, standards, and policies can be developed in a manner that is collaborative and endorsed by all stakeholders. The intent is for AV regulation, education, and outreach to be clear, consistent, and trustworthy, regardless of how they are delivered.

The number of CAV deployments has significantly increased over the last five years. Motor vehicle safety remains a top concern for the U.S. Department of Transportation (USDOT). AVs alone have been estimated to have the potential to greatly increase vehicle safety and reduce the number of motor vehicle deaths. In alignment with USDOT guidance, many states have taken steps to enable and regulate AV deployments, especially in the areas of licensing, reporting, and operations.

This white paper is organized into two primary focus areas that are described as follows.

State-of-the-Practice Review

A state-of-the-practice review of safety standards development was conducted to understand how safety-related activities can benefit Texas. The review discusses efforts at the federal government level to include the Federal Motor Vehicle Safety Standards (FMVSS); current efforts across states, including state legislation and AV testing protocols from various state departments of transportation; and safety standards development in professional organizations and research institutions. Although no single model policy or safety standard has been officially endorsed or adopted industry-wide, it is plausible that future regulations will evolve from some of the existing efforts described in the state-of-the-practice review.

Reporting Crash Factors

Crash-reporting standards and protocols remain an open but important question since such data will help to identify factors contributing to crashes and inform liability determinations. A summary of crash reporting in Texas is provided, along with a summary of guidelines for reporting AV crash data by law enforcement and other authorities.

State of the Practice: Safety Standards and Policies

Since the introduction of vehicles with automated functions, government agencies at both the federal and state levels have developed policies to govern these vehicles. These policies have focused on the inclusion of AVs into state legislation and clarification of what constitutes a driver. Because safety remains a top concern, states have begun to pass legislation to monitor the safety of AV deployments, with international standards-setting bodies and research institutes working to create standards that can govern the safety of these technology-rich vehicles.

Federal Safety Standards and Policy Developments

To better evaluate the safety of AVs, several efforts have recently been undertaken (1). USDOT has established six guiding principles for shaping policy on automated vehicles:

1. "We will prioritize safety.
2. We will remain technology neutral.
3. We will modernize regulations.
4. We will encourage a consistent regulatory and operational environment.
5. We will prepare proactively for automation.
6. We will protect and enhance the freedoms enjoyed by Americans "(2).

Starting with *Automated Driving Systems 2.0: A Vision for Safety* (ADS 2.0), USDOT has outlined key safety elements for automated driving systems (ADSs). This guidance is voluntary, with no compliance requirement or enforcement mechanism. The sole purpose of this guidance is to support the industry as it develops best practices in the design, development, testing, and deployment of AV technologies.

Automated Vehicles 3.0: Preparing for the Future of Transportation built upon ADS 2.0, breaking down the roles for states and federal agencies in regard to automation activities. The latest report in the series from USDOT, *Automated Vehicles 4.0: Ensuring American Leadership in Automated Vehicle Technologies* (AV 4.0), discusses federal agencies' roles in safety governance. AV 4.0 highlights the National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA), Federal Transit Administration, and Federal Highway Administration as the most relevant agencies in regard to vehicle automation (1, 2, 3).

ADS 2.0 also presents an overview of the Voluntary Safety Self-Assessment (VSSA). The VSSA document is written by the original equipment manufacturers (OEMs) to demonstrate their best practices and industry best practices, outlining how they:

- Consider the safety aspects of ADSs.
- Communicate and collaborate with departments of transportation.
- Encourage the self-establishment of industry safety norms for ADSs.
- Build public trust, acceptance, and confidence through transparent testing and deployment of ADSs.

In its implementation guidance to developers, NHTSA encourages "concise information" and that VSSAs not be used as an "exhaustive recount of every action the entity took to address a particular safety element" (**Error! Bookmark not defined.**). The following 12 safety elements are included in a VSSA:

1. Vehicle cybersecurity.
2. System safety.
3. Operational design domain.
4. Object and event detection and response.
5. Fallback (minimal risk condition).

6. Validation methods.
7. Human-machine interface.
8. Crashworthiness.
9. Post-crash ADS behavior.
10. Data recording.
11. Consumer education and training.
12. Federal, state, and local laws.

NHTSA has also been in the process of reviewing the FMVSS. This review is necessary to determine how extensively the FMVSS need to be updated to remove any barriers that inhibit the inclusion of AV technologies. Two approaches are being used to review the standards:

- **A driver reference scan** to reveal the standards that either implicitly or explicitly refer to a human driver.
- **An AV concepts scan** to identify which standards potentially pose a barrier to AV capabilities and designs.

The FMVSS do not explicitly address AVs; instead, they assume a human driver, and numerous standards reference the driver. A driver is defined in FMVSS §571.3 as "the occupant of the motor vehicle seated immediately behind the steering control system" (4). This definition of a driver presents a major barrier to AVs with new interior designs that remove the steering controls from the vehicle. As automation progresses, eventually reaching full autonomy, this definition will need to be flexible to include both a human driver and the vehicle's software as the driver. Alternative designs that allow for driverless operations face particular barriers, especially for occupant crash protection and controls and displays. Currently, only one company has been granted an exemption from the requirements to include driver steering controls because the company's vehicles travel at low speeds and are designed to carry only goods and not passengers (5).

Although the use of exemptions is expected to continue for AV developers who do not plan to transport passengers, NHTSA has recognized that barriers exist to vehicles with nontraditional interior layouts. Recognizing these barriers, NHTSA has issued a notice of proposed rulemaking (NPRM) to modernize occupant protection safety standards for vehicles without manual controls. The NPRM proposes to adapt numerous FMVSS and clarify ambiguities in current standards on occupant protections. The rule updates will adapt safety requirements to vehicles with ADSs that lack traditional manual controls by revising requirements and testing procedures to account for the removal of these controls. Although amending the FMVSS for vehicles equipped with ADSs that do not have manual controls, the proposal will not change existing occupant protection requirements for vehicles that include these traditional vehicle controls (6).

State Safety Standards and Policy Developments

In conjunction with efforts at the federal level to safely integrate CAVs onto the nation's roadways, many states have initiated ongoing efforts as well. According to guidance from USDOT, states' responsibilities for AV regulation include licensing human drivers, registering motor vehicles in their jurisdictions, enacting and enforcing traffic laws and regulations, conducting safety inspections (if they so choose), and regulating motor vehicle insurance and liability (2). Within these areas of responsibility, states have begun to review and amend existing regulations to allow for CAV testing and operations.

The following subsections provide an overview of regulatory activities in key states. (Texas is presented first, and then other states are in alphabetical order.)

Texas

Texas has positioned itself to be highly favorable to AV testing and operations. Legislation passed in 2017 amended state code to allow for the testing and operation of AVs on Texas roadways with the ADS engaged. When the ADS is engaged on a motor vehicle, the owner is considered the operator to ensure the compliance of operations with applicable laws and regulations. Under Texas law, and as adopted by other states as well, the operator of an AV is not required to physically be located within the vehicle but is expected to respond to any request to intervene. Should an incident occur, an AV must be equipped with a recording device installed by a manufacturer that does any of the following: records the speed, direction, location data, steering performance, and braking performance; collects seat belt indications; and/or transmits information concerning a crash to a central communications system. As with conventional motor vehicles, an AV must be registered and titled according to state regulations but does not have to be registered specifically as an AV (7).

Arizona

Arizona allows the testing of fully autonomous vehicles without the need for a driver present in the vehicle. Like regulations in other states, operations without a driver can occur if the vehicle is fully autonomous, able to comply with all applicable traffic laws, and complies with all applicable FMVSS. Prior to testing of AVs, the AV developer must notify the Arizona Department of Transportation and, if testing a fully autonomous vehicle, submit a Law Enforcement Interaction Protocol (8). The protocol must provide information on:

- Communications with fleet support specialists.
- Safe removal of the AV from the road.
- How to recognize that the vehicle is in autonomous mode.
- The cities in which testing operations will occur.
- Any additional information the manufacturer thinks is critical for risk mitigation (9).

To further increase the safety of AVs during testing, the Arizona Commerce Authority established the Institute of Automated Mobility (IAM). As part of its initiatives, IAM is in the process of developing a safety assessment methodology for ADS-equipped vehicles. As part of this methodology, the creation of metrics that provide measurable and meaningful insights are under study for both AVs and human-driven vehicles interacting on roadways (10).

California

California began its Autonomous Vehicle Tester (AVT) program in 2014. As part of the program requirements, an AV company must submit an application to the AVT program. Within the application process, the AV testing entity must provide:

- Documentation on the vehicles being tested, including make, model, model year, and any other identifying information.
- An outline of the driver or operator training program.
- Pertinent insurance or surety information (11).

Once an application to the AVT program has been approved, the permit is valid for two years before renewal. Collision reporting is mandatory and must be completed within 10 days for any collision that results in property damage, bodily injury, or death. California regulations also require the reporting of AV disengagements over the year. Disengagements occur when the full control of the vehicle is passed from the ADS to the driver. The data collected on disengagements include the vehicle information, disengagement initiation, location, and event timeline that led to the disengagement (12). While disengagement reports can give some insight into the testing activities of AV companies, the safety insights that can be gathered from these reports are limited because the intensity of testing and the severity of the disengagement cannot be determined. Using disengagements as a meaningful safety performance metric is under debate because many believe that it is not a reliable reflection of the rigors of testing and the complexity of the operating environment. Disengagement data might be more meaningful if the data can provide information related to the cause of driver takeover.

Florida

Perhaps one of the most open states for on-road AV testing, Florida most recently updated its state regulations in 2019. Under current state regulations, vehicles do not need to register specifically as AVs. Further, AV developers can test on Florida roads without a licensed human operator present within the test vehicle. Although this provision provides a favorable environment for developers, it creates challenges for determining the safety of AV operations because it is not easily known who is testing within the state or where testing operations are taking place (13).

Michigan

Because Michigan is historically at the heart of the U.S. automotive industry, efforts within the state have been made to make it favorable to AV testing and deployments. Legislation passed in 2016 allows for the testing and operation of AVs with and without a driver being physically present in the vehicle. As part of the legislation, the ADS remote- or expert-controlled assist system shall be considered the driver or operator of the vehicle while the ADS is engaged. These ADS operations can take place after the manufacturer has notified the Michigan Department of Transportation of its self-certification, which includes pertinent information on the geographic boundary of testing. The Michigan code also states that the manufacturer shall maintain incident records and periodically submit summaries to both the Michigan Department of Transportation and NHTSA, but the code does not specify a time frame for how periodically these reports should be submitted. Last, while the ADS is engaged, the manufacturer is liable for any incident that may take place during the course of testing (14).

Nevada

Nevada was one of the first states to allow AV testing in 2011. The state has amended its regulations as AV technology has advanced. Like Pennsylvania, Nevada requires that AVs be registered but only if the vehicles meet the requirements of the FMVSS and have been affixed with a label pursuant to the FMVSS. Unlike both Pennsylvania and California, Nevada regulations have provisions for driverless autonomous testing, as long as the vehicle has the capability to achieve a minimal risk condition if a failure of the ADS should occur (15).

Pennsylvania

Following discussion with AV technology developers, the Pennsylvania Department of Transportation (PennDOT) developed *Automated Vehicle Testing Guidance* for testing within Pennsylvania. The guidance was first issued in July 2018 and updated in September 2020 and requires that a notice of testing be submitted before any AV testing takes place on Pennsylvania roadways (16).

The notice of testing collects:

- Information on the tester applying for testing.
- Vehicle information.
- Safety driver information.
- Location information.
- Either a safety and risk mitigation plan or a VSSA that follows NHTSA guidance.

Along with the notice of testing, PennDOT requests data from testers on a semiannual basis, ensuring that less than six months of testing has occurred before submitting the initial data collection form. The information collected includes the approximate miles of travel by ADS-engaged AVs, the type of roadway that the majority of testing occurred on, and the counties in which the testing occurred (16).

PennDOT does not collect disengagements and other metrics, other than miles traveled, leaving it to the AV testing companies to use metrics of their choosing to determine the safety of their vehicle platforms.

Discussion of State Approaches

These summaries of state activities describe various approaches to policy and regulation in key states, highlighting that some states enforce heavier regulations and reporting requirements. States with lighter legislation, such as Texas, may potentially have a more business- and innovation-friendly environment, with more testing and industry activity. Since AV technology is still under development, significant regulations to craft appropriate policy may benefit by waiting until further information is available from mature deployments.

In regard to metrics, any proposed metric should be reliable and meaningful; otherwise, it may present false information about the safety performance of these technologies.

Standards Organizations

Standards to ensure road safety have been under discussion and development within a variety of venues and with myriad stakeholders. This section provides some standards developed by international standards development bodies, as well as private companies and organizations. Some standards are voluntary and/or still under development, and not all standards have been adopted by federal authorities for OEM compliance.

SAE 3197

To be used with SAE J1698—Event Data Recorder (EDR), SAE 3197—ADS Data Logger provides standards on the collection of ADS information for use in analyzing crashes and crash-like events. This multiple-part standard presents data element definitions that are specific to Level 3–5 ADSs, provides a minimum data element set, and specifies the common ADS data logger record format. The first part of the standard, Output Data Definition, provides common data output formats and definitions for data elements that can be used in the analysis of vehicle crashes and crash-like events. The second portion of the standard, Retrieval Tool Protocol, works with existing industry standards to identify physical interfaces and define protocols to retrieve records stored in the EDR devices. The final portion of the standard discusses and defines procedures that may be used to validate EDR conformance with FMVSS reporting requirements during vehicle-level crash testing (17).

Automated Vehicle Safety Consortium

The Automated Vehicle Safety Consortium (AVSC) is a consortium of AV developers and OEMs coordinated by SAE International. Aimed at working to inform and accelerate industry-wide standards, the consortium has identified safety principles that guide its work: proper systems in place for testing interactions with people and systems; and the collection, protection, and sharing of data. AVSC has published best practice reports that cover the principles it has identified for the safe development of SAE Level 4 and 5 AVs, with best practice reports covering safety operator selection and training, and describing operational design domains (ODDs), among others (18).

ISO 26262

Developed as a functional safety standard for use in the automotive industry, ISO 26262 is titled Road Vehicles—Functional Safety. The standard is a risk-based safety standard that applies to electric and electronic systems in vehicles and includes driver assistance, propulsion, and vehicle dynamic control systems. The goal of the standard is to ensure safety throughout the life cycle of automotive equipment and systems. ISO 26262 covers all aspects of functional safety: design, implementation, integration, verification, validation, and configuration. A key component to this standard is the identification of automotive safety integrity levels (ASILs). ASILs measure the risk of a specific system component and are determined by three factors—severity, exposure, and controllability (19).

ISO/PAS 21488

Similar to ISO 26262, ISO/PAS 21448—Safety of the Intended Functionality was developed to account for edge cases that may not result in safety hazards from system failures. This standard covers malfunctions in the absence of faults and unintended impacts from technological shortcomings of the system by design. As such, the standard is used as a complement to ISO 26262 to allow AV developers to assure the functional safety of their vehicles. Because it covers the safety of the intended function (SOTIF), the standard defines SOTIF as “the absence of unreasonable risk due to hazards resulting from functionality insufficiencies of the intended functionality or by reasonably foreseeable misuse by persons” (20).

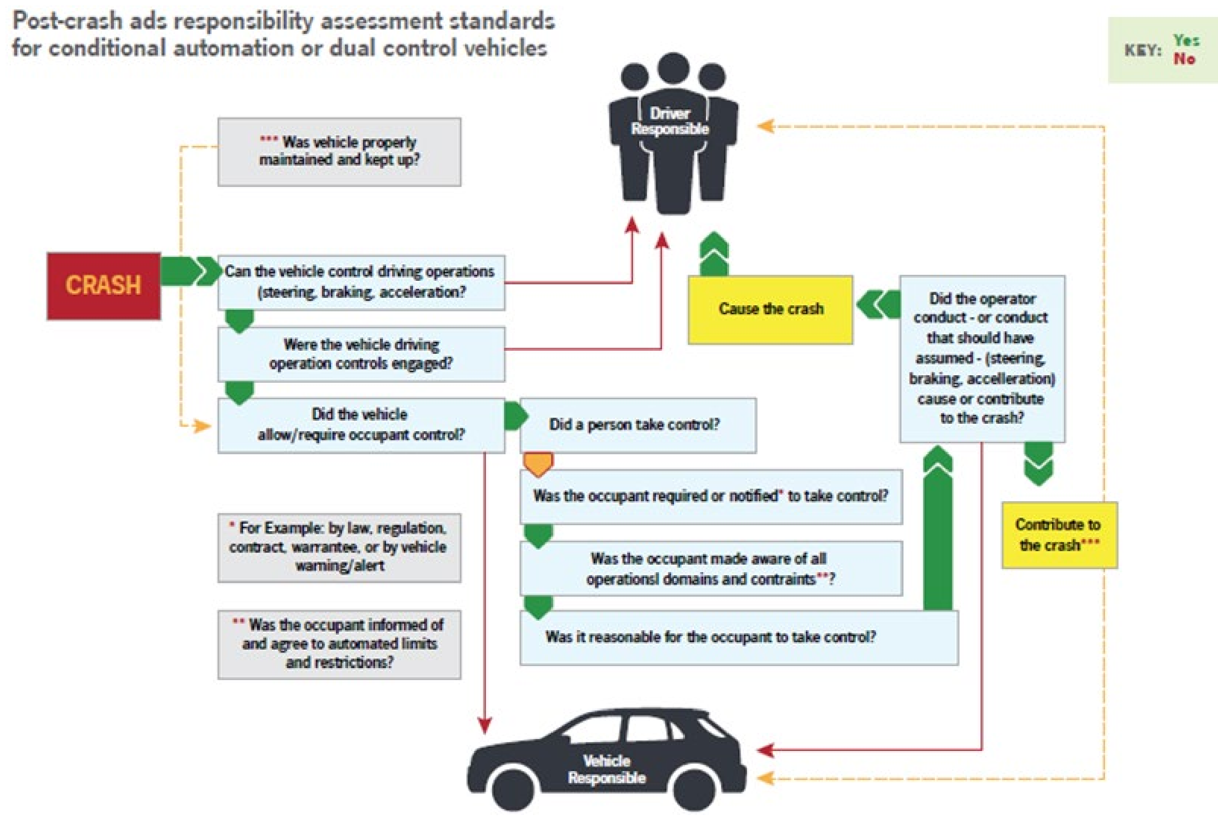
ANSI/UL 4600

In April 2020, Underwriters Laboratories published ANSI/UL 4600, the Standard for Safety for the Evaluation of Autonomous Products—its first standard addressing AVs and other applications. A diverse body of international stakeholders was convened by Underwriters Laboratories to participate in the Standards Technical Panel to develop the document. This group proposed content, shared knowledge, and reviewed and voted upon the proposals that ultimately achieved consensus in the first edition of UL 4600. UL 4600 was created to help ensure that safety was considered during the full design process for AVs. One of the first standards of this type, UL 4600 received American National Standards Institute approval in April 2020. The emphasis on safety is accomplished through a repeatable assessment process of safety cases. While many standards typically prescribe certain requirements and testing procedures, UL 4600 relies on a goal-based approach, prescribing topics to address but not requiring specific tests and procedures, which allows the standard to stay technologically neutral (21).

UL 4600 covers machine-learning-based functionality validation along with other autonomy functions. Because the UL 4600 standard is goal based and not prescriptive on the tests required, the standard permits compliance with other standards (e.g., ISO 26262 and IEC 61508) but does not require compliance. Among the areas covered by UL 4600 are safety case construction, risk analysis, safety-relevant aspects of the design process, testing, tool qualification, autonomy validation, data integrity, human-machine interaction, life-cycle concerns, metrics, and conformance assessment.

National Association of Mutual Insurance Companies

While Underwriters Laboratory and Edge Case Research focused on vehicle safety and validation with UL 4600, the National Association of Mutual Insurance Companies (NAMIC) recognized the complexity of conditional automation and the liability challenges that come with automation. As the complexity of AVs has increased, so has a lack of understanding about the role of the driver and vehicle. In its policy paper on dual-control systems, NAMIC discusses how the lack of understanding of the operations of dual-control vehicles and vehicles with advanced automation impacts consumer confidence, effective legislation, and ADS development. Providing information on the responsibility of the driver versus the vehicle, NAMIC developed a framework to help determine the responsible party in the event of a crash. Figure 1 provides the framework for responsibility (22).



Source: NAMIC (22)

Figure 1. NAMIC Responsibility Framework.

AV Data Initiatives

A desire exists to move toward standardized data to facilitate monitoring and evaluating AV safety performance, especially for insurance and liability, crash analysis, and driving system verification. Challenges to data standardization include differing and proprietary systems.

Recognizing the need for data exchange among public and private agencies and AV developers, USDOT launched the Data for Automated Vehicle Integration (DAVI) program in 2018. Noting that a lack of data exchange could impede the safe integration of AVs, the DAVI program focuses on identifying, prioritizing, monitoring, and addressing needs for the exchange of data across modes for AV integration. To promote AV data exchanges, the DAVI program follows these guiding principles:

- Promote proactive data-driven safety, cybersecurity, and privacy-protection practices.
- Act as a facilitator to inspire and enable voluntary data exchanges.
- Start small to demonstrate and then scale up toward a bigger vision.
- Coordinate across modes to reduce costs, reduce industry burden, and accelerate action.

USDOT published its DAVI framework to facilitate the creation of common data exchanges across multiple modes. The framework defines the key categories, goals, participants, and priorities of data exchanges and is designed to create consistency. The framework presents real-world examples and the data specific to each category. The framework includes:

- Business-to-business data exchange.
- Business-to-government data exchange.
- Infrastructure-to-business data exchange.
- Open training data.

A number of companies created open training data sets to advance computer vision and other ADS functions following the announcement of the DAVI program. USDOT launched the Work Zone Data Exchange, which was identified through a series of roundtables, using the data exchange framework. The program provides grants to public roadway operators to create unified work zone data feeds available for third-party use. Work zone safety can be increased by allowing and using data feeds to disseminate consistent work zone information to the public (23).

Reporting Crash Factors

As AVs begin to be deployed on roads, safety officials are concerned about the interaction between law enforcement and these vehicles. The two main data-related concerns are:

- How to identify contributing factors and liability should an AV be involved in a crash.
- How vehicle-crash-reporting mechanisms should consider automated driving features.

To determine the contributing factors and liability of a crash, officials rely on crash reports from first responders to understand the crash scene and the factors that led to the crash. Texas, like many states, relies on first responders to complete a crash report (Texas Department of Transportation [TxDOT] Form CR-3) while on scene or shortly afterward. Among the information collected in these reports are the crash location, the date of the crash, the vehicle, the driver, and personal information. Contained in the information on the severity of the crash is information on the damage, injuries, and persons killed. Based on the scene and information collected from drivers and eyewitnesses, first responders record factors and conditions that led to the crash on the form (Figure 2). This last section is the most concerning for officials because crash reports have not kept pace with AV development. Currently, no codes exist that represent the ADS as a potential contributing factor to a crash (24).

FACTORS & CONDITIONS	36 Contributing Factors (Investigator's Opinion)						37 Vehicle Defects (Investigator's Opinion)					Environmental and Roadway Conditions						
	Unit #	Contributing			May Have Contrib.		Contributing			May Have Contrib.		38 Weather Cond.	39 Light Cond.	40 Entering Roads	41 Roadway Type	42 Roadway Alignment	43 Surface Condition	44 Traffic Control

Source: TxDOT (24)

Figure 2. TxDOT CR-3 Crash Factors and Contributions.

To provide a uniform standard for crash report collection, NHTSA developed the Model Minimum Uniform Crash Criteria (MMUCC) in 1998 in cooperation with the Governors Highway Safety Association. The most recent edition was published in 2017. Created as a voluntary guideline that represents the minimum model set of data elements that describe a motor vehicle crash, the MMUCC provides states with a uniform approach to collecting on-scene crash data. The data elements record both events during and after a crash, and states are encouraged to collect as many of the recommended elements as possible.

Recognizing that crash reports need to collect information on increased technology on vehicles, the MMUCC in its latest edition added a section on dynamic data elements. As defined by the MMUCC, dynamic data elements are "those items that are either in such a state of flux or so new to the evolving discipline in acquisition they cannot yet be measured reliably" (25). Using this definition, the MMUCC considers AV technology to be a dynamic data element. In further discussions, the MMUCC points out that collecting information on vehicle automation is difficult because current methods of collecting data through observation are unreliable, and a centralized database on vehicle automation does not exist. Although information on crashes is currently gathered through observation and firsthand accounts of those on board the vehicle, the ADS in the future can help law enforcement with crash analysis by collecting positional data pre- and post-crash in accordance with FMVSS and SAE 3197 standards.

Even though the collection of data on automation is difficult, the inclusion of questions on crash reports that ask about automated functions (e.g., is an automation system present in the vehicle? Was the automation system engaged at the time of the crash?) can help safety officials better determine the circumstances of a crash and the liability and safety of vehicles on the road. Consideration of how the information collected will be used can help determine the questions to include on the forms. This consideration is important because crash data are often requested and can lead to accuracy questions on over- or underrepresentation of crash types and factors (e.g., distracted driving).

Opportunities

Because CAV technology is still maturing, safety evaluation and perceptions will continue to evolve. As these technologies progress through research and development phases, there will be periods of great advances in safety as well as static periods. As progress continues, companies are incentivized not to deploy technology that is unsafe or underdeveloped since incidents greatly hurt companies' reputations and undermine public trust. While advocates for safety will seek to enforce stricter safety standards for these technologies, fully accepted definitions, standards, and protocols do not yet fully exist. As technology develops and more and more autonomous features are incorporated into traditional vehicles for a variety of operational environments, the public will gain a greater understanding and familiarity with the safety advantages of this technology.

Based on the review of federal, state, and international standard organizations, great strides have been made in ensuring AV safety. Conversely, the interaction of AVs with law enforcement officials, particularly in crash investigations, still presents challenges. Thus, opportunities for continued collaboration between public and private sectors exist.

Public- and Private-Sector Short-Term Collaboration Opportunities

Short-term opportunities for Texas include:

- AV education—Design and develop an AV public education campaign with national partners; carry out distribution through local officials and first responders and through other avenues such as the Texas CAV Task Force website and social media campaigns.

- **Deployment highlights**—Work with AV developers to create a website showing a map of AV testing and deployments within Texas that highlights each deployment.

Public- and Private-Sector Long-Term Collaboration Opportunities

Long-term opportunities for Texas include:

- **Collaboration**—Promote ongoing and open public-private stakeholder dialogue and collaboration efforts on safety information and transparency.

Data-Sharing Opportunities

Because AVs rely on mass amounts of data to operate, the sharing of data is paramount to the ensured safety of these vehicles. Regarding the need to protect proprietary information, short- and long-term opportunities are available to enhance the safety of AVs.

Data-sharing collaboration opportunities include:

- **Data-sharing discussions**—Initiate conversations on data sharing (including security and privacy considerations) that focus on what data can be shared, what data cannot be shared, and what data are open for discussion.
- **Crash factors**—Encourage discussion between operators and developers and law enforcement to explore how to incorporate AV and automated driving function crash factors into state crash report forms (CR-3).

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APPENDIX C

Understanding Perceptions and Opinions about Connected and Automated Vehicle Technology: Advancing the Dialogue

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Texas CAV Task Force White Paper Subcommittee on Education, Communication, and User Needs

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Acknowledgments

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's

performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the “CAV Terminology” white paper for a full listing of terms and definitions used in this developing technology ecosystem.

List of Terms and Acronyms

AAA	American Automobile Association
ADAS	advanced driver assistance system
AV	automated vehicle
CAV	connected and autonomous vehicle; also, connected and automated vehicle
CV	connected vehicle
FAQ	frequently asked question
GPS	global positioning system
ITS	intelligent transportation system
NHTSA	National Highway Traffic Safety Administration
PAVE	Partners for Automated Vehicle Education
TTI	Texas A&M Transportation Institute
USDOT	U.S. Department of Transportation
WYDOT	Wyoming Department of Transportation

Executive Summary

The transportation sector has experienced substantial disruption in the last decade. Advances in technology, both in vehicles and infrastructure, have changed how systems are operated, managed, and maintained. The rate of advancement will continue to increase, and transportation agencies will likely adopt some technologies because of the promise of helping them achieve agency goals. Yet, the general public still does not fully understand or care about the transportation network, even though they expect it to always be available.

Billions of dollars are being invested by private companies as well as local, state, and federal public agencies to implement the technologies associated with connected and autonomous vehicles (CAVs). These technologies have the potential to dramatically change personal, freight, and public transportation. Benefits include improved safety and reduced congestion, more efficient land use and reduced emissions, and new or improved personal mobility and socioeconomic opportunities. The benefits to be realized will be proportional to the rate of public acceptance and adoption.

CAV technology holds much promise, but questions remain surrounding its widespread use and adoption. The issues include planning, policy making, regulatory and legal frameworks, institutional issues, operations, funding, and ultimately public trust and acceptance. Addressing these issues and answering these questions will require many agencies to work cooperatively across disciplines in a rapidly changing environment. Some questions are known at this time, while more are likely to arise as implementation progresses. For now, pilots, demonstrations, and first-use cases provide useful data inputs to answering some of the questions and serve to introduce the public to the technologies.

The Texas CAV Task Force's Subcommittee on Education, Communication, and User Needs supports statewide efforts to inform and engage with agencies, stakeholders, industry, and the general public. The majority of outreach and engagement, to date, is associated with pilots and demonstrations although some surveys have assessed the general public's awareness, familiarity, and use of various automated features currently available on vehicles—as well as overall trust in these technologies. The results of the efforts thus far show confusion around the concepts of automated vehicles (AVs), connected vehicles, and autonomous vehicles. This confusion makes it difficult to engage meaningfully with the public about impacts, use, and preference. Additionally, the public may not be fully aware of how these technologies can and will impact their daily lives.

Where pilots and demonstrations have been implemented, research conducted afterward shows that use or experience with CAV technologies suggests a greater likelihood of acceptance. Survey respondents who had experiences with CAV features tended to feel comfortable and safe using them. In the Texas A&M Transportation Institute's survey of the Frisco Drive.ai pilot, 78 percent of respondents who had taken a ride in an AV had positive opinions of AVs, whereas 49 percent of respondents who had not taken a ride in an AV had positive opinions of them (1).

Familiarity and experience have increased favorability in pilots, but trust in the technologies appears more limited, with the majority of survey respondents since 2016 indicating that they would be afraid to ride in a fully automated vehicle. Some of the concern extends beyond the technology itself and references laws surrounding autonomous vehicle safety, systems vulnerability, and operating complexity.

Education and outreach to multiple audiences are necessary to build awareness, generate trust, and thereby increase adoption. Efforts should expand beyond the identification of benefits and should seek to answer questions and address issues across broad categories based on audience. Baseline research should inform these efforts by identifying the positions and interests of each audience. Overarching key messages will be supported by secondary messages that are relevant to each audience. Education and outreach should function in a continuous feedback loop so that as issues are raised, input can be gathered, and solutions can be formulated.

Education and outreach about CAV benefits and opportunities in Texas will benefit from fundamental communication of best practices for effectiveness. These include:

- **Audience identification**—Identifying the audience and their motivations will enable development of messages that empower supporters, convince uncertain individuals, and minimize the impact of opponents.
- **Market research**—Learn about the audience, what they care about, and what messages will best convince them.
- **Message design**—Several principles define the best ways to design a message, including keeping it simple, staying positive, using metaphors, making it personal, and offering a call to action.
- **Message delivery**—Inconsistent delivery will derail even the best messages. Continually and consistently repeat the message so it will not get lost (2).

A stakeholder engagement plan and a complementary public outreach plan can guide development of materials and provide a comprehensive roadmap for education and outreach efforts beyond the key messages. Development of such plans will ensure that messaging is consistent across formats. The plans will also serve to allocate adequate time and resources by identifying specific actions. The plans can prioritize activities.

The Education Subcommittee, with its broad multidisciplinary representation, is the forward-facing entity responsible for executing an engagement plan. The subcommittee's charge and responsibility are to develop tools and resources that allow for meaningful engagement. These are already being developed. The engagement plan lays out what, when, where, and how engagement will occur—the *tactics*. But an engagement strategy also establishes the reason for engagement—the *why*. The subcommittee has the cachet to engage with everyone in the mobility ecosystem to discuss the *why* of engagement.

This white paper is a living document that will evolve as more research and feedback inform education and outreach. This paper is not the engagement plan itself nor does it discuss specific tactics; rather, it lays the foundation for the subsequent work of the Education Subcommittee.

Introduction

"Many transportation departments are concerned that the public is relatively uninformed about such issues as how transportation facilities and services are financed, how they are provided, how well they function, and, in general, the importance of an effective transportation system"; this quote is included in the opening summary of National Cooperative Highway Research Program Report 20-24(93), *Mobile Messages: Moving People to Support Transportation* (3). The report was written in 2015, but the quote was written in 1994 as part of the introduction to the *Public Outreach Handbook for Departments of Transportation* (4). Nearly three decades later, these words still ring true. Agencies today still grapple with how to effectively communicate their mission, their functions, their needs, and their performance.

At the same time, the transportation sector has experienced substantial disruption in the last decade. Advances in technology, both in vehicles and infrastructure, have changed how systems are operated, managed, and maintained. The rate of advancement will continue to increase, and transportation agencies will likely adopt some technologies because of the promise of helping them achieve an agency goal. Yet, the general public still does not fully understand or care about the transportation network, even though they expect it to always be available.

Billions of dollars are being invested by private companies as well as local, state, and federal public agencies to implement the technologies associated with **connected and automated vehicles (CAVs)**. These technologies have the potential to dramatically change personal, freight, and public transportation. Benefits include improved safety and reduced congestion, more efficient land use and reduced emissions, and new or improved personal mobility and socioeconomic opportunities. While growth in technological advances may happen exponentially, benefits may take longer to be realized (5).

The rate at which benefits are realized is proportional to the rate of adoption. CAV adoption will require concerted and sustained efforts to address the myriad issues surrounding implementation including planning, policy making, regulatory and legal frameworks, institutional issues, operations, funding, and ultimately public trust and acceptance. Addressing these issues will require many agencies to work cooperatively across disciplines in a rapidly changing environment.

The State of Texas strongly supports the development of these technologies. One indication of such support is the convening of the Texas CAV Task Force. The Texas CAV Task Force is charged with identifying and exploring many of the identified issues, including public awareness and public education. The Texas CAV Task Force's Subcommittee on Education, Communication, and User Needs strives to inform and engage the general public, elected and appointed officials, industry, and business about the opportunities associated with CAVs. This begins with tools that help to educate and inform discussions. One such tool is a website that includes research and resources for a variety of audiences. This is an important first step. It provides a foundational understanding so that as the technologies advance and unanswered questions arise, the discussions are informed by a common knowledge and understanding. Additional research will inform tactical education efforts that speak to specific issues that are unknown at this time, including impacts on workforce, education, land use, economic development, etc.

This white paper outlines efforts to educate the public through pilots, demonstrations, and first-use operations. The paper also presents the results of consumer acceptability following some CAV pilot programs, identifies tactics that may be effective, and suggests strategies for future educational efforts.

This white paper is a living document that will be revised as necessary to reflect changes in strategic direction, findings from research, and feedback from stakeholders. There are many unknowns at this time. Indeed, it is impossible to even know all of the relevant questions as this disruptive technology evolves. The evolution will be iterative in much the same way that intelligent transportation systems (ITSs) evolved into the smart, integrated systems that are in widespread use today. The advancement and deployment of ITSs in transportation provide a valuable use case to model CAV deployment. The Texas CAV Task Force and the Education Subcommittee are committed to identifying issues, exploring options, and conducting research. Each of these actions supports informed decision making. The subcommittee will engage with stakeholders, elected and appointed officials, industry, and other partners to develop and deliver an effective engagement strategy that supports CAV technology initiatives in Texas. This white paper is not the engagement plan itself nor does it discuss specific tactics; rather, it lays the foundation for the subsequent work of the Education Subcommittee.

Background

The U.S. Department of Transportation (USDOT) reports that more than 80 companies across 36 U.S. states and the District of Columbia are currently testing more than 1,400 self-driving cars, trucks, and other vehicles (4). The private sector is predominately leading these efforts in autonomous vehicles; however, some states such as Texas are aggressively pursuing opportunities with connected vehicle pilots, and a few cities have demonstrated low-speed autonomous shuttles. The federal government is supporting three connected vehicle pilots in Wyoming, New York, and Florida.

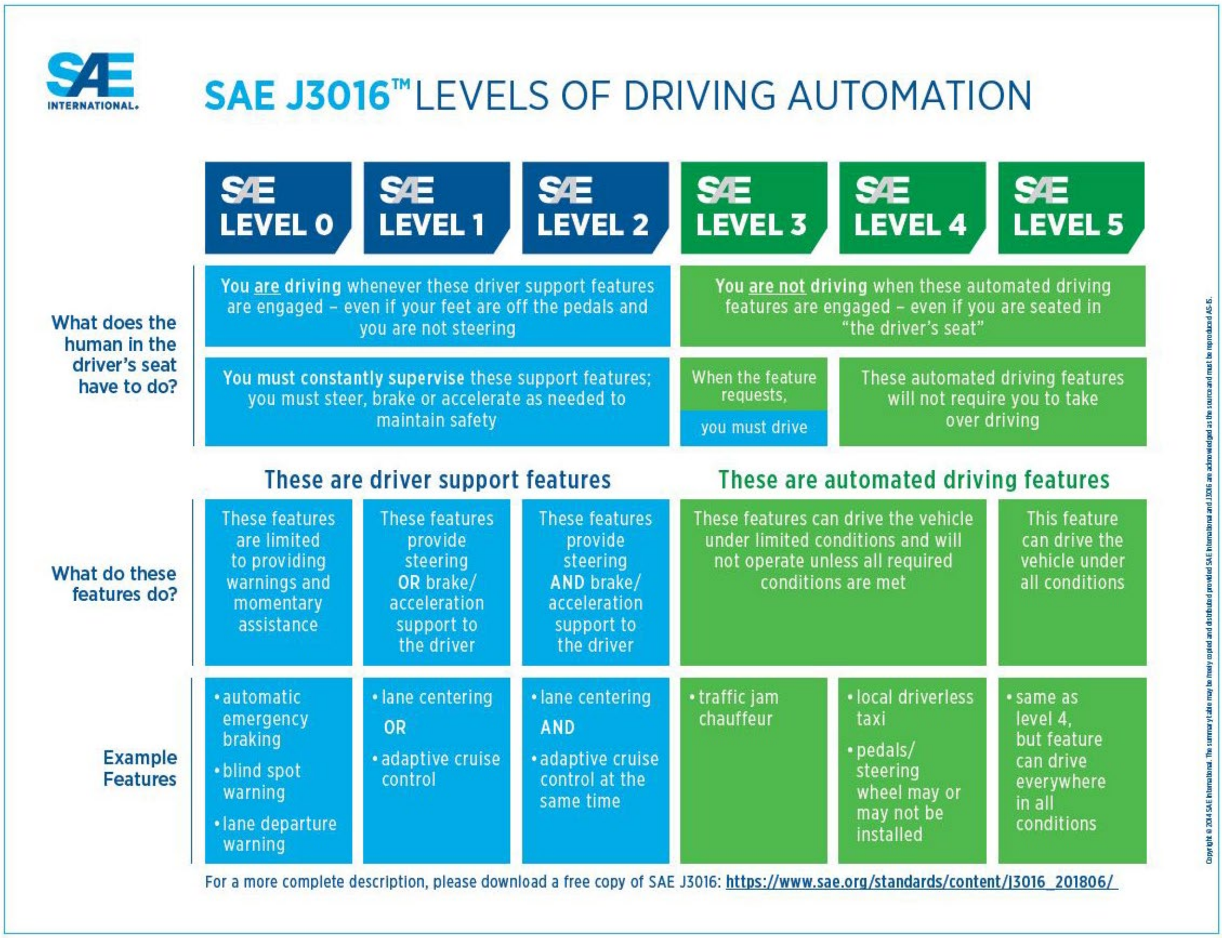
Pilots and demonstrations are imperative to increase public awareness, build trust, and gain acceptance. They also serve to advance technology through operation in specific environments and by identifying challenges and limitations. Likewise, cities and local implementers learn how these technologies can be deployed within their environments and what system changes may be required to accommodate or enhance the deployments. Finally, industry and the private sector benefit by learning, firsthand, how the public reacts to the experimentation. These data indicate the public's acceptance and can serve to guide educational and marketing outreach efforts.

Terminology and Taxonomy

To understand the issues related to public education and acceptance of CAVs and technology, a brief overview of terminology and a taxonomy of technology are necessary. Indeed, the understanding of a common nomenclature is essential to meaningful public education.

CAV technologies are distinct yet complementary. Often the two systems work together to facilitate improved mobility. **Connected vehicles (CVs)** are equipped with communications devices within the vehicle that transmit data to other devices in the vehicle or to external devices that may be in other vehicles or part of the infrastructure or part of another communication service such as a person's smartphone. Applications include everything from traffic safety and efficiency, infotainment, parking assistance, roadside assistance, remote diagnostics, and telematics to autonomous self-driving vehicles and the global positioning system (GPS) (6). Safety applications are designed to increase situational awareness. Specific features include adaptive cruise control, automated braking, incorporation of GPS and traffic warnings, smartphone connections, alerts about hazards, and blind-spot warning systems. CV communication technology (vehicle to vehicle) could mitigate traffic collisions and improve traffic congestion by exchanging basic safety information such as location, speed, and direction between vehicles within range of each other. The technology can supplement active safety features, such as forward collision warning and blind-spot detection (6).

Automated vehicles (AVs) are equipped with technology that moves some or all of the driving responsibility from a human driver to the machines housing the technology. SAE International has defined levels of automation, and these definitions are now routinely accepted by the industry. Figure 1 illustrates the SAE levels of driving automation. A vehicle is considered autonomous, as opposed to automated, when equipped and operating at Level 4 or 5.



Source: SAE International (7)

Figure 1. SAE Levels of Driving Automation.

The complexity of understanding the levels of automation is compounded by the varied marketing and branding names applied to what are collectively known as **advanced driver assistance systems (ADASs)**. The American Automobile Association (AAA) reported that in 2018 at least one ADAS feature was available on nearly 93 percent of new vehicles available in the United States (8). But the lack of standardized naming conventions for ADASs may confuse motorists in understanding and using these systems. Even regulatory agencies such as the National Highway Traffic Safety Administration (NHTSA) and SAE International have multiple names for some automated systems.

Workshop participants at the Advanced Vehicle Technology Consumer Education and Communications Workshop convened by USDOT in July 2019 reported that in addition to different manufacturers using different terms to describe the same feature, manufacturers also use similar terms to describe functionally different systems (9). Additionally, manufacturers typically package and market multiple ADASs under one single brand name that does not sufficiently describe the functionality. This makes it difficult for consumers to research comparable features when considering purchasing a vehicle with one or more ADASs.

Failure to clearly communicate can lead to misuse that may result in system failures that in turn can lead to crashes. This erodes public trust. AAA has advocated for a standard naming convention of all ADASs (8).

While not directly related to terminology, there are also concerns about how a consumer is educated about using an ADAS in a vehicle. Abraham et al. (10) report that in some cases vehicle dealerships might be expected to provide instruction on ADASs. However, no requirements mandate training or education on the part of dealerships or manufacturers. Many consumers that purchase vehicles with ADASs may be left to figure out the intended purpose of a particular ADAS and how it works by reading the manual associated with the vehicle, conducting their own research on the internet, or even relying on friends and family to explain how the systems work. Clearly, technological advances have increased the complexity of operating a vehicle. New operating systems also require new skills and expertise to service and maintain these systems. These are opportunities. The Education Subcommittee can form and lead partnerships that enable dealers, manufacturers, and consumers to create and disseminate educational resources that inform users about the proper use of CAV technology. Similarly, the Education Subcommittee can work with educators and employers to develop curricula and training programs that will train people to meet the needs of this expanding industry, thereby enhancing economic development and employment opportunities.

If a driver does not have full understanding of an ADAS—its purpose and its functionality—this can lead to frustration and/or disappointment with the system and fatigue for the driver. Ultimately, a driver may disable the systems entirely, thereby negating the safety benefits of the ADAS (10).

The connection between public education and acceptance and common terminology may seem obscure, but a common vocabulary is a necessary step in building meaningful public education and outreach programs. A separate paper within this series includes specific definitions of a multitude of terms.

Connected and Automated Vehicles and Mobility

When considering AVs, it is common to first think of self-driving cars. To be sure, popular media and savvy marketing have focused on a future in which people will travel freely while engaging in other, more enjoyable pursuits such as reading, working, or spending time with friends and family. But it is important to present a clear representation of what connected and automated technology encompasses and the plethora of options for mobility across multiple modes. Each application has ramifications for public acceptance.

At some point in the future, the self-driving car, an **autonomous** vehicle with **automated** features, may easily take a single person from his or her home to the workplace in much the same way as it happens today, but CAV technology is being applied to trucks, shuttles, taxicabs, unmanned aerial systems (e.g., drones), transit vehicles, and even neighborhood delivery vehicles. These applications have far-reaching implications for how transportation infrastructure and services are planned, delivered, operated, maintained, and funded. These applications will undoubtedly improve safety by removing the potential for human error. They may also mitigate congestion by maximizing system efficiencies. Land use will likely change. Acres and acres of land currently allocated for vehicle parking can be redeveloped for its highest and best use because autonomous vehicles can now drop people at their destinations and remove themselves from the dense urban core. Transit vehicles may become more efficient as CAV technologies improve operations. Real-time communication can alert a connecting bus that it should wait. Transit riders may take autonomous neighborhood vehicles from their home to a park-and-ride lot for a CV transit trip to downtown. People may decide they no longer need a private automobile and may opt for shared autonomous vehicles.

Autonomous vehicles will offer new freedom to those individuals that suffer from disabilities that make independent travel impossible. Likewise, older adults and youths can gain and maintain independence afforded by CAV technology. This is especially true in suburban and rural areas that offer few modal alternatives. CAV technologies can also make it safer for people that are walking and biking within the transportation network. Technology can alert drivers to pedestrians and cyclists and vice versa.

Autonomy and connectivity are also being deployed and tested in the freight arena. Truck platooning uses CV technology to allow several trucks to travel as a single platoon, thereby increasing efficiency. A single driver leads the platoon. Platooning has the potential to improve the operational efficiency of trucking for the movement of goods. Connected freight vehicles and platooning have the potential to address or eliminate current issues such as driver shortages, freight vehicle parking for mandatory rest periods, and overall job satisfaction in the trucking industry. Additionally, connected freight vehicles continuously provide data about road and weather conditions that can alert other drivers and transportation system operators that may need to initiate proactive measures to mitigate dangers.

Finally, unmanned aerial systems are another mode using CAV technology. From just-in-time grocery delivery to personal transport, these systems will also impact the future of transportation and the movement of goods across the globe.

Of course, for each of the benefits touted, unanswered questions remain. Will autonomous vehicles increase vehicle miles traveled and negatively impact the environment? Will the benefits and burdens be evenly or equitably distributed? Will land use changes exacerbate urban sprawl, or will other policies, programs, and technological advances mitigate these effects? Additionally, technological advances will impact the workforce and necessitate changes in educational programs. Perhaps there will no longer be a need for long-haul truck drivers or local delivery drivers, but there will be a need for workers to implement these systems. New integrated traffic management systems will require expertise beyond traditional civil engineering programs. These approaches are multidisciplinary, encompassing communications, computer science, bio-mechanics, robotics, and many types of engineering, to name a few. This will require changes in educational programming to supply a workforce that has the training and education to operate these systems.

In every application of CAV technology, there are positives and negatives and many unanswered questions. USDOT, state and local governments, and certainly the private sector have collectively committed, either formally or informally, to advancing these technologies. What is necessary for adoption and widespread implementation is public acceptance. Public acceptance is achieved through awareness, education, and trust. Trust may be the biggest factor in acceptance. In this case, the public must trust the technology. They must believe that the implementers, be they private or public, are competent and capable of delivering the anticipated benefits. But the public must also trust that the technology has been properly tested and vetted. The public must trust the integrity of a government charged with protecting and safeguarding the public welfare and have confidence in its ability to act in the public's best interest.

Pilots, demonstrations, and initial first-use operations activities are a means to demonstrate technology, instill confidence, and build trust. Evaluations of the public's response to pilots and demonstrations provide insights into areas of concern or features that generate mass appeal. Additionally, messages used for education and communication can be assessed for effectiveness and may inform future outreach efforts.

Gauging Public Perception

In July 2018, Drive.ai pilot-tested a self-driving shuttle service on public roads in Frisco, TX. Following completion of this pilot, the Texas A&M Transportation Institute (TTI) surveyed the community to gauge the acceptance and public perception of the pilot. TTI researchers found that 54 percent of those surveyed out of the general public (which included people that had not ridden in the vehicle) had a favorable view of AVs after the Drive.ai pilot (1).

MILO pilot-tested a continuous autonomous shuttle service in Arlington, TX, in 2017. Surveys found that 97 percent of riders supported AV generally and that 99 percent of riders felt safe on the MILO shuttle (11).

Surveys from a 2018 Drive.ai pilot in Arlington show similar data. The surveys found 98 percent of riders felt safe in the AV over the course of 760 trips (12).

The surveys after these three pilots indicate that experiences with an AV and riding in an AV have significant impacts on the public's perception and acceptance of CAV technologies and services. People who have experienced AV technologies for themselves tend to feel safe in those vehicles.

An important caveat to reported acceptance and/or willingness to use or purchase is the context in which survey respondents are answering. A person that had a firsthand experience on an AV shuttle will likely have different opinions than a respondent who has not experienced an AV. Likewise, the structure of the question is important in interpreting responses. A question that asks the respondents about the favorability of the pilot can be interpreted in many ways if the question is not explicit. A respondent may reply that his or her impression of the pilot was less than favorable, but that response may not have anything to do with the technology. This respondent may have other issues with the pilot such as the hours it was available or the number of stops it made. Likewise, questions about favorability are very different than questions about perceived safety, as are the reasons for the answers. For these reasons, it is important to carefully scrutinize data surrounding surveys about public opinion to understand intent, context, data collection methodology, and any other extenuating factors. How results are communicated and to whom may also need to be considered. Data presented by the company behind the technology may be viewed with more skepticism than data presented by public agencies. Pilots and demonstrations that are evaluated by objective third parties such as academic institutions are likely to be viewed as the most credible.

Knowledge and Awareness

Public knowledge and awareness of CAV technologies and services are skewed. The public has a greater awareness of AV technology than CV technology. This is likely due to the publicity surrounding AV developments such as Tesla's autonomous features and tests and Google's AV testing. Likewise, private companies—including both technology and automotive manufacturers—spend millions of dollars marketing their innovations. Interestingly, 98 percent of the Frisco survey respondents had heard of self-driving vehicles, but many may have been unaware of the automated features that are already in use in their own vehicles (4). This data point underscores the confusion surrounding the naming conventions for various features. This issue is especially prevalent in vehicles with partial automation capabilities. Misunderstanding and/or misuse of automation features leads to risky driving behavior. Disproportionate media attention surrounding crashes involving vehicles using CAV technologies can erode public confidence in the technology.

In 2018, AAA completed a study that asked participants about their personal vehicle and what ADAS features were installed on the vehicle. The study found that 83 percent of respondents who were asked about adaptive cruise control were first-time owners of the technology, and 52 percent reported that they did not know how the feature worked when they purchased the vehicle, but only 45 percent remembered being offered any training on the technology. Moreover, only a slight majority, 58 percent, answered correctly when asked about the basic functionality of the feature. In the study, 90 percent of respondents were first-time owners of vehicles with lane-keeping assist, and 56 percent reported that they did not know how the feature worked when they purchased the vehicle (13).

Similar confusion surrounds responses about ownership versus use. While automotive manufacturers deploy ADASs on new vehicle models, CAV technology may also be used in mobility as a service. In this scenario, individuals experience CAV technology as a shared mobility option through autonomous shuttles or shared neighborhood vehicles, as opposed to purchasing a private vehicle with these capabilities. Each model will have unique effects on adoption and acceptance.

The public seems to have less knowledge about CV technology. CV technology requires at least some interface with other vehicles, other mobility options, or local infrastructure, such as traffic signals. Uses that include infrastructure are typically initiated by state and local governments rather than the private sector although the private sector is usually a partner in this endeavor. Funding these initiatives through the city or state budgeting process faces the same challenges as all budgeting processes—how much to invest and for what benefit. Consequently, few cities or states have the ability to heavily invest in CV technology as a standard practice. CV applications use technology that allows communication between and among vehicles, other mobility options, infrastructure, and wireless devices to improve the operational efficiency of the transportation network. This efficiency provides many benefits, but the public may be less aware that traffic signals are communicating with one another to maximize throughput on a congested route or to other vehicles, bicyclists, and pedestrians about safety risks at an intersection.

USDOT supports the efforts of education and increased awareness through its pilot programs. USDOT also creates and publishes many informational products such as fact sheets and regular website updates. In many cases, these are targeted to audiences such as policy makers and industry rather than the general public. Therefore, the reach to the general public may be limited. As USDOT pilots in Tampa, FL, New York, NY, and Wyoming are completed, communication about the results should be highlighted to a variety of audiences. This will increase public awareness.

Another indicator of public knowledge around CAV technologies and services is the introduction of university courses about the topic. For example, Slippery Rock University in Pennsylvania offered a literature and creative writing seminar course centered around CAV technologies and services. This enabled students, who were not experts on CAV technologies and services, to better understand what these technologies are and explore the impacts of widespread use of CAV technologies and services in society. The professor of the course, Dr. Patrick McGinty, stated during a webinar he gave with Partners for Automated Vehicle Education (PAVE) that students left the course with a belief that CAV technologies and services are safe and will become widespread in coming years (14).

Sentiment

Surveys have gauged public sentiment for CAV technologies and services, usually conducted as part of pilots or demonstrations. Generally, public sentiment is favorable but cautious, with most survey respondents believing that CAV technologies and services have the potential to make roads safer. However, more research needs to be done. More exposure through demonstrations and pilots will foster understanding that will help the public feel comfortable using CAV technologies and services. Use or experience with CAV technologies suggests a greater likelihood of acceptance. Survey respondents who had experiences with CAV features tended to feel comfortable and safe using them. In TTI's survey of the Frisco Drive.ai pilot, 78 percent of respondents who had taken a ride in an AV had positive opinions of AVs, whereas 49 percent of respondents who had not taken a ride in an AV had positive opinions of them (1).

Cost seems to be a concern when determining the rates of adoption and use of CAV technologies and services. Many vehicles equipped with CAV technologies are expensive due to the newness of the technology, making them inaccessible for many people to own. TTI researchers for the Frisco Drive.ai survey found that 60 percent of respondents would own a Level 4 or 5 AV if cost were not a barrier (1). However, the main concern of survey respondents was simply how new the technology is and the belief that there needs to be more testing and pilots of CAV technologies and services before the respondent would feel comfortable owning or using a vehicle equipped with CAV technology. In public-opinion research about the likelihood of owning a Level 4 or 5 vehicle, most people did not think it was worth the expense.

Dr. McGinty, who taught the AV seminar at Slippery Rock University, found that one of the major concerns his students voiced about CAV technologies and services was about how prepared society is, as a whole, to accept and adopt these innovations (14). The course discussed some of the implications relating to job losses due to widespread CAV use and the impacts that those economic changes might have on society.

Overall, the general public tends to agree that CAV technologies and services will likely make roads and travel safer for all. Safety is seen as the predominant benefit. However, most people also believe that more testing is needed, and pilots should be conducted before CAV technologies and services are widely used and adopted.

Cost may be another perceived barrier to the acceptance and adoption of CAV technologies and services. In fact, many ADASs now come standard on new vehicles, so in effect, consumers may already be investing in AV technology. Cost is also a factor for public agencies deploying CV technology. To be most effective, these deployments will require extensive investment and the cooperation and coordination among many governmental entities.

Trust

While the public purports to acknowledge the safety benefits of CAV technology, their trust in those technologies seems more limited. Zmud et al. (13) summarize the results of the annual AAA vehicle technology survey fact sheets from 2016 through 2019 shown in Table 1.

Table 1. AAA Survey Trust in CAV Technology.

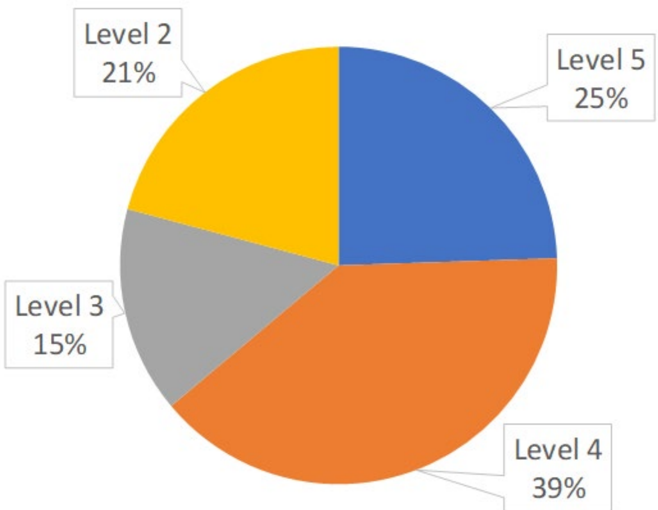
Survey Factor	Phase I	Phase II	Phase III	Phase IIIb	Phase IV
Survey period	Jan. 2016	Jan. 2017	Dec. 2017	April 2018	Jan. 2019
Number of respondents	1,832	1,012	1,004	1,014	1,008
Percent of respondents afraid to ride in a fully automated vehicle	75%	78%	63%	73%	71%
Percent of women afraid to ride in a fully automated vehicle	82%	85%	73%	83%	N/A
Percent of men afraid to ride in a fully automated vehicle	67%	69%	52%	63%	N/A
Percent of respondents who want at least one ADAS feature on their next vehicle	61%	59%	51%	55%	N/A

N/A means not applicable.
Source: Zmud et al. (13)

The annual AAA survey was repeated in January 2020, but a change in methodology means the results year to year are not comparable for 2020. However, of the 1,301 people surveyed in 2020, only 12 percent say they would trust a vehicle to drive itself while they are in it. Roughly about half of respondents want laws to ensure self-driving cars are safe. Respondents are also concerned about the vulnerability to hacking of self-driving vehicles, and 44 percent want easy-to-understand information about how self-driving vehicles will work (15).

Results from the open-ended text responses in the Frisco Drive.ai pilot indicate that not many people prefer or would accept Level 5 vehicles yet because they did not fully trust the technology. However, a small percentage (19 percent) were ready to fully cede control of driving to an AV because they trust the technology (1). Acceptance of Level 4 or 5 technology was highest among young respondents, early adopters of technology, and those that already own vehicles with an ADAS (1).

The Frisco Drive.ai pilot also asked respondents what level of technology they trusted most to reduce the likelihood of being in a crash. Figure 2 provides these results.



Source: Zmud and Sener (1)

Figure 2. Percentage of Respondents Indicating Level of Autonomy Most Trusted.

The authors note some insightful open-ended text responses from queries about the rationale for their choice:

- "People who reported most trusting Level 5 thought the technology would be fully tested to be safe, would best address human driving errors and distractions, and would represent the most advanced safety features.
- "People who most trusted Level 4 did not believe in the readiness of the Level 5 technology and felt Level 4 is the next best thing in terms of advanced safety features.
- "People who most trusted Level 2 and Level 3 also did not believe in the technology readiness of higher levels of automation, and they were not psychologically ready for self-driving cars" (1).

These responses are telling in that there seems to be a willingness to accept the technology to improve safety, yet when asked to personally subscribe, there is not yet enough trust in the technology. This study and the others that have been conducted that ask similar questions all point to increased acceptability due to increased awareness and knowledge. Pilots and demonstrations provide that opportunity to engage the public with the technology and allow them to experience it firsthand. This can and does increase acceptance.

This is not to say that all issues of trust in the technology can be overcome with pilots and demonstrations. Indeed, results of the 2020 AAA survey indicate the public has other concerns that are somewhat outside the technology itself, including a reliance on the government to ensure their safety by enactment of laws.

Education and Outreach

The largest efforts to educate and reach the public have been in areas implementing pilot programs. Outreach efforts generally preceded the launch of the pilot, and marketing continued throughout the pilot. Following the pilots, research has been conducted to assess the user's experiences, but very little research has been conducted to evaluate the messaging associated with the pilots. CAV technologies necessitate high-level key messages, primarily related to the expected benefits of the technologies, with safety being the biggest benefit lauded by the public and the private sector. Other implementations will benefit from a more concerted effort to research what has been effective and with which specific audiences.

Strategies for Success

Development of outreach strategies should be informed by baseline research. Efforts should be made to understand what the public knows and understands about CAV technologies. This foundational research can identify misperceptions and address them in message development. Issues that are important to specific audiences can be identified so that message platforms can speak directly to them. Additionally, how and by whom messages are communicated are important. In areas where there is a low level of trust or confidence in government, a public agency may be well served to enlist a spokesperson that is respected in the community to speak on its behalf.

These are important considerations in the development of any education and/or outreach program. But education and outreach are also needed within the public agencies that are instrumental in the deployments and within the state and local governments that make the deployments possible. It is imperative that leadership identifies and communicates a strategic direction for a CAV technology program. Indeed, each agency should consider how CAV technologies can contribute to achieving broader agency goals. This must be communicated within and beyond the agency so that everyone supports the common objective. Specific performance measures should be developed so that progress can be reported to the public. Advancement toward achieving goals and objectives will demonstrate commitment to the program(s) and ensure resources are available to continue.

Education and outreach will need to extend beyond the identification of benefits. Other questions loom that are important to the public and other agencies. Currently, questions surround the legal and regulatory nature of CAV technology. These public policy issues are the responsibility of elected officials, but the public will require answers in order to become supportive. Education and outreach should address the following broad categories:

- Agency implications.
- Freight implications.
- Economic implications.
- Environmental implications.
- Societal implications.

Each category has numerous known questions as well as questions that are unknown at this time. There are currently answers to some but not all questions. The Education Subcommittee will continue to compile and research issues that arise and will disseminate resources that serve to foster continuous education. Education and outreach will function in a continuous feedback loop (Figure 3) where issues are identified, solutions proposed, input gathered, and more questions identified.

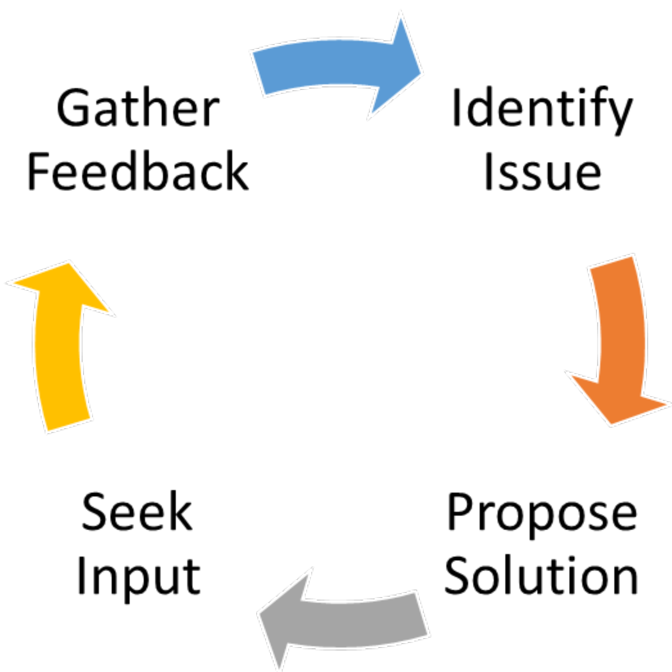


Figure 3. Continuous Feedback Loop.

This list is certainly not exhaustive. Some questions can be answered fully or partially now. The Education Subcommittee intends to serve as a purveyor of information. As research is completed and resources are developed, the subcommittee will convey findings and tools to relevant agencies, partners, and the public.

Pilot Outreach

Outreach and messaging strategies for CAV pilot programs have varied from program to program. Some common outreach techniques across pilot programs were to create webpages for pilots as well as social media profiles and hashtags to promote the pilots online. Also providing opportunities for local media outlets to report on the pilots, such as hosting press conferences or drafting news releases, was a common method of outreach. Both the Tampa, FL, and Wyoming USDOT pilots coordinated with local press and media outlets to promote the pilot programs to their communities.

Holding demonstrations of CAV technology was another way that agencies promoted their pilot programs to the public. The Drive.ai pilot program hosted training on its technology specifically to first responders, which was a unique and targeted outreach strategy to reach key stakeholders and community members. The USDOT pilot programs in Wyoming and Tampa, FL, also hosted public demonstrations at local showcases and public events as a means of conducting public outreach. Table 2 shows the messaging the Wyoming Department of Transportation (WYDOT) used when promoting the pilot program to different audiences, from stakeholders to the media and general public. WYDOT tailored messages to each audience, based on their common goals and interests. The primary messages focus on the pilot's ability to improve safety for drivers and road users, while the secondary messages target each audience's interests and/or pain points (16).

Table 2. WYDOT Messages and Audiences.

Message	Audience						
	Federal/State/Local Government	Stakeholders	Trucking Industry	Media	General Public	Other CV Pilots & International Partners, Academia, Researchers	Vendors
Primary Message theme							
The Wyoming CV pilot uses state of the art technology to make our highways safer and reduce accidents.	X	X	X	X	X	X	X
The Wyoming CV pilot saves lives and improves traffic flow at the same time.		X	X	X	X		
Wyoming's CV pilot technology is easy and safe to use, and protects drivers' privacy.		X	X	X			
Secondary Message themes							
The Wyoming CV pilot improves efficiency, helps business continuity and productivity, and reduces traffic congestion by minimizing weather-related accidents.	X	X	X	X			
The Wyoming CV pilot is an innovative and worthwhile usage of taxpayer resources for the public good.	X			X	X		
The Wyoming CV pilot is a model for how to use innovative technology to improve quality of life for drivers, businesses, and residents.	X	X				X	

Source: Garcia et al. (16)

Research from pilots about user experience indicates that younger audiences, people that identify as early adopters, and those familiar with ADASs are the most accepting of CAV technology. Some audience segmentation has occurred and seems consistent across pilots. Additional efforts can build on these findings.

Moving Forward in Texas

The Education Subcommittee should necessarily focus initial efforts on outreach and education. *Outreach* establishes initial contact with constituents and stakeholders, providing awareness and information. This lets the audience determine their level of interest, position, and any actions they might wish to take. *Education* provides context to the audience. Education explains why the audience should be interested. It gives stakeholders the tools to be better informed but also provides knowledge that can be used to inform others. Education is not about persuasion but merely providing information.

At this stage, a few key messages should be developed. With input from the entire Texas CAV Task Force, key messages about CAV opportunities in Texas should be developed and propagated. What are the four or five key things that the state wants to convey about CAV development in Texas? The subcommittee will continue to develop tools to inform and educate by providing materials, resources, and outcomes of pilots and demonstrations. In addition to providing information, the subcommittee should help the audiences understand why this should be important to them and their role in advancing CAV technologies in Texas. Developing key messages, providing context, and defining roles are crucial first steps. The key messages provide consistency. Secondary messages can speak to specific audience interests, but the key messages should remain the same regardless of the messenger or the medium. This preserves the integrity of the message and reduces any confusion. Market research can assess the impacts of these efforts.

Education and outreach about CAV benefits and opportunities in Texas will benefit from fundamental communication best practices for effectiveness, including:

- Audience identification—Identifying the audience and their motivations will enable development of messages that empower supporters, convince uncertain individuals, and minimize the impact of opponents.
- Market research—Learn about the audience, what they care about, and what messages will best convince them.
- Message design—Several principles define the best ways to design a message, including keeping it simple, staying positive, using metaphors, making it personal, and offering a call to action.
- Message delivery—Inconsistent delivery will derail even the best messages. Continually and consistently repeat the message so it will not get lost (2).

A stakeholder engagement plan and a complementary public outreach plan can guide development of materials and provide a comprehensive roadmap for education and outreach efforts beyond the key messages. Development of such plans will ensure that messaging is consistent across formats. The plans will also serve to allocate adequate time and resources by identifying specific actions. The plans can prioritize activities. Subplans should be developed for different audiences. For example, a plan specific to the legislature should focus on why investment in these activities is important and how legislation can support that; a plan aimed at local government should include development of information that addresses local issues and why these activities are important.

As outreach occurs, it is imperative that its effectiveness be measured. This evaluation will reveal what messaging is resonating and what methods are most effective. Evaluation can identify gaps in knowledge that can be addressed. Evaluations can also uncover misperceptions that can be addressed before they become set in the public's opinion. Systematic and consistent evaluation will reveal trends over time that will aid in understanding outreach effectiveness. Polls and surveys are useful methods of evaluation, but qualitative research through structured interviews and focus groups allows for a deeper understanding of why a person feels a certain way about something. These rich data will inform subsequent outreach efforts. To be clear, this evaluation should focus not only on the public's perception of CAV technology but also on the effectiveness of the educational information that is being provided. Not assessing the effectiveness of outreach and educational campaigns is a misstep that results in wasted time and resources.

In addition to tailoring messages for specific audiences, information should be provided in a manner that is appropriate to the audience. In all instances, the information should clearly communicate the key messages. It should be comprehensible to the intended audience without the need for additional research. Messages should be available in the media of choice for the receiver and should be accessible and available as requested by the receiver. Fact sheets, frequently asked questions (FAQs), myths, and truths are products that provide information in an easy-to-manage and -digest format. Moreover, this information can be provided in many forms such as printed materials, a website, videos, and social media.

An outreach and education program should focus on the success of pilots and actual business operations deployments. At the same time, the program should not neglect challenges encountered and the lessons learned from those challenges. Research has shown that acceptance is greater with exposure. Pilots and demonstrations are important to give all audiences a firsthand experience.

The Education Subcommittee, with its broad multidisciplinary representation, is the forward-facing entity responsible for executing an engagement plan. The subcommittee's charge and responsibility are to develop tools and resources that allow for meaningful engagement. The engagement plan lays out what, when, where, and how engagement will occur—the *tactics*. But an engagement strategy establishes the reason for engagement—the *why*. The subcommittee has the cachet to engage with everyone in the mobility ecosystem to discuss the *why* of engagement. For example, this could include representatives of the education sector, advocates for the disabled community, and first responders as communities that may not immediately see the relevance to their missions.

Resources

This section lists resources with more information about CAVs, pilot programs, public opinion, and outreach.

Fact Sheets

Intelligent Transportation Systems Joint Program Office. *New York City, New York: Connected Vehicle Pilot Deployment Program*. U.S. Department of Transportation.
https://www.its.dot.gov/factsheets/pdf/NYCCVPliot_Factsheet.pdf.
This fact sheet provides an overview of the USDOT New York City CV pilot program, including the types of CV technology being tested and the locations in the city where the pilot is being run.

U.S. Department of Transportation. ***What Public Officials Need to Know about Connected Vehicles.***
https://its.dot.gov/factsheets/pdf/JPO_PublicOfficials_v6.pdf.
This USDOT fact sheet provides some key information specifically for public officials regarding CVs, including how they operate, the benefits of CVs, and how to prepare for their deployment.

Intelligent Transportation Systems Joint Program Office. ***Wyoming Connected Vehicle Pilot Deployment Program.*** **U.S. Department of Transportation.**
https://www.its.dot.gov/factsheets/pdf/WyomingCVPilot_Factsheet.pdf.
This fact sheet provides an overview of the USDOT WYDOT CV pilot program, including where it is being implemented and what technology is being used.

Intelligent Transportation Systems Joint Program Office. ***Tampa, Florida, Connected Vehicle Pilot Deployment Program.*** **U.S. Department of Transportation.**
https://www.its.dot.gov/factsheets/pdf/TampaCVPIlot_Factsheet.pdf.
This fact sheet provides an overview of the USDOT Tampa, FL, CV pilot program, including what types of technology are being used and where the pilot program is being run.

Reports

Perkins, L., N. Dupuis, and B. Rainwater. ***Autonomous Vehicle Pilots across America: Municipal Action Guide.*** **National League of Cities, 2018.**
https://www.nlc.org/sites/default/files/2018-10/AV%20MAG%20Web.pdf.
This report summarizes a variety of AV pilot programs being run across the United States. The report identifies specific programs and provides a brief overview of each one.

Websites/Webpages

Partners for Automated Vehicle Education. Homepage.
https://pavecampaign.org/.
The PAVE website describes the organization's goal to increase public knowledge and understanding of AV technology. The site hosts a variety of resources including news articles and webinars relating to AV technology.

National Highway Traffic Safety Administration. AV TEST Initiative.
https://www.nhtsa.gov/automated-vehicles-safety/av-test-initiative-tracking-tool.
This NHTSA webpage shows the AV pilot programs currently running across the United States. The map shows the location of the pilots and provides links to further information about each pilot program.

U.S. Department of Transportation. ***Preparing for the Future of Transportation: Automated Vehicles 3.0.*** **October 4, 2018.**
https://www.transportation.gov/av/3.
This webpage provides an overview of the USDOT AV 3.0 program. The page includes a presentation outlining the goals of the program, the different levels of automation, and the next steps in moving toward accepting and implementing AV technologies across the country.

National Operations Center of Excellence. Vehicle to Infrastructure Deployment Coalition.
https://transportationops.org/V2I/V2I-overview.
This webpage provides an overview of the Vehicle to Infrastructure Deployment Coalition, a group designed to encourage discussion and collaboration among stakeholders about issues surrounding vehicle-to-infrastructure program deployments.

Intelligent Transportation Systems Joint Program Office. Public Availability of Connected Vehicle Documents. U.S. Department of Transportation.
https://www.its.dot.gov/pilots/cv_docs.htm.
This USDOT webpage provides information about documents from USDOT CV pilot programs that are publicly available and where to find them.

Wyoming Department of Transportation. Wyoming DOT Connected Vehicle Pilot.
https://wydotcvp.wyoroad.info/.
This website for the WYDOT pilot project includes many resources and how to get involved.

Webinars

Partners for Automated Vehicle Education. *PAVE's Virtual Panel: The View from the Rider's Seat: Insights from Early AV Customer Experience.* June 17, 2020.
https://www.youtube.com/watch?v=P5DwbiopdWw&feature=youtu.be.
This PAVE webinar provides information on how users and drivers are responding to AV technology developments. Speakers include a PAVE representative/moderator, an executive from Lyft, an executive from the APTIV AV developer, and a representative from a data company called Dataspeed.

Partners for Automated Vehicle Education. *PAVE's Virtual Panel: Engaging Stakeholders, Building Trust.* May 27, 2020.
https://www.youtube.com/watch?v=eUim4ErXIR8&feature=youtu.be.
This PAVE webinar provides information and discussion on how to better engage stakeholders and gain public trust with regard to AV technology. Speakers include representatives from Mothers Against Drunk Driving, a non-profit called SF New Deal, the National Federation of the Blind, and a representative from an AV developer called Cruise.

Podcasts

Davis, K. *Mobility: Decoding the Secret Sauce*. Anchor, 2020.
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This podcast discusses the issues surrounding marketing and communications with regard to mobility issues, including CAV technologies and pilots.

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City of Frisco, Texas. ***Driverless Car Company Drive.ai Rolls Out in Frisco*****. August 1, 2018.**
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New York City Department of Transportation. ***NYC DOT Connected Vehicle Pilot—Part 1*****. July 17, 2017.**
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This video describes the applications being tested in a New York City Department of Transportation pilot.

Wyoming Department of Transportation. ***WYDOT Connected Vehicle Pilot Program Deployment.*** **July 21, 2017.**
https://www.youtube.com/watch?v=9TPluh2dm20.
This video describes the Wyoming I-80 pilot project.

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Metropolitan Transit Authority of Harris County. ***Ride into the Future*****.**
https://www.ridemetro.org/MetroPDFs/GettingAround/Autonomous-Shuttle-Brochure.pdf.
This brochure includes FAQs, safety tips, and shuttle stops.

Special Events

City of Arlington. Drive.ai On-Street Autonomous Shuttle Program. May 2019.
http://events.r20.constantcontact.com/register/event?oeidk=a07egaqd92md68bbb26&llr=8fn9w5iab.
The City of Arlington, TX, hosted a special event to debut the Drive.ai self-driving, ride-hailing service in the entertainment district.

Press Releases

City of Austin. ***Austin to Pilot INRIX Platform for Autonomous Vehicle Deployment*****. July 17, 2018.**
https://www.kxan.com/news/local/austin/austin-joins-pilot-program-to-help-manage-self-driving-vehicles. This press release provides information about the INRIX Road Rules program.

City of Austin. ***Austin-Bergstrom Begins Autonomous Vehicle Testing.*** **August 2, 2019.**
https://austintexas.gov/news/austin-bergstrom-begins-autonomous-vehicle-testing.
This press release provides information about the Easy Mile EZ10 pilot at the Austin-Bergstrom International Airport.

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APPENDIX D

Connected and Automated Vehicle Data Issues and Opportunities

Texas CAV Task Force White Paper Subcommittee on Data, Connectivity, Cybersecurity, and Privacy

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Acknowledgments

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's

performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the "CAV Terminology" white paper for a full listing of terms and definitions used in this developing technology ecosystem.

List of Terms and Acronyms

ATCMTD	Advanced Transportation and Congestion Management Technologies Deployment
AV	automated vehicle
BSM	basic safety message
CAV	connected and autonomous vehicle; also, connected and automated vehicle
CCPA	California Consumer Privacy Act
CV	connected vehicle
C-V2X	cellular vehicle to everything
DAVI	Data for Automated Vehicle Integration
DOT	Department of Transportation
DSRC	dedicated short-range communications
EDR	event data recorder
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FTC	Federal Trade Commission
GDPR	General Data Privacy Regulation
GPS	global positioning system
HAV	highly automated vehicle
HD	high definition
IEEE	Institute of Electrical and Electronics Engineers
ITS	intelligent transportation system
ML	machine learning
NCSL	National Conference of State Legislatures
NHTSA	National Highway Traffic Safety Administration
OBU	onboard unit
ODD	operational design domain
OEM	original equipment manufacturer
PII	personally identifiable information
RSU	roadside unit
SPaT	Signal Phase and Timing
TxDOT	Texas Department of Transportation
USDOT	U.S. Department of Transportation

V2C	vehicle to cloud
V2I	vehicle to infrastructure
V2N	vehicle to network
V2P	vehicle to pedestrian
V2V	vehicle to vehicle
V2X	vehicle to everything

Executive Summary

Automated vehicles (AVs) represent a switch in driving responsibility from human to machine to improve driving safety and efficiency. Connected vehicles (CVs), in contrast, have internal devices that enable wireless communication with devices internal and external to the vehicle for enhanced safety and other functionality. Questions about AVs and CVs do not now revolve around whether such technologies should or should not be implemented; they are already with us. Current decision making should revolve around how to shape their deployments to benefit Texas and its citizens.

In Texas, public agencies and private companies are partnering to ensure a safe and successful integration of both AVs and CVs into the state's transportation ecosystem. Such technologies bring opportunities to reduce crashes and improve roadway safety, along with quality-of-life, economic, and environmental benefits. However, a safe and successful integration depends on understanding and addressing an array of critical policy and planning issues related to vehicle data.

AVs and CVs use an array of sensors and other technologies to collect vast amounts of data from their own vehicles and the environment around them, as well as rely on volumes of different types of data from various sources to operate safely. Thus, data privacy, data security, and cybersecurity are important concepts in the context of AVs and CVs. *Data privacy* relates to the collection, access, and use of sensitive personal information, such as geolocation, driver behavior, or biometrics. Without necessary protections to prevent breach of personal information emanating within and from AVs and CVs, harm could occur to numerous individuals, organizations, and agencies. *Cybersecurity* refers to security protections for systems in the vehicle that actively communicate with other systems or other vehicles. Recent data indicate that cyberattacks aimed at vehicles are on the increase. Some of the biggest risks relating to data privacy or cybersecurity are related to data security (or access). Risks exist if AV or CV data are accessed by third parties that are not committed to privacy principles or that cannot protect vehicle systems from cyberattack.

AVs and CVs bring many data challenges due to the sheer volume of data that is involved. And the testing phases of AVs and CVs (which are where the industries are focused now) generate more data than the operational phases. Therefore, confronting the aforementioned data issues, as well as the critical issue of who owns these data, is a priority now. Data ownership directly affects who can collect, access, use, and benefit from vehicle data. It is an evolving challenge that needs to be understood and eventually resolved. Data ownership, and other data issues, requires ongoing collaboration among public- and private-sector stakeholders to address such questions as:

- Which entities are collecting, storing, and using what AV and CV data?
- What data gaps exist that hinder innovation and furthering the public interest?
- What data can be shared or exchanged to facilitate the safe and successful integration of AVs and CVs into the transportation ecosystem?

Answering these questions will begin to clarify how Texas can continue to be an innovation leader in these emerging vehicle technologies to the benefit all Texas citizens.

Introduction

In Texas, the push toward emerging transportation technologies, like connected vehicles (CVs) and automated vehicles (AVs), is strong. Such technologies have the potential to greatly reduce crashes and improve roadway safety over time. These technologies also provide opportunities to reimagine personal mobility and commercial transport with quality-of-life, economic, and environmental benefits.

Texas's push is guided by circumstances that make it among the nation's innovation leaders. The state has a start-up culture, world-class research universities, and a skilled workforce. Early on, the Texas Technology Task Force and the Texas Innovation Alliance established a solid foundation for research, collaboration, and innovation across the state. The Texas AV Proving Ground Partnership was one of 10 pilots designated by the U.S. Department of Transportation (USDOT) in 2017 to encourage testing and information sharing around these technologies. USDOT later rescinded all U.S. proving grounds. State laws allow automakers and others to test AVs without a driver inside and the use of connected braking systems on the state's roads and highways. Texas has an active 5.9-GHz intelligent transportation system (ITS) license and has numerous active CV deployments. The Texas Connected and Autonomous Vehicles (CAV) Task Force is building on the momentum already established in the state. This white paper presents a technical brief on key issues relating to CV and AV data, reflecting the combined perspective of a specialized subcommittee of the Texas CAV Task Force.

AVs and CVs are distinct technologies. AVs represent a switch in driving responsibility from human to machine to improve driving safety and efficiency. CVs, in contrast, have internal devices that enable wireless communication with devices internal and external to the vehicle for enhanced safety and other functionality. While CVs are expected to enhance the benefits of vehicle automation, the deployment of CV technology is not a precondition to the deployment of AVs. In other words, not all AVs will be CVs, and not all CVs will also be AVs. AVs and CVs use an array of sensors and other technologies to collect vast amounts of data from their own vehicles as well as the environment around them. The data that AVs and CVs capture, store, and share will play a critical role in their testing and deployment and in optimizing vehicle and network performance, enhancing the vehicle user experience, and improving safety. However, data-related technical and policy issues may pose challenges in both AV and CV development and public acceptance.

This paper starts with a brief description of AVs and CVs and related policy issues as foundational information for the subsequent discussion of data issues and to place the data issues in the context of the current state of technology development. The paper identifies the types of data that CVs and AVs use to operate safely, as well as data that they generate. The paper also raises opportunities and challenges, and provides examples of data-sharing and data-exchange activities. These technologies have facilitated (and will continue to enable) collaborative associations among automakers, other original equipment manufacturers (OEMs), technology firms, communications firms, and other businesses outside the realm of the traditional automotive industry; and among various public-sector entities.

Connected Vehicles

> *CVs have internal devices that enable wireless communication with devices internal and external to the vehicle for enhanced safety and other functionality.*

According to the Institute of Electrical and Electronic Engineers (IEEE), the term *connected vehicles* refers to "applications, services, and technologies that connect a vehicle to its surroundings" (1). More specifically, a CV has various communication devices (embedded or portable) that enable in-car connectivity with other devices present in the vehicle and/or enable wireless connection of the vehicle to external devices, networks, applications, and services. In 1996, General Motors, working with Motorola, pioneered the first CV service. Its OnStar telematics system was a subscription-based safety service that enabled voice calls to a call center that contacted emergency responders when an airbag was deployed (2). Over time, the functions supported by vehicle connectivity have changed. For example, soon after the OnStar launch, global positioning system (GPS) locational systems were added to support navigation, safety, and anti-theft services. The increased functionality occurred as an ever-increasing collection of technologies has been pushed to market by OEMs and other entities, such as navigation services (e.g., Garmin) and technology companies (e.g., Apple CarPlay and Android Auto).

Types of CV Applications

Today, CV systems support a variety of safety, convenience, navigation, infotainment, and vehicle diagnostics applications. Because the CV ecosystem is complex, there have been many proposed approaches for categorizing the functions supported by CV systems. The Information Technology and Innovation Foundation identified four types of CV applications based on how they connect with the vehicle, the user, a service, or other vehicle and infrastructure systems (3). The four types are described as follows and also summarized in Table 1:

- **In-vehicle** applications involve communications that primarily occur within the vehicle between its various parts and are oriented toward safety or maintenance. Since 1996, cars have been legally required to have onboard units (OBUs), which gather information on engine problems, maintenance status, fuel efficiency, etc. These data are sent wirelessly to vehicle manufacturers or their third-party suppliers, and also may be accessed by drivers through aftermarket devices and smartphone apps.
- **Driver and passenger** applications relate to navigation, entertainment, or remote control of the vehicle. These applications also connect directly to personal devices, enabling internet services within the vehicle.
- **Third-party service** applications support a range of both private-sector services (e.g., in-car payment services, vehicle recovery systems, roadside assistance apps, and insurance) and public-sector services (e.g., mileage-based usage fees, road pricing fees, and smart parking).
- **Infrastructure and other road user** applications refer to an evolving group of vehicle communications, known as vehicle-to-everything (V2X) technologies.

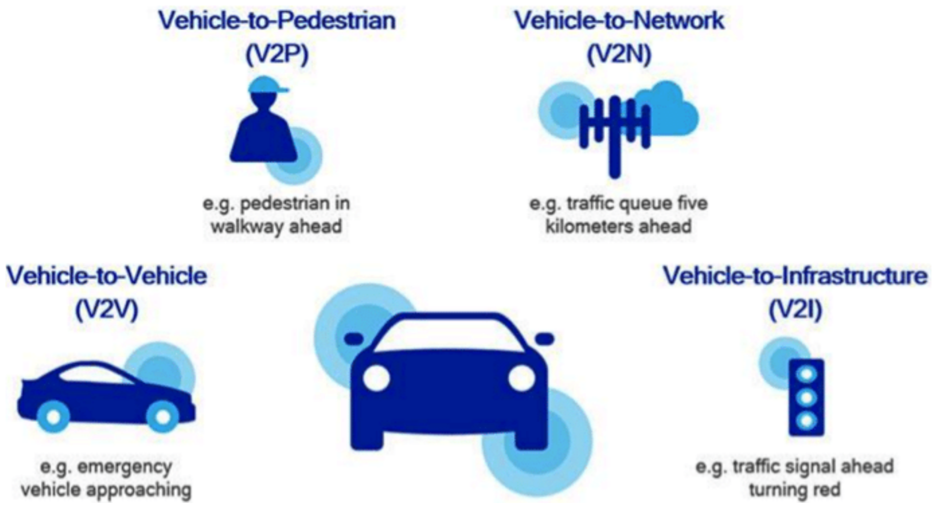
Table 1. Types of CV Applications Based on Type of Interaction.

Type of CV Application	Description	Examples
In-vehicle	Applications that involve interactions between different components within the vehicle	Diagnostics, predictive maintenance, and safety applications such as blind-spot warnings
Driver and passenger	Applications that involve interactions with a user within the vehicle	Entertainment, navigation, personal device integration, remote control, Apple Car Talk, and Google Android Auto
Third-party service	Applications that facilitate transactions with third parties using the vehicle	In-car payment services, roadside assistance, insurance, and tolling
Infrastructure and other road user	Applications that primarily operate through interactions with other vehicles and connected infrastructure; also known as V2X	Crash response, adaptive traffic lights, emergency vehicle warnings, queue and work zone warnings, and integrated smart home technologies

Source: McQuinn and Castro (3)

The fourth type of CV applications, V2X, is powerful because it takes advantage of the synergy between different communications technologies, making the whole greater than the sum of its parts (see Figure 1). Such communication technologies include (4):

- **Vehicle to vehicle (V2V)** enables vehicles to exchange data (e.g., speed, location, and heading) wirelessly in real time for safety purposes via the 5.9-GHz spectrum band.
- **Vehicle to infrastructure (V2I)** enables vehicles to exchange data with road infrastructure and roadside units (RSUs) for safety, environmental, mobility, and other benefits.
- **Vehicle to pedestrian (V2P)** enables network infrastructure to communicate vehicle actions to different vulnerable road users, such as pedestrians and bicyclists.
- **Vehicle to network (V2N)** allows vehicles to use cellular networks to communicate with a V2X management system or enables vehicles to interact with other vehicles and road infrastructure.
- **Vehicle to cloud (V2C)** leverages V2N access to broadband cellular mobile networks to offer data exchange with the cloud. Many of the V2V, V2I, or V2P applications conceptualized as being handled via OBUs/RSUs can be handled via these cellular vehicle-to-everything (C-V2X) connections.



Source: Malinson (5)

Figure 1. V2X Communication Technologies.

CV Connectivity

Connectivity for the different types of applications is enabled through various means. At its simplest, some CVs offer Bluetooth® to link wirelessly to other devices, such as smartphones, within short distances of the vehicle to enable hands-free calling, locking and unlocking mechanisms, etc. Beyond this, there have been two categories of vehicle communications (6).

> *The two basic types of V2X communications are:*
> - *DSRC using the underlying radio communications provided by IEEE 802.11p.*
> - *Cellular-based V2X (C-V2X).*

The first is dedicated short-range communications (DSRC), which uses the underlying radio communication provided by IEEE 802.11p. It has extremely low latency (i.e., it is fast) and has minimum delay (i.e., enables high data transmission rates), which are required to safely manage multiple vehicles in traffic in real time. Up until recently, DSRC has been the only V2X communication technology available.

The second is C-V2X. In 2016, the standards organizations that develop protocols for mobile telecommunications (3rd Generation Partnership Project) published V2X specifications based on wireless broadband communication as the underlying technology, known as C-V2X. In addition to the direct communication (i.e., V2V and V2I), C-V2X also supports wide-area communication over a cellular network (V2N). 5G is expected to be a key enabler of more reliable cellular communication for V2X applications. With lower latencies, C-V2X may allow more robust V2C operations (i.e., direct from the cloud to vehicles) (7). As discussed in a subsequent chapter, the Federal Communications Commission (FCC) adopted new rules in November 2020 opening up the communications spectrum once reserved for DSRC to include 5G communications, which will have the long-term effect of sunsetting DSRC in favor of C-V2X.

A third connectivity path is also emerging; in-vehicle Wi-Fi is becoming standard in many newer vehicles.

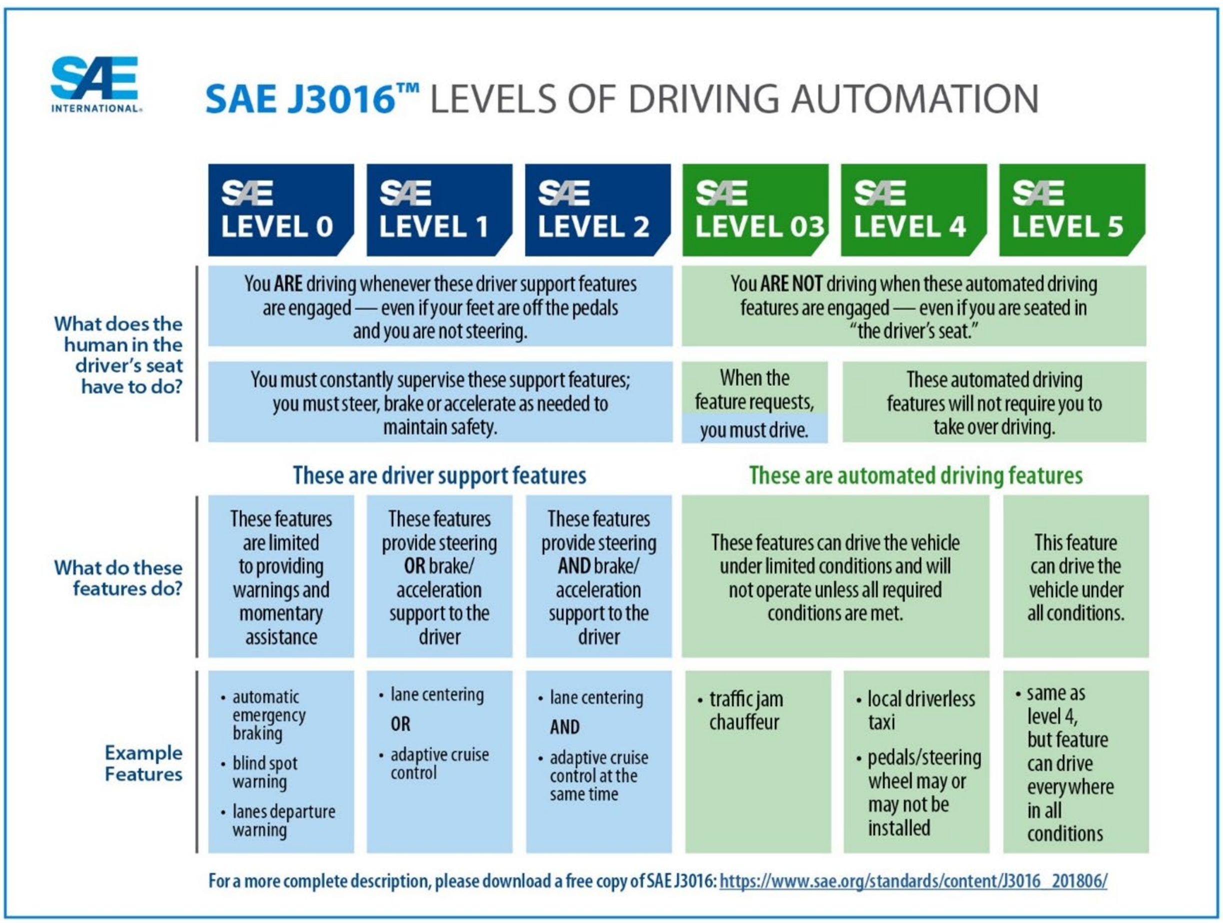
Automated Vehicles

While CVs offer potential safety and other benefits by communicating with other vehicles, road infrastructure, cellular networks, and the cloud, AVs offer potential safety and other benefits by gradually removing the primary source of driving accidents and crashes: a human driver. AVs represent a switching of the responsibility for the driving task from human to machine.

AVs represent a switch in driving responsibility from human to machine to improve driving safety and efficiency. While CVs may enhance the benefits of AVs, they are not a precondition for AV deployment.

Levels of Automation

As Figure 2 illustrates, SAE International has developed six levels of automation, which are differentiated based on whether the human in the driver's seat needs to drive or not (8). AVs comprise Levels 1–5. Autonomous vehicles (i.e., capable of operating without human involvement) comprise Levels 4 and 5. Level 0 does not qualify as an AV since the technology does not drive the vehicle. The current fleet operating on U.S. public roads consists primarily of vehicles ranging from Levels 1 to 3.



Source: SAE International (8)

Figure 2. SAE Levels of Driving Automation.

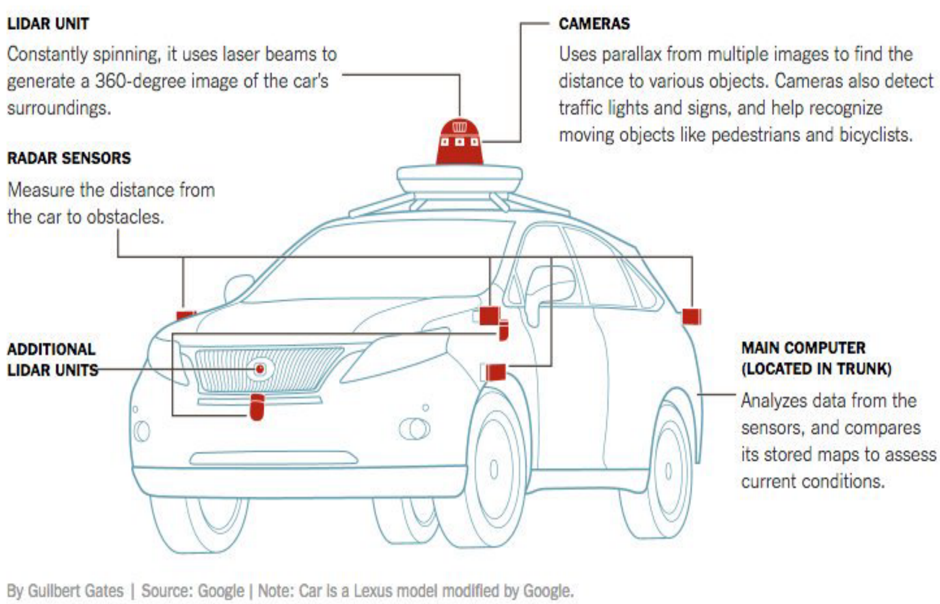
Highly automated vehicles (HAVs) rely heavily on machine learning (ML) systems. AVs are first programmed with basic knowledge, and then through ML they draw from both accumulated experiences and continual feedback to detect patterns, adapt to circumstances, make decisions, and improve driving performance to achieve the performance level of an HAV.

Although in 2016 many auto industry leaders expected Level 4 AVs to be commonplace on highways in the early 2020s, this does not seem as likely today. Acknowledging that building ML systems for AVs that can replicate the nuanced cognitive decisions made by human drivers is more difficult than originally claimed, OEMs are pushing out their timelines for higher-level AVs (9). However, there are many current demonstrations of Level 4 fleet services. For example, robotaxis in the form of minivans are serving paying customers without a trained vehicle operator through a smartphone app in Chandler, AZ (10). In Texas, autonomous shuttles are currently serving passengers at the Dallas-Fort Worth, TX, airport (11) and delivering groceries for Kroger in Houston, TX (12). The next section discusses the regulatory environment that is enabling testing and demonstrations of higher levels AVs in Texas.

Technologies Enabling AV Driving

AV driving functionality is handled through a variety of technologies (see Figure 3), including the following (13):

- **Radar** (radio waves) measure distances between the car and obstacles around it.
- **Lidar** (laser sensors) build a 360-degree image of the car's surroundings.
- **Cameras** detect people, lights, signs, and other objects.
- **Satellites** enable GPS to pinpoint a vehicle's position.
- **High-definition (HD) maps** determine and modify routes the car takes.



Source: Gates (12)

Figure 3. AV Technologies.

To attain human-like perception, AVs need to capture extensive surrounding information from the myriad of its AV technologies. Each of the radars, cameras, and other sensors used by the vehicle for autonomous driving purposes has limitations, so the sensor data need to be combined in order to achieve safe-driving functionality. For example, while camera systems can recognize other vehicles, lidar applications are better for accurately calculating the position of the vehicles, and radars are better at estimating speed (14). Each of these sensors compiles a lot of data because AVs rely heavily on ML algorithms, and ML in turn relies heavily on observed data. Vehicles at lower levels of automation may rely on one or more data inputs to enhance driving safety. However, at the higher levels of automation, vehicles must be able to make sense of a constant flow of information.

The function, hardware, and software of AV systems vary widely across the industry, but the way in which they operate is largely consistent (15):

1. The environment is monitored using a combination of sensors (e.g., cameras, radar, and lidar) (see Figure 4).
2. An onboard computer processes the information relayed from the sensors and combines it with GPS data, the known vehicle state (e.g., speed, orientation, steering, and brake application), and three-dimensional mapping data to estimate the vehicle's absolute position.
3. These steps create a virtual representation of the world, which includes the subject vehicle and all other road users, objects, and their intended path.
4. The vehicle determines an appropriate course of action (e.g., avoiding a collision) while obeying traffic laws.

Source: Burke (16)

Figure 4. AV Images from Camera, Radar, and Lidar, Respectively.

The onboard computer processes the different data inputs in step 2 using sensor fusion (14). The sensor inputs and other information, such as digital maps, feed into a high-performance, centralized computer that combines the relevant portions of data for the vehicle to make driving decisions. Given the number of sensors built into autonomous vehicles and the amount of data they generate, affirming data ownership (e.g., the owner of the vehicle or the company operating the AV fleet) of the synthesized or fused data and determining relevant privacy protections are important but as of yet unresolved considerations, as discussed in a subsequent chapter.

In addition to the aforementioned policy issues, there are unresolved technical issues associated with onboard sensor fusion. For example, the data streams processed using data fusion are different from each other in many ways, such as in the format of the data or in their temporal/spatial resolution. The data streams need to be aligned with each other to make autonomous driving reliable, accurate, and safe.

There are several initiatives to develop open data standards to make fusion efforts easier while offering data privacy protections. For instance, a consortium comprised of German companies and research institutions has developed a fusion platform with open interfaces (i.e., Open Fusion Platform) that enables automobile manufacturers and suppliers to cost-effectively integrate data from highly and fully automated self-driving technologies (17). In addition, AV companies, such as Waymo, Audi, Ford, Toyota, Lyft, Argo AI, and NuTonomy, are opening up their AV data sets to tackle ML challenges (18, 19). The most prevalent model for this is a data exchange, a form of data sharing, in which free, curated data sets reveal a segment of a company's data while proprietary information is protected.

Government Regulation of CVs and AVs

The United States has a complex regulatory environment, with local, state, and federal government agencies, as well as Congress, having authority to create rules that may govern CV and AV operations.

In general, development and deployment of CVs and AVs can be shaped to benefit society through positive collaboration among stakeholders, appropriate policies over time, and regulation when needed. The United States has a multilayered environment for regulation of vehicles and infrastructure, with federal, state, and local government creating rules for various aspects of vehicle travel and its supporting technology. In addition, Congress has the authority to establish federal regulatory frameworks or standards for vehicles, such as safety or emissions standards.

USDOT, through the National Highway Traffic Safety Administration (NHTSA), has responsibility for the safety of motor vehicles (20). FCC is responsible for management of the electromagnetic spectrum, upon which many of the technologies central to enabling CV and AV functionality depend (21). States are responsible for such items as licensing of vehicles and operators, minimum vehicle standards, insurance, roadway usage, and traffic laws, as well as other issues including privacy, security, criminal law, and environmental regulation (20). Unless states adopt laws that override local regulation, local ordinances govern many aspects of everyday vehicle use, such as speed limits, parking, ride services, and the like. In addition, states and local governments are responsible for planning, building, managing, and operating transit and the roadway infrastructure.

Federal Activities

Connected Vehicles

In December 2019, FCC adopted a notice of proposed rulemaking that would split the 5.9-GHz band between ITS uses like safety-related vehicle communications and unlicensed operations like Wi-Fi (22, 23). The proposal reduces the amount of spectrum available for ITS uses from 75 MHz to 30 MHz and would allow both C-V2X devices and DSRC devices to use it. The residual 45 MHz would be opened up to non-transportation uses. Two decades ago, the 5.9-GHz band was reserved solely for DSRC to enable safety-related vehicle communications, but FCC reasoned that it has remained largely untapped for that purpose and wanted to spur innovation in cellular and Wi-Fi technologies.

FCC adopted the new rules in November 2020 in order to, as it stated in its order, "begin the transition away from DSRC to C-V2X technology" (24). Under the new rules, ITS services must vacate the lower 45 MHz of the band within one year.

In 2016, NHTSA and USDOT released a notice of proposed rulemaking that would require all new light vehicles, after the year 2023, to be equipped with V2V communication technology for safety purposes. However, this mandate was not enacted. While the clear intent of USDOT is to facilitate CV development and testing, it is being done without rulemaking in the following ways:

- **USDOT's Connected Vehicle Pilot Deployment Program** has been sponsoring CV projects in New York, NY, Tampa, FL, and Wyoming. The pilots focus on testing V2I, V2V, and V2X applications that could facilitate safety, mobility, and environmental benefits. Findings from the pilots should be available in 2022. (More information is available at https://www.its.dot.gov/pilots/.)
- **USDOT's Advanced Transportation and Congestion Management Technologies Deployment** (ATCMTD) grants have been funding projects for the past five years that deploy cutting-edge technologies, including CV technologies. Eligible grantees include state departments of transportation (DOTs), local governments, transit agencies, and metropolitan planning organizations. (More information is available at https://cms8.fhwa.dot.gov/newsroom/us-department-transportation-awards-433-million-advanced-transportation-and-congestion.)
- **A Signal Phase and Timing (SPaT) challenge** was issued by the V2I Deployment Coalition to state and local DOTs to achieve deployment of DSRC-enabled infrastructure with SPaT broadcast capability. The goal was approximately 20 signalized intersections in each of the 50 states by 2020. (More information is available at https://transportationops.org/spatchallenge.) Austin was the first city in Texas to enter the challenge; it was succeeded by Houston and San Antonio (25).
- **A CV Pooled Fund Study** has been created by a group of state, local, and international transportation agencies and the Federal Highway Administration (FHWA) in order for infrastructure providers to play a leading role in prototyping and testing practical, infrastructure-oriented CV applications that lead to deployment. Twenty-five state DOTs (including the Texas Department of Transportation [TxDOT]), one county DOT in Arizona, and Transport Canada are involved. (More information is available at https://highways.dot.gov/research/projects/connected-vehicles-pooled-fund-study.)
- **FHWA's National Highway Performance Program** allows funding for infrastructure-based ITS capital improvements, including the installation of V2I communication equipment, as does **FHWA's Surface Transportation Block Grant Program.** (More information is available at https://www.fhwa.dot.gov/fastact/factsheets/nhppfs.cfm and https://www.fhwa.dot.gov/fastact/factsheets/stbgfs.cfm.)

As of August 2020, USDOT estimated that there were 67 operational and 76 planned CV deployments in the United States (26). Many of these are associated with testbed, SPaT, and ATCMTD deployments. Texas has three ATCMTD grants:

- 2016—ConnectSmart: Connecting Transportation System Management Operations and Active Demand Management.

- 2017—Texas Connected Freight Corridors: A Sustainable Connected Vehicle Deployment.
- 2018—I-10 Corridor Coalition Truck Parking Availability System.

Despite two decades of federal efforts and funding, V2I technology has been slow to become extensively deployed. There is a financial aspect to this. Financing V2I technology requires large upfront investments of capital and resources, along with ongoing maintenance and operations. But there are also institutional issues that some suggest stem from a lack of clearly defined government and private roles (27).

Automated Vehicles

So far, NHTSA has not issued safety regulations or standards that specifically regulate driverless vehicles (19). In 2017 and 2018, NHTSA offered voluntary guidelines for industry in designing best practices for testing and deploying AVs on the surface transportation system (28, 29). In 2019, NHTSA detailed principles to protect users and communities (e.g., safety, cybersecurity, and data privacy), promote efficient markets (e.g., remain technology neutral), and facilitate coordinated efforts among federal agencies to support AV technology growth and leadership (22).

However, in early 2020, NHTSA issued a notice of proposed rulemaking that would modernize numerous Federal Motor Vehicle Safety Standards for vehicles equipped with automated driving systems (30). For example, NHTSA proposed to apply front passenger protection requirements to the traditional driver seating position when a steering wheel is not present in the vehicle. Also, in November 2020, NHTSA requested comment on the development of a framework for automated driving system safety, which would define, assess, and manage the safety of automated driving system performance while ensuring the needed flexibility to enable further innovation. (More information is available at https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/ads_safety_principles_anprm_website_version.pdf.)

Around the same time as USDOT's early guidance documents were being released, Congress was attempting to address the need for a federal framework for autonomous vehicle regulation. The House of Representatives passed the SELF DRIVE Act, and a separate bill, the AV START Act, was reported from a Senate committee. Neither bill was enacted. However, in September 2020, the SELF DRIVE Act was reintroduced with the rationale that the coronavirus crisis has made the need for self-driving cars more apparent as people seek contactless ways to get around and have goods delivered (31).

State and Local Activities

Connected Vehicles

The National Conference of State Legislatures (NCSL) provides current information on state legislative efforts related to CVs and AVs. (More information is available at https://www.ncsl.org/research/transportation/autonomous-vehicles-legislative-database.aspx.) According to this database, eight states have pending legislation relating to infrastructure and CVs. These tend to address cybersecurity and privacy, as well as enable vehicle platooning and sensor connectivity. Four states (including Texas, as discussed in the next section) have enacted legislation.

Automated Vehicles

To date, 29 states and Washington, DC, have passed legislation relating to AVs. Most of these legislative and regulatory actions solely address testing and liability issues within the state. So far, legislation has been state specific, with no attempt at coordination across states. To expand AV ubiquity in the future, states will need to come to agreement on how vehicles should behave when operating autonomously to facilitate AV travel across state lines.

Texas Context

Connected Vehicles

Texas is one of 32 states with an active 5.9-GHz ITS license and has numerous active CV deployments. In addition to the three ATCMTD projects listed previously, Signal Phase and Timing (SPaT) and connected corridor projects are operating in Arlington, Austin, College Station/Bryan, Houston, and San Antonio. (More information is available at https://www.txdot.gov/inside-txdot/division/planning/innovative-projects.html.)

> *In Texas, the push toward AVs and CVs is strong with a market-based regulatory approach that is enabling many pilot deployments for AV and CV technology advancements.*

According to the NCSL database, in 2017, Texas enacted legislation that defined a "connected braking system" as a system by which the braking of one vehicle is electronically coordinated with the braking system of a following vehicle, and allowed the use of a connected braking system on states roads. In 2019, a bill failed that would have regulated the operation of public transit vehicles equipped with connected braking systems.

Automated Vehicles

Until 2017, Texas law did not authorize AVs for testing or operation on Texas roads (32). However, during the 2017 legislative session, lawmakers passed a bill that allowed AVs to test and drive on Texas roads. The law required AVs to follow the authorized rules of the road in the state, to be insured, and to be equipped with an electronic recording device. This law defined an "automated motor vehicle" as having an automated driving system, which was itself defined as hardware and software that are collectively capable of performing all aspects of an entire driving task without the intervention or supervision by a human operator. The law also specified that the automated driving system is considered to be licensed to operate the vehicle as long as it is engaged (32).

In the last legislative session, two bills were filed but failed to be enacted. The bills were meant to tweak Texas's self-driving car laws. One would have increased liability of manufacturers in the event of a crash involving an AV, and another would have required providers to equip vehicles with a failure alert system and the latest software.

Since 2017 when AV testing was authorized under state law, Texas has had more than 20 AV pilots and demonstrations. (More information is available at https://cavtaskforce.texas.gov.) They have primarily been pilots in simplified or geofenced operational design domains (ODDs) like university campuses or business/entertainment centers. The ODD specifies the conditions under which the vehicle is able to operate with respect to roadway types, speed range, weather conditions, and other constraints. The majority of these AV pilots have been either to test and enhance the safety functionality of the vehicle or for data collection to train the vehicle's ML algorithms to accurately detect and decode objects such as pedestrians, street signs, and lane markers.

Data Privacy, Data Security, and Cybersecurity

Data Privacy Risks

Data privacy is defined as the capability of individuals to "determine for themselves when, how, and to what extent information about them is communicated to others" (33). It is important to consumers because a breach of personally identifiable information (PII) can cause harm, such as the risk of identity theft and other types of fraud. But it is also important to organizations and agencies because unauthorized collection or inadequate protection of PII introduces multiple risks like reputational damage, fines, lawsuits, and other possible penalties.

> ***Data privacy*** *relates to the collection, access, and use of sensitive personal information.*
> ***Data security*** *refers to the processes that limit access to sensitive personal information.*
> ***Cybersecurity*** *refers to measures used to protect a computer system (including a vehicle) against unauthorized access by a hacker.*

Data privacy is associated with data ownership. The question of data ownership directly affects who controls PII and, therefore, who can collect, access, use, and benefit from it. Individuals are assumed to own personal information about themselves, and thus are typically asked to opt in or give consent for activities (e.g., for telematics applications) that may capture it.

As vehicles become increasingly connected and automated, the volume of data they collect, combine, store, and communicate increases. Complex questions arise as to whether such data constitute PII and are subject to privacy protections (34). A single piece of data can be PII, such as a Social Security number. Likewise, multiple pieces of data when merged can be PII, even when the individual pieces would not be. As an example, a license plate number does not identify a specific person; rather, it identifies a vehicle. However, the license plate number may be linked or associated with an identifiable person through a linkage with other information, such as date of birth, gender, and zip code. Once information is associated with a specific individual, it becomes PII. With all the data collected by AVs and CVs, identifying the driver (and even the passengers) is possible although OEMs and companies operating fleets seek to mitigate this risk.

Often, we think that the privacy impact of collecting personal data can be reduced if data are anonymized (i.e., identifying information is removed) prior to subsequent processing and use of the data. But in recent years with increasing implementation of data science (which involves algorithm development, data inference, and predictive modeling), researchers have shown that anonymized data can be easily re-identified through linkages among multiple data. For example, European researchers have shown that a data set with 15 demographic attributes would identify 99.9 percent of Massachusetts residents and that fewer attributes would be needed for smaller geographies (35). As another example, Massachusetts Institute of Technology researchers used just four anonymized spatiotemporal data points (i.e., a person's location at a given time) to uniquely re-identify 90 percent of the 1.1 million individuals in a financial transaction database (36). Moreover, the researchers found that knowing the price of a transaction dramatically increased the likelihood that someone could be re-identified. The implication for CV and AV data is that even if PII is stripped from an original data set, a risk of exposure of sensitive information still exists if those data are stored, analyzed, and reused without adequate protections.

Data Privacy Protection

In the United States, there is no comprehensive federal law governing the collection, use, and sale of personal information, such as the European Union's General Data Privacy Regulation (GDPR). (More information is available at https://gdpr-info.eu/.) The GDPR was designed to harmonize data privacy laws across all European Union member countries and to provide broad data protections and rights to individuals. There is the potential for large fines and reputational damage for those businesses found in breach of the GDPR.

The United States has a patchwork of federal and state laws to address data privacy protections.

In early 2020, the European Data Protection Board published draft guidelines on the processing of personal data in the context of CVs and mobility-related applications. Notably, the draft guidelines require granular consent to collect both personal and non-personal data from CVs. Companies appear to be complying with these requirements. (More information is available at https://edpb.europa.eu/our-work-tools/public-consultations-art-704/2020/guidelines-12020-processing-personal-data-context_en.)

Federal Statutes

Unlike the comprehensive approach to data privacy regulation in Europe, federal statutes and regulations addressing privacy issues in the United States are generally tailored to specific sectors, purposes, and types of information. The Driver Privacy Act of 2015 is one example. It stipulates that a vehicle's event data recorder (EDR) data, which is produced immediately before and during an accident such as the date, time, vehicle, and engine speed, belong to the owner or the lessee of the vehicle in which the EDR is installed (37). There is no similar type of law that pertains to other types of data coming from vehicles. Another example is the Health Insurance Portability and Accountability Act, which governs the use and disclosure of an individual's health information (37).

Those entities not subject to industry-specific regulation typically use the Federal Trade Commission's (FTC's) *nonbinding* Fair Information Practice Principles to guide their data privacy practices (34):

- **Notice:** Provide clear and conspicuous notice of what information is collected, how it is collected, how it is used, and whether it is shared with other entities.
- **Choice:** Offer choices as to how PII is used beyond the use for which the information was provided (e.g., to consummate a transaction).
- **Access:** Provide reasonable access to the information that is collected, including an opportunity to review information and to correct inaccuracies or delete information.
- **Security:** Take steps to protect the security of the information collected from consumers.

Federal law does not require companies to have a privacy policy or to notify consumers of their privacy practices.

State Statutes

States laws have added to the patchwork approach to privacy protection in the United States. Many individual states have adopted their own privacy protection laws. The California Consumer Privacy Act (CCPA), which was inspired by the European Union's GDPR, is the most comprehensive of the state legislation. The CCPA began being enforced on July 1, 2020 (38). Although this law was not designed specifically for vehicles, it covers the collection of PII by vehicle systems and through phone or telematics connections (39). The law grants California residents several rights, including the right to request what PII a business has about them, to opt out of the sale of their PII, and to request their PII be deleted. Nevada and Maine have also recently passed stringent data privacy laws, but these laws apply only to online data collection. California's law pertains to online and offline businesses.

At least 11 states, including Michigan, Massachusetts, Hawaii, Minnesota, and Washington, have proposed data privacy laws during the 2019 or 2020 legislative sessions. None were signed into law. Of all the states, North Dakota has considered what happens to the data produced by self-driving cars (40). A bill, enacted in 2017, calls for the state DOT to study "the data or information stored or gathered by the use of those vehicles." A failed bill from the same year would have granted ownership of data to the vehicle's owner and allowed sharing of data with the consent of the customer.

Texas's data privacy legislation is confined to breach notification (which really pertains to data security) and requires businesses to disclose "as quickly as possible" any breach to individuals whose sensitive personal information was, or is believed to have been, acquired by an unauthorized person (41). An enacted 2019 bill introduced a timing requirement for notification of 60 days of a breach occurring. Separately, the bill created an advisory council to study data privacy laws and produce recommendations regarding protections.

Industry Efforts

Twenty OEMs developed privacy principles for vehicle technologies and services in 2014 and reviewed these again in 2018 (42). The auto industry privacy principles have been in effect for all model year 2017 vehicles and beyond. Overall, the privacy principles require clear and prominent notices about the collection of information, the purposes for which it is collected, and the types of entities with which the information is shared. The OEM's privacy principles require consent from the vehicle owner for sharing information with third parties. These privacy principles are enforceable against the signatory OEMs by FTC. The auto industry was considered to have addressed protecting consumer privacy in a proactive manner by developing and committing to the privacy principles, which were still considered best in class at the 2018 review compared to other industries.

Data Security

Data security is directly associated with data access. *Data access* refers to a user's ability to retrieve data stored within a database or other repository. Entities that have data access can move, use, or manipulate the stored data. There are varying levels of data access that range from totally open to restricted access (34). EDR data are an example of data with restricted accessed; that is, the data are only accessed via specialized software with the expressed consent of the vehicle owner or lessee.

At the other end of the spectrum is open data, which implies that data are available to be freely used, reused, and redistributed by anyone. (More information is available at http://opendatahandbook.org/ guide /en/what-is-open-data/.) OpenStreetMap, a collaborative project to use crowdsourced geodata to create a free editable map of the world, is an example of totally open data. (More information is available at https://www.openstreetmap.org/about) Standards for open data are critical to ensuring privacy protection.

Levels of data access between open and controlled require some sort of membership or user authentication. An example is Uber Movement data where Uber makes its trip data available via a public website to users who request and receive approval to access it. (More information is available at https://movement.uber.com/?lang=en-US) Another example is the General On-Demand Feed Specification, which is a membership-based organization that is developing an application programming interface to enable discoverability of on-demand vehicles. (More information is available at https://mobilitydata.org/.) The Open Fusion Platform is a type of access-controlled secure data platform.

Cybersecurity Risks and Protections

Cybersecurity, in the context of vehicle systems, refers to security protections for systems in the vehicle that actively communicate with other systems or other vehicles (43). In 2019, there were 176 digital and electronic cyberattacks aimed at vehicles, more than double the 78 attacks from the previous year (44). The incidents ranged from stealing cars by hacking keyless entry fobs to tracking trucks by compromising online fleet services. More attacks were conducted by malicious actors than by researchers and white-hat hackers.

Three main risks are associated with hacking CVs or AVs:

- The hacker might gain access to the vehicle through keyless entry bypass.
- The hacker might attempt to take control of the vehicle remotely.
- The hacker might attempt to access the user's personal (or sensitive) information, which could then be used for phishing attempts or other kinds of fraud.

While cybersecurity issues are a challenge for CVs, security becomes a bigger concern with Level 4 and Level 5 AVs, in which software and connectivity play a much bigger and more critical role for the safe driving of vehicles. Unlike traditional vehicles, CVs and AVs may also be vulnerable to cyberattacks that can spread from vehicle to vehicle.

Underscoring the increasing severity of vehicle cybersecurity risks, in 2020 the United Nations issued—and 53 countries adopted—a new regulation that requires vehicle makers in jurisdictions in Japan, South Korea, and the European Union to secure CVs from cybersecurity threats (45). While the United States participated in discussions, it did not vote. Therefore, U.S. vehicle manufacturers are not held to the United Nations regulation. However, those that sell vehicles in jurisdictions under the cybersecurity regulation must comply.

In the United States at the national level, NHTSA has issued nonbinding guidance to the automotive industry for improving motor vehicle cybersecurity (46). NHTSA's guidance focuses on a layered solution to harden the vehicle's electronic architecture against potential attacks and to ensure vehicle systems take appropriate actions in the event that an attack is successful. The guidance suggests that the automotive industry follow the National Institute of Standards and Technology's documented Cybersecurity Framework, which is structured around the five principal functions—identify, protect, detect, respond, and recover—to build a systematic approach to developing layered cybersecurity protections for vehicles. In addition, both FTC and USDOT have endorsed voluntary information sharing of cybersecurity threats through industry groups. The SELF DRIVE Act, reintroduced in 2020, will require manufacturers to create cybersecurity policies on how they will respond to cyberattacks for vehicles that are highly automated.

Cybersecurity protections have also been introduced at the state level. In 2020, California became the first state to regulate the cybersecurity standards of connected devices (47). It requires reasonable security on any Internet of Things device to prevent unauthorized access, modification, or information disclosure. Oregon passed a similar law soon after.

Some of the biggest challenges relating to data privacy or cybersecurity protection are related to data security. Risks are associated with who has access to or can access sensitive data, such as geolocation, driver behavior, or biometrics. Risks exist if such data are accessed by third parties that are not committed to privacy principles or who cannot protect the data from a hack. As an example, in November 2020, Massachusetts passed a ballot measure to require auto manufacturers that sell vehicles with telematics systems in the state to equip them with a new standardized open-access data platform (48). Beginning with model year 2022, vehicle owners and independent repair facilities will be able to retrieve a vehicle's mechanical data and run diagnostics through a mobile-based application. A concern is that auto repair facilities without robust security processes could leave consumer data—and the vehicles themselves—vulnerable to cybersecurity threats. NHTSA has raised concerns this ballot initiative would prohibit manufacturers from complying with both existing federal guidance and cybersecurity best practices.

CV and AV Data Use and Data Generation

Data Used by CVs and AVs

CVs and AVs, in similar and different ways, combine a variety of technologies and sensors to transmit information about their position and to perceive their surroundings, including DSRC and cellular communications, radar, lidar, computer vision, sonar, and GPS, among others. Shimada et al. (49) identified four types of data that CVs and AVs use to operate safely. Table 2 presents these data types and offers descriptive information about them. Not all entities conducting testing may be using all of the types of data listed.

The data are both static and dynamic (50):

- **Static data** are collected from various sources over time, stored, and subsequently analyzed and/or aggregated.
- **Dynamic data**, sometimes referred to as *data in transit*, are often used in real time without necessarily being stored. This results in hyper-local and hyper-current data.

Table 2. Types of Data that CVs and AVs May Use to Operate Safely.

Data Type	Description	Example	Source	Use
Permanent static	Digital map data	HD geospatial detail for streets	• Private third party • Generated by vehicle sensors	Enable lane-accurate positioning/localization
Transient static	Roadside infrastructure	Road signs, landmarks, and permitted routes	• Road operators	Parking/no-parking zones and notice of speed changes
Transient dynamic	Traffic conditions, road conditions, and environmental conditions; traffic signals	Existence of a slippery road	• Road operators • Private third party • Generated by vehicle sensors	Existence of work zones/lane changes; enable V2I signal phase
Highly dynamic	Movements of vehicles, pedestrians, etc.	Wrong-way driver	• Generated by vehicle sensors	V2V and V2P warnings

Source: Shimada et al. (49)

As Table 2 shows, CVs and AVs use data from different sources to operate safely. Generally, the sources are either on board (i.e., generated by) the vehicle or externally sourced from other vehicles, private third-party providers, or road operators. When operating, the vehicle prioritizes or first acts on the onboard data, that is, the data coming from vehicle sensors, cameras, etc. (51). When externally sourced data are available, such as HD maps, the vehicle uses them to support or complement the sensor data. Such redundancy is important. The trick is diversity (i.e., different types of sensors and data) and redundancy (i.e., overlapping sensors and data) that can verify that what a car is detecting is accurate (13).

Data Generated by CVs and AVs

As vehicles continue to become more automated and more connected to each other, surrounding infrastructure, mobile devices, the cloud, they will use significantly more data to operate safely. They will also generate and record many types of data as they operate on roads. Some of these data are user generated such as driver/passenger identity, use patterns of in-vehicle apps, service information (e.g., payment of tolls and parking reservations), or direct communications from the vehicle (e.g., calls, texts, and emails). These data can be provided by pairing the vehicle with a mobile phone device or through user interaction with the vehicle. Other data are vehicle generated. These data include vehicle measures, vehicle safety data, environmental probe data, vehicle diagnostics data, vehicle emissions data, and biometrics data (e.g., fingerprints or facial patterns). The vehicle-generated data are produced from advanced sensors, processors, enhanced driver interfaces, and other OBUs that are able to record and deliver data internal and external to the vehicles, such as ITS equipment distributed along the roadside such as traffic detectors and traffic signals.

Data ownership is an important aspect of data generated by CVs and AVs. Data ownership is complicated and nuanced, and often data ownership is in the eye of the beholder. Research among OEMs, data aggregators, and owner/operators found that (34):

- OEMs acknowledge that the owner or lessee of the car is the owner of the connected car data; however, OEMs are able to access and control the data through user agreements. Privacy principles are used to provide transparency to their data collection, use, and sharing practices so as not to discourage customers from opting into the agreements. Customer trust in terms of opting in is essential for the OEMs' ongoing use of the data to improve their automotive products and develop new customized offerings.
- Data aggregators consider themselves to be the owners of the information that they sell that is derived from the CV or AV data. These data have been gathered from many sources, processed, and formatted into new information products. While they may not be the owners of the source data, they believe they are the owners of the new information products that they create.
- Owner-operators consider themselves to be the owners of the data collected by their sensors. Since the data are recorded by sensors outside the vehicle, they view the data as fair game. Broadcast data are viewed as public information.

Given these different views on data ownership, does it matter? It matters because ownership of data is tantamount to control, determining who can process, use, and share the data. Ownership also implies who can profit from it. However, just as important, ownership implies a broader responsibility—data stewardship—where the owner must consider the consequences of how the data are used, particularly how a particular use might impact data privacy or data security.

Table 3 identifies and describes the main types of CV- and AV-generated data. The information is presented to reflect the type of data that *might be possible* to collect and share; not all AV and CV companies conducting testing will be collecting all of the data identified. In addition, while immediate owners/stewards are identified in the table, there may be additional owners and nuances to ownership that are not referenced and that will need to be addressed in the long term.

A comparison of Table 2 and Table 3 shows much overlap in the data a vehicle uses to operate safely and the data generated while it is operating.

Table 3. Main Types of Data Generated by CVs or AVs.

Data	Description	Owner/Steward	Potential Users
Safety	Static data. Environment and vehicle data associated with safety situations.	• Vehicle owner/ OEM of vehicles • Application developer	• State and local policy makers • Federal policy makers • State and local transportation infrastructure owners and operators • Law enforcement • Insurance companies
Diagnostic	Static data. Technical vehicle status (e.g., engine performance and tire pressure level).	• Vehicle owner/OEM	• OEM • Current vehicle owner • Auto repair facilities • Vehicle inspection agencies
Road infrastructure	Static data. Road infrastructure conditions (e.g., road geometry and markings).	• Vehicle owner/OEM • Manager of back-office data management system or data warehouse	• Traffic data aggregators • State and local infrastructure owners and operators • Mapping aggregators
Biometrics data	Static data. Face, iris, voice, and fingerprints.	• Vehicle owner/OEM	• Law enforcement • Insurance companies • Health or medical companies
Location	Static and dynamic data. GPS coordinates, mileage, routes taken, and time spent at locations.	• Vehicle owner/OEM	• Traffic data aggregators • Mapping aggregators • State and local transportation infrastructure owners and operators • Insurance companies
Driving behavior	Static and dynamic data. Speed, acceleration, travel times, volumes, occupancy, and use of autonomous functions.	• Vehicle owner/OEM • Manager of back-office data management system or data warehouse	• Traffic data aggregators • State and local transportation infrastructure owners and operators • Insurance companies
Service information	Static and dynamic data. Payment of tolls, calculation of insurance premiums, and parking reservations and fees.	• Vehicle owner/OEM • Application developer	• Toll road or road pricing operations • Parking lot owners • Insurance companies • Location-based services
Traffic and road conditions	Dynamic data. Vehicle, people movements, wait time in highway entrance/exit, traffic density per highway lane, average time for red traffic lights, and road surface weather conditions (e.g., icing).	• Vehicle owner/OEM • Manager of back-office data management system or data warehouse	• Traffic data aggregators • State and local transportation infrastructure owners and operators

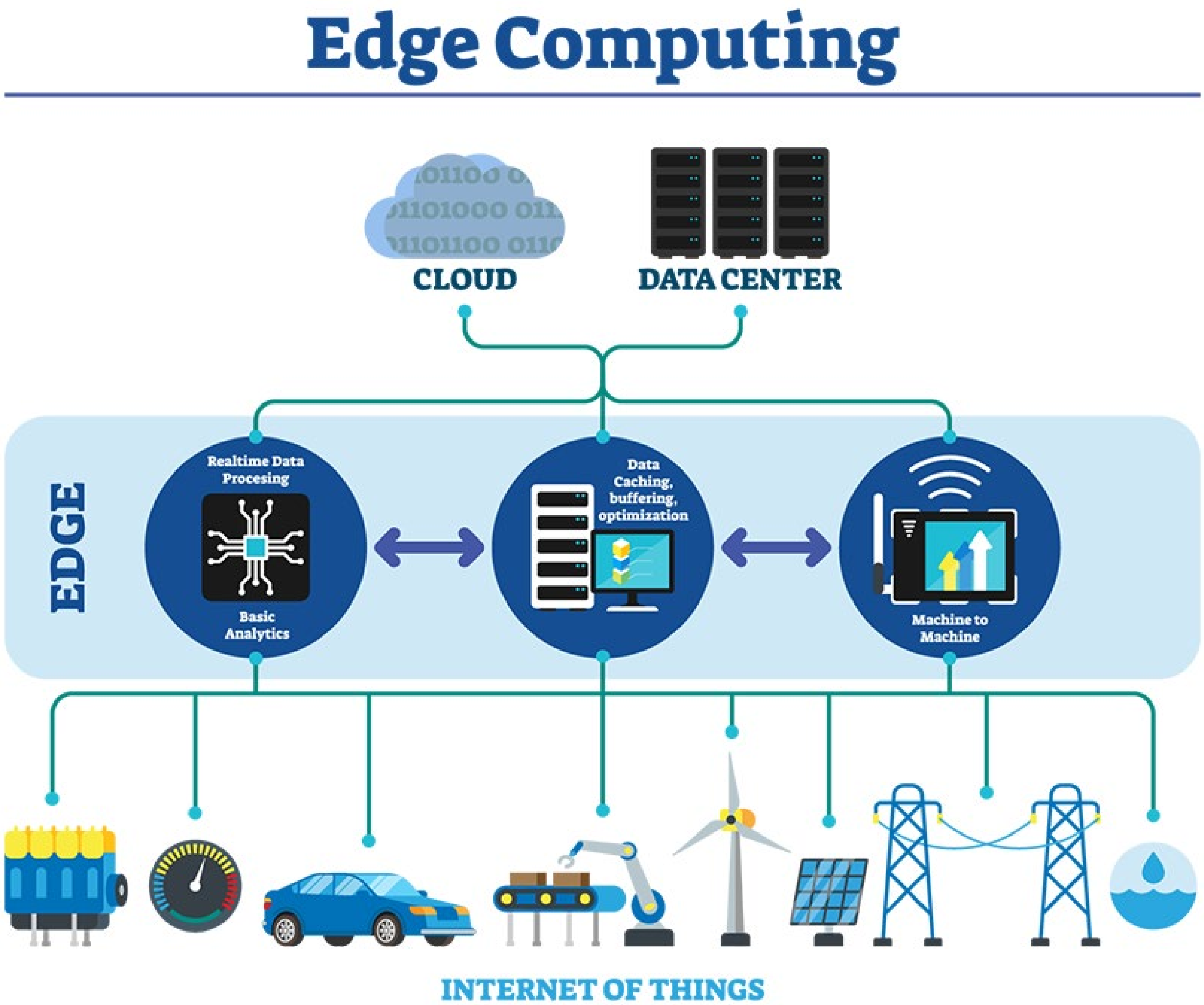
Sources: Synthesized from Hong et al. (50), Somers (51), and Zhang (37)

Data Management Challenges

As noted in Table 3, CV and AV technologies generate large volumes of data from a vehicle's sensors, which can be outward looking (e.g., cameras, radar, and lidar instruments) and also inward looking (e.g., logged engine output and exhaust emissions). CV and AV technologies also rely on large volumes of data for safe operation, like HD map information. This volume of data creates increasing data storage and data management challenges. While innovations in data optimization, connectivity choices, and data storage locations are expected to mitigate these challenges, some uncertainties are still to be worked out. As of yet, there is no consensus on just how much data CVs and AVs will generate and therefore what the data storage needs will be (52). Expert estimates range from less than 1 terabyte per day to as much as 32 terabytes per day. As a comparison, in 2018 Twitter's 336 million active users were estimated to generate 12 terabytes of data (53).

The amount of data generated is expected to vary from vehicle to vehicle based on the number and types of sensors and other technologies on the vehicle. Current prototype versions of fully autonomous vehicles can have anywhere from 20 to 40 different kinds of sensors (54). Also, the data generation between consumer-owned AVs (and CVs) and robotaxi vehicles will differ. The latter are expected to be operational for more hours each day than the average consumer and so will generate more data (54). In addition, experts have noted that testing phases of AV and CV development will generate more data than the operational phases. For example, during the testing phase, an AV is collecting as much data as possible about its surrounding environment to train its ML systems (52). Once the systems have been adequately trained, the vehicle just scans the environment to monitor the accuracy of system performance and to identify unknown objectives or situations, thus generating and using less data.

Also, experts disagree about how much data will be stored in the vehicle versus in the cloud or in another distributed network infrastructure (52). How the data are stored will depend on the vehicle system or functionality being supported. Most experts agree that automated driving systems will need to process large volumes of data on board the vehicle in real time to provide driving functions such as collision avoidance, automatic braking, and adaptive cruise control (55). The need for in-vehicle storage grows as the car achieves greater levels of autonomous driving capabilities. Other functions, such as V2X, communicate in a peer-to-peer network that requires storage with low latency, such as edge computing (56). As illustrated in Figure 5, edge computing brings data storage and computation closer to the devices that are generating the data, rather than relying on a central location, such as in the cloud, which can be farther away (57). Edge computing helps decentralize data processing and lower dependence on the cloud (58). This is done so that data, especially real-time data, do not suffer latency issues that can affect an application's or system's performance. Also, according to IEEE, traditional cloud computing is plagued by growing operational costs and greater data security threats.



Source: IEEE (58)

Figure 5. Edge Computing versus Cloud Computing.

The need and desire for data must be coupled with a stakeholder's ability to manage them. For example, one OEM, as it ramped up to launch its autonomous prototype vehicles, spent nearly $300 million on two new data warehouses in the cloud (54). This explains the growing interest among OEMs and other CV or AV developers to explore avenues for monetizing data that have commercial value, such as driving behavior data (34). Such data have a bigger impact on OEMs' internal systems and have a higher value for monetization. As another example, U.S. federal law does not assign ownership, access, and use limitation to broadcast data, that is, a defined data packet that is broadcast to many recipients, such as a basic safety message (BSM). For V2V messages, BSMs are non-identifiable data communicated by a vehicle providing location and speed but not the vehicle identification number or license plate number. An example is a vehicle broadcasting a message that "I am here," "I am moving in this direction at this speed," or "I just slammed on my brakes." As a result, USDOT and FHWA do not currently have a specific policy assigning data ownership or limiting access to BSM data (59).

The relevant stakeholders in a CV deployment must be able to provide strong data security and well-structured policies for each step in a data management life cycle. This was the experience during the New York City CV Pilot Deployment (60). The volume of new V2X data introduced privacy challenges for the deployment team (e.g., ensuring anonymity and the inability to track), as well as data management challenges, in order to obfuscate the correlation of individual drivers with any raw or processed data. These challenges, which required the agreement on data security methods from all V2X stakeholders (e.g., the traffic system operators, cities, counties, fleet operators, researchers, and third-party data providers/consumers), significantly delayed the CV pilot deployment.

Many state and other public agencies have existing programs to manage ITS and traffic planning data. While most have *considered* the benefits and challenges of integrating AV or CV data into existing data programs, few have specific plans to add such data to their data management platforms and processes (61). Rather, according to MetroPlan Orlando's best practices review, most agencies are just beginning to explore how CV and AV data might be used to improve real-time operations and enhance near- or long-term transportation planning. For example, traffic engineers have suggested that vehicles equipped with traffic light information applications could facilitate the management of traffic flow and reduce congestion.

Opportunities and Challenges for Data Sharing and Data Exchange

Opportunities for Data Sharing and Data Exchange

The vast amount of data used by CVs and AVs, as well as the data that are generated by them, can be useful to a range of stakeholders representing both public and private interests, as Table 2 and Table 3 show. Some data elements are critical for public-sector organizations to better serve the traveling public, while others are critical for private-sector developers and operators to further develop their CV and AV technologies. With this in mind, it is important for stakeholders to identify exactly what data they need and for what purposes, rather than trying to get access to all data. As mentioned previously in this paper, tough challenges are associated with the sheer volume of vehicle data and the lack of standardization. In addition, the CV and AV ecosystems are rapidly evolving, making it extremely difficult for states to enact policies that balance the needs of all stakeholders. USDOT, in its guidance documents of 2016 (62), 2017 (27), 2018 (28), and 2019 (20), has tried to balance the government's interest in safety and industry's desire for flexibility for profitable innovation. USDOT encourages the sharing of relevant data and believes it is important in the introduction of CVs and AVs to transportation systems.

Data sharing and data exchange are not the same thing (63). **Data sharing** happens when the same data resource is shared among multiple applications or users. Data sharing describes a system that accommodates participation by several organizations—all having joint control and continual access to the data, and all deriving mutual benefit from the use of the data. The following are some examples of mutually beneficial data-sharing activities:

Data sharing and data exchange represent two different approaches for access and use of the same data resource.

- **USDOT's Secure Data Commons** is a cloud-based analytics platform for sharing data and collaborating on improving research, tools, and algorithms relating to the shared data sets.

Currently, it features data sets from the Waze Connected Citizen Program, the Connected Vehicle Pilot Deployment Program, and the American Transportation Research Institute Freight Mobility Initiative. (More information is available at https://www.its.dot.gov/about/its_jpo.htm.)

- **On-Farm Data Sharing** is a shared database on crop yields among farmers' networks that facilitates analyses across space and time, and provides much more useful and robust answers to crop production questions than data from one farmer's field alone. (More information is available at https://www.rd-alliance.org/groups/farm-data-sharing-ofds-wg.)
- **The U.S. Electric System Operating Data Tool**, sponsored by the U.S. Energy Information Administration, makes consistently formatted and hourly electricity operating data from the contiguous 48 states, including actual and forecast demand, net generation, and the power flowing between electric systems, available to the electric system balancing authorities in those states. (More information is available at https://www.data.gov/energy/.)
- **DataSphere**, an initiative of the CEO Roundtable on Cancer, relies on chief executive officers to provide data on cancer drug trials and works with third-party data aggregators to pool the information on the hundreds of cancer drugs being developed at any given time in meaningful ways for shared use by all the chief executive officers. (More information is available at https://www.projectdatasphere.org/data-platform/access-data.)

Data exchange is a form of data sharing, but unlike with data sharing, the benefits derived from a data exchange are not necessarily reciprocal (63). Each organization may receive some type of benefit from the exchange, but these are not necessarily the same shared benefit. In a data exchange, one organization transfers data to another organization as a one-to-one, episodic exchange with no further interaction or updating of the data by the sourcing organization (63). In the exchange, the sourcing organization can be compensated for the data or not. Once in the hands of the consuming organization, the data are processed and manipulated by the consuming organization without the direct participation of the sourcing organization. The following are examples of data exchange:

- In **Uber Movement**, Uber makes its trip data available via a public website to users who request and receive approval to access it. (More information is available at https://movement.uber.com/?lang=en-US.)
- **Facebook's Data for Good** program provides access to publicly available aggregated mobility data that come from Facebook subscribers. Facebook also provides access to non-publicly available data to researchers. (More information is available at https://dataforgood.fb.com/docs/facebook-data-for-good-publicly-available-data/.)
- **Cuebiq** provides access to mobility flow and location-based data for analyses related to COVID-19 impacts. (More information is available at https://www.cuebiq.com/.)

USDOT's Data for Automated Vehicle Integration (DAVI) addresses AV data-sharing and -exchange needs across modes of transportation. (More information is available at https://www.transportation.gov/av/data,) The DAVI framework identifies four types of data-sharing/exchange opportunities.

- **Business to business:** Key stakeholders are OEMs, shared transportation service providers, and insurance companies for purposes of mitigating cyber threats, increasing safety through shared learning, and informing insurance and liability issues.
- **Business to government:** Key stakeholders are OEMs, shared transportation service providers, state and local governments, and federal government agencies for purposes of understanding performance during testing phases and informing policies and investments.
- **Infrastructure to business:** Key stakeholders are infrastructure owners and operators, infrastructure technology companies, in-vehicle and aftermarket services, OEMs, and shared transportation service providers for purposes of increasing safe navigation, mitigating congestion, and optimizing infrastructure investments.
- **Open training data:** Key stakeholders are government, industry, academia, and individuals for purposes of improving safety performance in common safety-critical scenarios and supporting basic research and education.

To advance data sharing or data exchange among the identified stakeholders *in each type*, it is necessary to determine:

- Which entities are collecting, storing, and analyzing what data?
- What data are the entities not collecting (whether due to regulation, industry-imposed standards, or not being of value to them)?
- What data gaps exist that hinder innovation and furthering the public interest?

Answering these questions would be especially important for data that might be of use to both the public and private sectors. These data could include accident or traffic flow data, which might be monetized and also used to promote public safety, and anonymized collision data, which could be useful to insurers to determine claims payments, OEMs to evolve their technology, and public-sector entities for incident mitigation.

Whether to seek data-sharing or -exchange opportunities depends on the needs of participating entities and their intended uses of the data. For example, stakeholders across sectors and industries who have different needs for the same data might want a data-exchange approach. On the other hand, when the data-based solution can be applied to problems that plague all stakeholders, more generalized data-sharing models may be appropriate.

> ***Data exchange*** *may be more appropriate when stakeholders across sectors and industries have different needs for the same data.* ***Data sharing*** *may be more appropriate when data can be applied to problems that plague all stakeholders.*

Toward that latter end, several initiatives in the United States and elsewhere have sought to identify high-priority data for data sharing (51, 64). Data are generally viewed as higher priority for private- or public-sector interests when associated with situations that present a significant safety issue. Table 4 presents these high-priority data categories, along with their potential owners. In June 2020, USDOT published a notice of funding opportunity for Work Zone Data Exchange demonstration grants. While the title says data exchange, it is really a data-sharing opportunity for public infrastructure owners and operators to make harmonized work zone data feeds ubiquitously available for use by third parties. The closing date for applications was in August 2020.

Table 4. High-Priority Data-Sharing Opportunities.

Data Type	High-Value Data	Owner/Steward
Work zones	Work zone locations, planned duration of project, planned lane changes/closures, and change in signage	• State and local transportation infrastructure owners and operators • Highway construction firms
Real-time traffic and road conditions	Traffic congestion variances, missing traffic signs or lane markings, potholes, and emergency road closures and detours	• Traffic data aggregators • Regional and local traffic management centers • State and local infrastructure owners and operators
Roadway inventories	Edge-to-edge data on roadways, such as curbs, bicycle lanes, pedestrian walkways, transportation network company/taxi pickup/drop-off zones, bridge heights and weights, overpass heights, road elevation, highway dividers, and parking/no-parking areas	• Mapping aggregators • State and local transportation infrastructure owners and operators
SPaT	State of the signalized intersection and how long the state will persist for each approach and lane that is active; usually used along with the geometry of the intersection	• State and local transportation infrastructure owners and operators
Cybersecurity	Incident types, source, target, duration, and implications	• OEMs • Shared transportation service providers • Commercial fleet operators • State and local transit agencies • State and local transportation infrastructure owners and operators
Safety performance	Environment and vehicle data associated with safety situations, AV disengagement/ re-engagement, and crash reports	• OEMs • Shared transportation service providers • Commercial fleet operators • State and local transit agencies

Sources: Somers (51) and USDOT (64)

Data-Sharing or Data-Exchange Models

Virtually all CV or AV data-sharing or data-exchange initiatives in the United States have been voluntary. The exception pertains to AV testing in California, where California regulations state that every manufacturer authorized to test autonomous vehicles on public roads must submit an annual report summarizing the disengagements of the technology during testing. (More information is available at https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/testing-autonomous-vehicles-without-a-driver/.) Reports are posted on the California Department of Motor Vehicles website. No other state mandates the sharing of AV testing data, and no federal rule requires AV companies to submit information about their testing activities to the government. USDOT, through its AV guidance documents, requests that companies that are testing self-driving cars submit voluntary safety reports. In 2020, NHTSA launched the Automated Vehicles Transparency and Engagement for Safe Testing Initiative, which established an online platform to facilitate sharing of high-level, on-road test data by participating AV companies. (More information is available at https://www.nhtsa.gov/automated-vehicles-safety/av-test-initiative-tracking-tool.)

Other voluntary national-level data-sharing activities in transportation include the following.

- In **NHTSA's Partnership for Analytics Research in Traffic Safety**, at least six OEMs and NHTSA share de-identified and anonymized data to examine the effectiveness of crash avoidance systems and to benchmark safety impacts. (More information is available at https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/parts_program011520.pdf.)
- **The Automotive Information Sharing and Analysis Center** is a central hub for sharing, tracking, and analyzing intelligence about potential cyber threats, vulnerabilities, and incidents related to connected vehicles. (More information is available at https://www.automotiveisac.com.)
- **The National Transit Map** collects and synthesizes public data using a common format to create and display a comprehensive map of fixed transit options in the United States. (More information is available at https://www.bts.gov/geography/geospatial-portal/national-transit-map)
- **The Federal Aviation Administration Aviation Safety Information Analysis and Sharing System** integrates and analyzes private- and public-sector data to plan for potential safety concerns in aviation. (More information is available at https://www.asias.faa.gov/apex/f?p=100:1.)
- Tri-Met, the transit agency in Portland, OR, worked with Google to develop the **General Transit Feed Specification,** which allows public transit agencies to publish their transit data in a format that can be consumed by a multitude of transit operators and a wide variety of software applications. (More information is available at https://gtfs.org/.)

Voluntary data-sharing initiatives have also occurred at the state level. MetroPlan Orlando's best practices review identified the following (61):

- **The Virginia Department of Transportation's SmarterRoads.org data portal**, which provides free, widespread access to roadway and transportation information.
- **The Florida Department of Transportation's Data Integration and Video Aggregation System**, a centralized data hub for the aggregation, fusion, and dissemination of near real-time transportation information and live-streaming video.

TxDOT has its own data-sharing initiatives. For example, TxDOT is sharing Inrix data with metropolitan planning organizations and other public agencies. The following are additional data-sharing activities:

- **The DriveTexas.org website** offers information about road closures, construction zones, flooding, damage, and accidents. Data are as close to real time as possible, and the website is a vital tool for the public during emergency situations. (More information is available at https://www.txdot.gov/inside-txdot/media-center/statewide-news/2017-archive/019-2017.html.)
- **The TxDOT Open Data Portal** is the agency's platform for sharing geographic information system data. (More information is available at https://gis-txdot.opendata.arcgis.com/.)
- **The Texas Connected Freight Corridors project** is Texas's largest deployment of CV technology. Through the deployment, TxDOT will acquire a rich set of traffic conditions data, including parking availability and border crossing times, and will share this information with other state agencies, metropolitan planning organizations, cities, and counties along the

I-35, I-10, and I-45 corridors; trucking/freight companies; trucking/freight manufacturers and equipment companies; and the traveling public. (More information is available at https://ftp.dot.state.tx.us/pub/txdot-info/trf/freight-corridors/faq.pdf.)

Challenges for Data Sharing and Exchange

Data sharing or exchange is both an opportunity and a risk. While CV and AV data are essential to planning and operations for the public and private sectors, sharing or exchanging data can be a risk depending on their use, accuracy, and whether the user understands the limitations of the data and uses them appropriately. For these reasons, many public agencies avoid situations that may present liability issues in terms of data quality or accuracy (61).

In addition, public agencies need to confront tensions related to data ownership, access, privacy, and security before considering opening data-sharing or -exchange platforms. Voluntary data-sharing initiatives are brokered on mutual benefit among all engaged stakeholders. However, many private companies are in direct competition and are therefore sensitive to sharing data they may see as proprietary in a public setting. Many vendors are more willing to share data when they are contracted to provide a service and under a nondisclosure agreement, but they are unlikely to share all data even under these conditions. For example, the Washington State GPS Freight Performance Measures project uses data from commercial fleet management GPS devices in trucks to develop statewide freight performance measures that in turn improve the performance of the system for trucks using it. The DOT assures the vendors that the GPS data is used for freight performance measurement only and not for regulatory or enforcement purposes. This addressed some concerns about providing an individual company's business-sensitive information, but the private-sector entities still required nondisclosure agreements.

The reluctance to share information pertains to the OEMs as well. Following an AV crash in 2015, the OEM used the raw data from the vehicle to determine what went wrong and to upgrade its software to include an improved algorithm (65). But the OEM did not share the improved algorithm with other OEMs, and as a result, the improved software algorithm remains a secret. By federal legislation, law enforcement does have access to EDRs for crash reconstruction and crash-reporting purposes, but would not have access to proprietary algorithms. Following the lead of USDOT, state legislatures, with the exception of California, have shied away from enacting comprehensive data-reporting laws because they want to encourage innovation in their states and so rely on voluntary reporting. There is recognition of the highly competitive nature of this technology and research and development. Each developer has proprietary systems and intellectual property that it must protect. Developers also have nonbinding commitments to protect data privacy, data security, and cybersecurity that need to be acknowledged.

Summary and Conclusions

This white paper represents the combined work of a subcommittee of the Texas CAV Task Force. This subcommittee is a dedicated group of public- and private-sector experts in CV and AV technologies, with an overarching and continuing responsibility to ensure the safe and efficient deployment and advancement of these technologies in Texas.

This white paper discusses high-level data issues and opportunities, the regulatory environment in which CVs and AVs operate, data used and produced by CVs and AVs, and influences on data ownership, data privacy, and data sharing and exchange. AVs and CVs represent symbiotic but uniquely different technologies. Without a federal mandate, CV deployments are slowly proceeding through a few federal and state initiatives. However, USDOT initiatives are increasing the number of CV deployments. The advancements are also influenced state and federal rule making, such as FCC rule making regarding allocation of the spectrum. Advancements in AV technology are more ubiquitous, largely through private-sector activities in testing and deployment; still, the time frame for the transition to higher-level AVs is not clear.

The United States has a complex regulatory environment, with local, state, and federal government agencies, as well as Congress, having authority to create rules that may govern CV and AV operations. Congress has authority to establish federal regulatory frameworks or standards. NHTSA has responsibility for the safety of motor vehicles. FCC manages the electromagnetic spectrum and has new rules on the splitting of the 5.9-GHz band between vehicle safety communications and unlicensed operations as of November 2020. States are responsible for operations of vehicles on public roads. Texas law has allowed automakers and others to test AVs without a driver inside and the use of connected braking systems on the state's roads and highways. In Texas, since CVs and AVs have been allowed to operate, more than 20 AV pilots and multiple CV pilots have operated, bringing with them opportunities for data sharing and exchange among private- and public-sector stakeholders.

Data privacy, data security, and cybersecurity are important concepts in the context of AVs and CVs. Data privacy relates to the collection, access, and use of sensitive personal information. Data privacy prevents a breach of PII that can cause harm to individuals, organizations, and agencies. Unlike widely thought, with data science analytics, anonymizing data no longer mitigates data privacy issues. In the United States, there is no comprehensive approach to data privacy regulation. FCC's nonbinding Fair Information Practices guide data privacy protections, but federal law does not require companies to have a privacy policy or notify consumers of their privacy practices. States such as California, Nevada, and Maine have data privacy laws, but only California's pertain to non-online business practices.

AVs and CVs use four types of data when operating: digital map data, data on roadside infrastructure, data on traffic and other road conditions, and data on the movements of other objects (i.e., people and vehicles). These data can be either on board (e.g., generated from a vehicle's sensors) or externally sourced. CVs and AVs also produce data as they operate or communicate with external vehicles and devices. Data generated include safety, diagnostic, road infrastructure, location, driving behavior, and traffic conditions. There is much overlap between the data CVs and AVs use and the data they generate.

CVs and AVs bring many data management challenges to both public- and private-sector agencies because of the vast amount of data that can be collected, transmitted, stored, and analyzed. And the testing phases of AVs and CVs (which are where the industries are focused now) generate more data than the operational phases. Therefore, confronting data management issues should be a priority.

CV and AV data are available and beneficial to both public and private organizations, so data sharing and data exchange among them are both wanted and needed. USDOT has launched several data-sharing initiatives, as have some state DOTs and private-sector consortia. Nearly all data sharing is done under a voluntary model—the preferred model under the current regulatory environments. For this to work, generalized data-sharing models need to focus on mutually beneficial scenarios.

The question of who owns these vehicle data has an evolving set of answers. It is informed by who has legal right to the data (e.g., vehicle owners in the case of EDRs), who has proximity to the data (e.g., OEMs), who has compiled and processed the data (e.g., data aggregators), and who operates the sensors generating the data (e.g., infrastructure owners/operators). Ownership also depends on characteristics such as the type of data, the stage of technology development, and the point in time the data are accessed and used. The issue of data ownership is an evolving challenge that still needs to be understood and resolved. It requires ongoing discussion among relevant stakeholders in the CV and AV ecosystems. It is important for groups such as the Data, Connectivity, Cybersecurity, and Privacy Subcommittee of the Texas CAV Task Force to continue working with public-private partners to deal with issues such as data sharing, data exchange, privacy, and cybersecurity protection. An exercise to inform these issues is to answer the following questions:

- Which entities are collecting, storing, and using what CV and AV data—how, for what purposes, and with what protections?
- What data gaps exist that hinder innovation and furthering the public interest?
- What data can be shared or exchanged to facilitate the safe and successful integration of AVs and CVs into the transportation ecosystem?
- What security and privacy protections need to be addressed and incorporated into AV and CV data collection and sharing?

Answering these questions will begin to clarify data ownership, data access, data use, and data-sharing issues. Particularly important are high-priority data for data sharing: information on work zones, real-time traffic and road conditions, roadway inventories, SPaT, cybersecurity, and safety performance. Addressing the ownership, technical, and policy issues surrounding these high-priority data categories will accelerate the safe deployment of AVs and CVs in Texas.

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APPENDIX E

Connected and Automated Vehicle Infrastructure Needs for Automated Freight

Texas CAV Task Force White Paper
Subcommittee on Freight and Delivery

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's

performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the "CAV Terminology" white paper for a full listing of terms and definitions used in this developing technology ecosystem.

List of Terms and Acronyms

AV	automated vehicle
CAV	connected and autonomous vehicle; also, connected and automated vehicle
CV	connected vehicle
C-V2X	cellular vehicle to everything
DSRC	dedicated short-range communications
ELD	electronic logging device
FCC	Federal Communications Commission
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standard
LSV	low-speed vehicle
MIZ	Mobility Innovation Zone
NHTSA	National Highway Traffic Safety Administration
OBU	onboard unit
PDD	personal delivery device
RSU	roadside unit
TCFC	Texas Connected Freight Corridors
TxDOT	Texas Department of Transportation
USDOT	U.S. Department of Transportation

Executive Summary

The freight network is at the heart of the Texas economy (Figure 1). In 2016, more than 2.2 billion tons of freight—19.7 tons per household and over 12,000 tons per business—moved within Texas, a volume that is anticipated to increase to over 4.0 billion tons by 2045 (1). By investing in smart infrastructure, maintaining an attractive regulatory environment, and taking a proactive approach to workforce development, Texas will improve roadway safety, optimize freight operations, and grow the Texas economy.

Source: Quintin Gellar—Pexels

Figure 1. The U.S. Freight Network.

The events of 2020 have accelerated the freight industry toward an automated future. With the rise of e-commerce and a demand for just-in-time deliveries, everything from packages and groceries to medications and last-minute school supplies could, in the future, be transported by connected and autonomous vehicles (CAVs). This acceleration presents an opportunity to reimagine the transportation infrastructure and identify improvements to support connected and automated freight while enhancing the safety and experience for all road users. For example, drivers could someday see truck platoons on the highway and even have the option to join the platoon as part of their daily commute. Additionally, the shift toward automation warrants a closer examination of changes needed to prepare the Texas workforce. In particular, there is a concern that current jobs in the trucking, manufacturing, and related industries may be displaced; however, there is strong analysis showing that the technology has the potential to instead boost productivity, attract a new generation of workers, and create new jobs. New skills and training programs can create jobs at a time when

Texas residents and businesses are retooling. By investing in smart infrastructure improvements and workforce development programs, Texas will be investing in accelerated economic competitiveness.

The Texas CAV Task Force Freight and Delivery Subcommittee sees the following as opportunities for the State of Texas related to freight and infrastructure:

- Prioritize roadway maintenance along CAV corridors, focusing on lane striping, pavement quality, and signage.
- Launch a cooperative research program targeted at research gaps for common infrastructure challenges such as work zones, forced merges, and transfer points.
- Expand the Texas connected freight network to include local roads, using the Texas Connected Freight Corridors project as an opportunity to develop critical applications, gain experience in connected vehicle technology, and formulate best practices for deployment.
- Invest in workforce development programs that upskill workers and create new educational pathways.

Introduction

The freight landscape is rapidly evolving. As new technologies and vehicle types continue to emerge, Texas's infrastructure and policies must keep pace. Many Texans rely on the freight ecosystem for their livelihoods. Connected and autonomous vehicle (CAV) technologies present significant safety and economic potential to the state. The Texas CAV Task Force represents a collaborative forum where the public and private sectors can work together to achieve success. In the wake of the COVID-19 pandemic, Texas must continue to make strategic investments in its freight infrastructure and workforce.

This white paper provides an overview of the ground-based freight ecosystem, highlighting challenges and opportunities in three environments:

- Long haul.
- Warehouses, distribution centers, and intermodal facilities.
- Last-mile delivery.

In addition, this paper examines shifts in the Texas freight workforce as the trucking industry evolves from a driver-based profession to a skills-based labor market. Finally, the white paper describes the infrastructure needs to enable connected freight capabilities and the potential safety benefits.

Ground-Based Freight

The advent of CAV technologies is transforming transportation. In particular, the freight industry is at the leading edge of the transformation, touting numerous research and development efforts on the ground and in the air. While several developments are taking place in unmanned aerial systems, the focus of this white paper is limited in scope to ground-based freight. The general consensus is that ground-based freight will advance at a faster pace than passenger services due to its simpler operating environment, for-profit business model, and quicker go-to-market strategy, providing early insights into infrastructure needs that could support automated vehicle (AV) operations more broadly. For instance, automated freight vehicles that are operating on limited-access freeways can provide information on lane striping, roadway geometry, and other roadway condition data. While navigating complex urban environments is more challenging, similar information-sharing concepts could be enhanced to yield insight into situations where there are more variables, such as avoiding pedestrians, yielding to bicyclists, and navigating signalized intersections.

In addition, automated freight is setting a positive example for conducting safe testing. Whether it is extensive training for those operating larger vehicles with heavier loads or proactively working with the residents to build awareness of personal delivery devices (PDDs) operating in local neighborhoods, the automated freight industry is taking precautionary measures to ensure safety. The following describes three basic infrastructure environments that compose the ground-based freight ecosystem.

Long Haul

Driving down the highway are thousands of long-haul trucks—Class 8 vehicles more commonly known as semis or 18-wheelers. Highly automated truck developers have focused on the middle mile—that is, the stretch of high-speed highway in between exits. Unlike passenger vehicles and PDDs, self-driving Class 8 trucks can be operated profitably mostly or exclusively on divided, limited-access highways, thus avoiding many of the pedestrians, pets, and bikes that make urban and suburban driving complex and unpredictable. So far, automation of short haul has not been a high priority. Larger trucks are hard to operate in dense urban environments, so the industry has left this task for experienced human drivers. With more lane miles than any other state and a booming population, Texas has prioritized the roadways that compose the Texas Triangle (I-10, I-30, I-35, and I-45) for CAV investments (Figure 2).

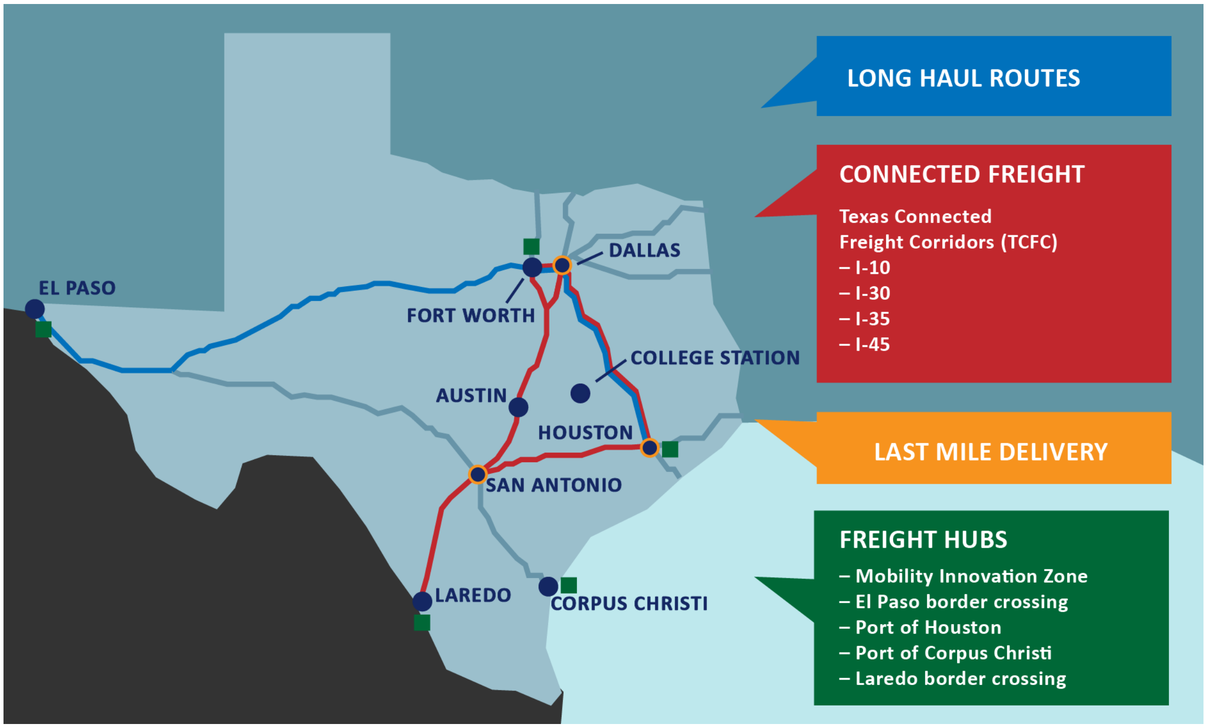

Figure 2. The Texas Triangle Connected and Autonomous Vehicle Activity.

Warehouses, Distribution Centers, and Intermodal Facilities

Along the supply chain are a string of warehouses, distribution centers, and intermodal facilities. In addition, Texas ports of entry—including seaports and border crossings—serve as tremendous hubs for freight activity. Increasingly, these facilities are co-locating to reduce drayage costs and accommodate increased freight volumes. Some automated freight developers are focusing on short-haul operations along routes that connect these facilities to one another or between distribution centers and retail customers. To spur investment, Texas can support CAV infrastructure in and around these nodes to create transportation-advantaged areas and attract companies to supply chain access.

Last-Mile Delivery

The final step in this process is last-mile delivery, which transports retail goods to consumers who are typically located at either home or work. Some last-mile delivery models are also connecting with consumers at convenient or central pickup locations such as community centers or downtown. The same features of the urban landscape that make it difficult to navigate are making it very lucrative to automate. To travel to each customer, the CAV must navigate a complex environment, so last-mile vehicles operate at lower speeds on local arterials, neighborhood streets, and sidewalks. Often operating in urban areas and pedestrian zones, last-mile delivery requires special infrastructure and regulatory considerations.

Texas: A Deployment Epicenter

In just the past five years, CAV testing has ramped up to include numerous connected and automated freight efforts. Operations are taking place along major highway routes, intermodal facilities, university campuses, local neighborhoods, and city sidewalks. What are the key factors behind this growing industry, and why Texas?

Clear Legislative Path

First and foremost, Texas offers a favorable regulatory environment for deploying CAVs. Governor Greg Abbott and the Texas Legislature have welcomed innovation, offering clarity where needed rather than requiring strict and overly burdensome regulatory and reporting requirements. This business-friendly path to deployment has put Texas at the leading edge, attracting many companies from California and other locations to both test and headquarter in the state.

More People, More Freight

Second, the Texas population is expected to grow from 28 million today to 55 million by 2050. It is estimated that 70 percent of the population will live in the four metropolitan areas of the Texas Triangle (Houston, Dallas-Fort Worth, Austin, and San Antonio), making it one of the largest markets in the country that operates under uniform regulations and is connected by high-quality infrastructure. In fact, if growth rates continue, Texas is set to surpass California in total population by 2045 (2). With more people comes an increased demand for goods, which is also expected to nearly double in the next 30 years.

Access to Talent

Third, Texas has a strong labor market with a robust technology sector. AV developers are choosing to headquarter or establish bases in Texas to take advantage of the access to both commercial driver license drivers and software engineers.

Education is another asset in Texas. There are opportunities to develop new curricula for K-12 schools to enrich learning in the transportation field, partner with community colleges to launch new certificate programs, and strengthen higher education programs with courses in CAV technologies. By continuing to invest in its workforce and education, Texas can remain at the forefront of job growth.

Partnership and Infrastructure

Finally, Texas infrastructure owners and operators have joined to approach CAV developers with a philosophy toward partnership. Recognizing that the Texas freight network is comprised of local, regional, and state facilities, public agencies are working alongside the private sector to develop common infrastructure standards, leverage CAV data to improve roadway maintenance practices, and prioritize investments. By sharing lessons learned and best practices, the Texas CAV Task Force is a collaborative model for identifying infrastructure enhancements to support CAV deployment.

The Freight Vehicle Lineup

Several connected and automated freight vehicle types are under development. Each vehicle is designed to operate in at least one of the following infrastructure environments: highway, local street, and sidewalk. Using a suite of sensors—lidar, radar, global positioning system (GPS), cameras, telecommunications, and other technologies—the vehicles are designed to steer, detect, and avoid obstacles while navigating safely to their final destination.

Automated Trucks

Traditional semi-tractor-trailer trucks that are Federal Motor Carrier Safety Administration (FMCSA) compliant are being automated to operate at highway speeds. The operation of highly automated trucks focuses on the part of the trip between entering the highway and exiting the highway with some extension off the highway to access warehouses, distribution centers, transfer hubs, and intermodal facilities. This has been referred to as the *middle mile* in some discussions. The highway environment has been identified as low-hanging fruit for automated operations because there is less complexity than urban streets. Highways do not have intersections, crosswalks, bike lanes, or street parking, which drastically reduces the variation in scenarios that a highly automated truck may encounter. In Texas, runs are being made regularly from El Paso to Dallas, between Dallas and Houston, and across I-10 beginning in California and ending in Florida. With increased technology, highly automated trucks can be safer and more fuel efficient and can transform the truck-driving profession.

Connected Trucks

Trucks may also be equipped with connected vehicle (CV) technology. Vehicle-to-vehicle communications enable trucks to platoon, where only the lead vehicle is driven by a human and the other trucks in the convoy rely upon GPS and sensor systems to follow. Vehicle-to-infrastructure communications can generate alerts such as “Work Zone Ahead” or give trucks priority at traffic signals by extending their green time. Currently, Texas is developing a set of CV applications that will enable truck drivers and operators to make better safety, routing, and business decisions. Furthermore, the trucking industry has integrated telematics to receive important alerts regarding traffic events and adverse weather. By combining technologies along the roadside and in the cab, Texas trucking can improve safety, fuel efficiency, and profitability.

Low-Speed Vehicles

For last-mile deliveries in urban areas, low-speed AVs are operating on-street at speeds up to 25 mph. The base vehicle is typically a full sedan or a purpose-built zero-occupant vehicle. Early use cases include grocery and medicine deliveries and will likely expand to other household items.

Personal Delivery Devices

For sidewalk-based deliveries, the two vehicle types for PDDs are wheeled and legged robots. Wheeled robots are the most efficient, perform well in structured environments, and are making improvements to traverse challenging surfaces. Legged robots have the advantage of navigating uneven surfaces, steps, and other obstacles. PDDs have load-carrying capacities ranging from 20 to 110 pounds and, in Texas, are restricted to a top operating speed of 10 mph in the pedestrian area and 20 mph on the side of the roadway.

Delivery Lockers

Mobile lockers are an emerging model in last-mile delivery with some companies developing purpose-built vehicles. The automated delivery vans typically operate on-street at speeds up to 60 mph and are customized to include 30–40 lockers. These vehicles are typically used to make multiple stops within a zone or may also be parked at a single location and serve multiple customers at the same time.

An Evolving Policy Landscape

Texas policy needs to ensure public safety while not hampering innovation. To mitigate policy uncertainty, Texas has focused on providing clarity and uniformity at the state level, has followed safety guidance at the federal level, and has relied on municipalities to issue permits and manage the curb space. The following highlights key issues for Texas to monitor in the arena of automated freight.

Federal

The U.S. Department of Transportation (USDOT) is committed to facilitating the next generation of transportation technologies. In particular, USDOT has published guidance documents referred to as AV 2.0 through 4.0, which describe the federal vision, regulatory authorities, research, priorities, and investments (3, 4, 5, 6). Significantly, in AV 3.0, FMCSA asserts its authority to take enforcement action if an automated system inhibits the safe operation of a commercial motor vehicle (CMV), while concluding that automated CMV operation is allowable under existing Federal Motor Carrier Safety Regulations (FMCSRs), assuming it can be compliant with the same operational requirements as a human-driven CMV. AV 3.0 also noted that FMCSA policy would no longer assume that the driver of a CMV is always human or that a human is necessarily on board, and that human-specific FMCSRs, such as drug testing and hours of service, would not apply to SAE Level 4 or 5 CMVs operating without a human driver. Furthermore, if FMCSA determines that state or local legal requirements may interfere with the application of FMCSRs, the department has preemption authority.

National Highway Traffic Safety Administration Exemptions. The National Highway Traffic Safety Administration (NHTSA) issues Federal Motor Vehicle Safety Standards (FMVSSs), which specify the design requirements for all motor vehicles. Before 1968, for example, not every vehicle had seat belts; the FMVSSs are responsible for requiring seat belts, airbags, and other safety measures. With AVs, however, some design specifications are no longer relevant. With no human driver, a steering wheel, brake pedal, and mirrors are no longer needed. Therefore, AV developers are applying to NHTSA for exemptions from the FMVSSs; at the time of this publication, some have been approved, while others remain pending. NHTSA has also announced a proposed rulemaking to update the FMVSSs with AVs in mind. Timely federal regulatory action is important to provide uniformity and support a growing CAV market.

Federal Motor Carrier Safety Administration Rulemaking. In addition to NHTSA's regulation of road safety and vehicle requirements of the FMVSSs, CMVs are also subject to the regulations of FMCSA. The FMCSRs focus on driver and carrier operations, including driver qualification, hours of service, vehicle inspections, financial responsibility, and other requirements that apply to the motor carrier industry. FMCSA has issued an advanced notice of proposed rulemaking related to the "Safe Integration of Automated Driving Systems-Equipped Commercial Motor Vehicles." The rulemaking is designed to update the FMCSRs in order to address safety, security, and privacy concerns relevant to automated driving systems.

Federal Communications Commission Rulemaking. In the world of CVs, there has been debate between two technologies:

- **Dedicated short-range communications (DSRC),** which has been proven to perform with such low latency that it can enable automated braking systems and other safety-critical applications.
- **Cellular vehicle to everything (C-V2X),** which uses the same network as a cell phone and has the potential for more ubiquitous coverage.

The Federal Communications Commission (FCC) has issued a ruling to reallocate the spectrum that is dedicated to transportation safety. While there was a 75-MHz allocation for DSRC, FCC has allocated the lower 45 MHz of the 5.9-GHz band for unlicensed operations such as Wi-Fi and allocated the upper 30 MHz for C-V2X operations (7). Existing DSRC implementations are able to continue operating in the upper 30 MHz; however, existing operations in the lower 45 MHz are required to cease operations after the one-year transition period. FCC is seeking comments on the appropriate transition paths for existing DSRC operations. Like many states with existing deployments, Texas is seeking a clear path forward.

State

Governor Greg Abbott and the Texas Legislature have demonstrated significant leadership in creating a business-friendly environment for CAV development. Specific to automated freight, three pieces of legislation signed into law by the governor are worth noting:

- **Senate Bill 2205** (effective September 1, 2017) specifies that AVs may operate on any public roadway, carry passengers, and operate without requiring a human to be present (8).
- **House Bill 1791** (effective May 18, 2017) allows trucks equipped with a connected braking system to platoon with one another (9).
- **Senate Bill 969** (effective June 10, 2019) provides a regulatory framework for PDDs that outlines rules for operation and specifies vehicle requirements (10).

As Texas continues to test and deploy new technologies, results and key findings can be summarized for the Texas Legislature for potential opportunities related to policy.

Local

In Texas, current legislation preempts local regulation of AVs. Municipalities do maintain regulatory authority over their curb space management practices, ensure compliance with traffic laws, and design the infrastructure and right of way. Cities such as Washington, DC, are testing systems that allow delivery drivers to reserve space at the curb to discourage double-parked vehicles that block traffic. The sidewalks are also becoming more congested as bicyclists, scooters, pedestrians, and PDDs compete for space. Cities are reimagining their rights of way to include dedicated lanes to minimize conflicts and ensure accessibility.

Long Haul

Trucks in Texas carry massive volumes of freight, so it makes sense that the majority of companies developing highly automated trucks have identified Texas as a proving ground. The state must strategically invest to maintain this edge.

The Challenge and the Opportunity

By far, the primary mode for moving freight is commercial vehicles. Over 700,000 truck trips are made daily in Texas, which is expected to grow to over 1 million by 2045 (11). This freight traffic relies on a robust roadway network.

Investing in highway infrastructure supports the economy by enabling safe and efficient transportation of goods. Developers have identified the middle mile, or entrance to exit on a roadway, as an ideal environment for the operation of highly automated trucks. Highways have limited intermodal interactions, which reduce the challenge of object identification and classification.

This is coupled with a national truck driver shortage, which continues to grow. In 2018, the driver shortage was estimated at over 60,000 drivers, with an expectation that it will grow over time (12). The average age of a commercial truck driver is 55 years old according to the Bureau of Labor Statistics, and the industry has trouble attracting a younger workforce (13). This means that, for now, highly automated trucks are unlikely to impact the existing employment of drivers and instead fill a gap between supply and demand. Additionally, the technology provides new jobs, which may be more attractive to the younger workforce.

Texas has become a hub for automated freight deployments, but the roads on which highly automated trucks must operate were designed long before the technology emerged. Through early deployments, the operators of highly automated trucks have identified challenges within the current infrastructure (Figure 3). The existing highly automated truck deployments demonstrate that they are capable of operating on the existing infrastructure, but consistent maintenance and infrastructure enhancements would enable broader deployments.

Some challenges are common across traditional and highly automated trucks. The three basic infrastructure needs where industry has reached consensus are:

- Consistent striping.
- Quality pavement.
- Standardized signage.

Faded or missing lane striping is challenging for vehicles that rely on striping to dictate the extent of a lane, uneven pavement can confuse the highly automated truck’s sensors, and non-standardized signage is difficult for highly automated trucks to read and interpret. Addressing any of these challenges will also benefit human drivers. With regards to signage, long-haul trucks traveling routes that span multiple states are particularly challenged by signage variations that occur across state lines. In addition, some infrastructure challenges are more difficult for highly automated trucks to navigate reliably or do not have a current solution. Highly automated trucks find the following roadway environments challenging due to their unexpected and highly varied nature:

- Work zones.
- Lane closures.
- Forced merge points.

There are also unique challenges, such as the issue of how to navigate weigh stations and inspections without a driver present. The Commercial Vehicle Safety Alliance, in partnership with the Federal Motor Carrier Association, has been working to develop a consensus approach to inspection of highly automated trucks (14). These new methods are being crafted with industry input, and Texas could reinforce its position as a leader in this space by adopting them early on.

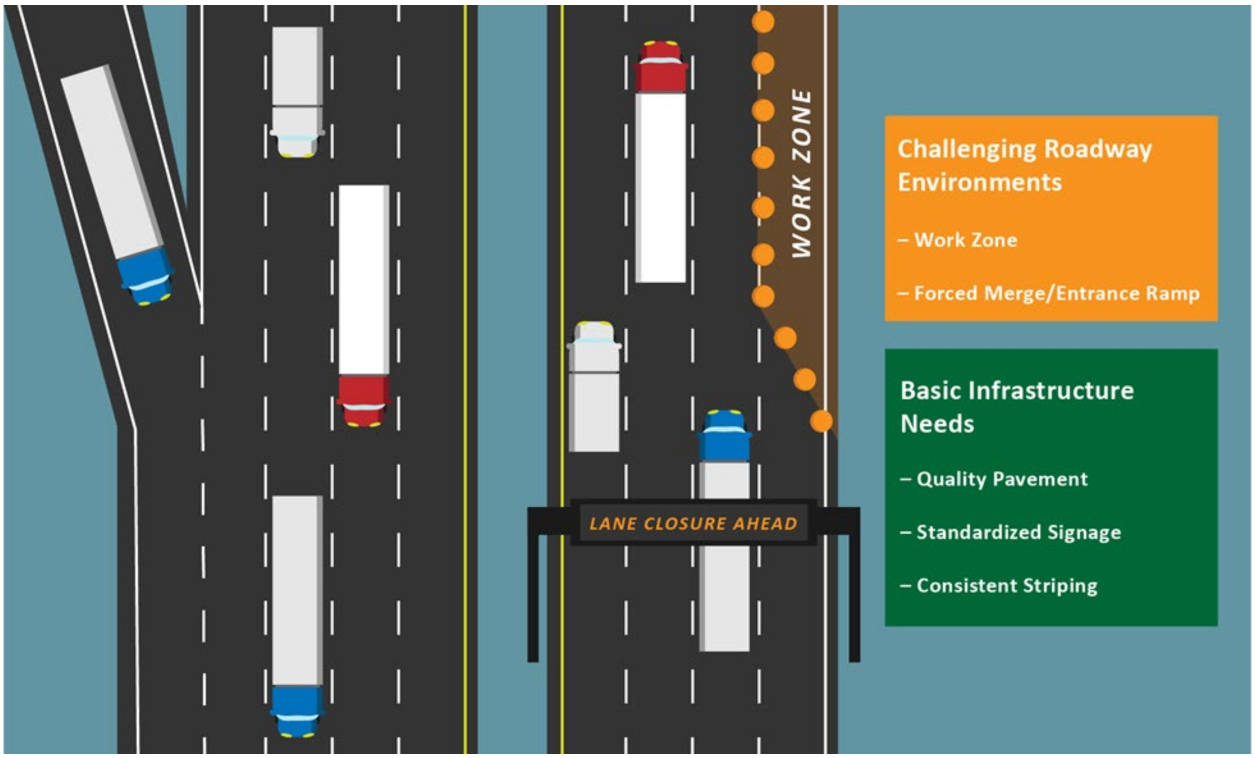

Figure 3. Roadway Environment Challenges and Basic Infrastructure Needs for Long Haul.

Infrastructure Close-Up

The operation of highly automated trucks focuses on the middle mile between entering the highway and exiting the highway. The highway environment has been identified as low-hanging fruit for automated operations because it has less complexity than urban streets. Highways do not have crosswalks, bike lanes, or street parking, which drastically reduces the variation in scenarios that a highly automated truck may encounter. In Texas, the interstate highways that compose the Texas Triangle are all highly used trucking corridors that provide access to the major metropolitan areas within the state. Multilane divided highways present an opportunity for highly automated trucks to focus on navigating the roadway environment without the complexity of intersections, tight corners, pedestrians, or bicyclists.

However, the highway environment does involve unexpected work zones, difficult-to-navigate forced merge points, faded or missing pavement markings, and no existing system for automated operations to transition to human operations for the more complex first and last mile. Addressing these challenge points would allow highly automated trucks to deploy broadly and boost the Texas economy.

Work Zones and Forced Merges

Highly automated trucks can be challenged in the work zone and temporary lane-closure arena by the need to navigate rapidly changing and unpredictable environments. Work zones are known to be challenging for both humans and computer-driven vehicles alike, with some new work even addressing the safety of construction workers as they are performing work. This reflects large value in finding ways to standardize the work zone environment and provide a safer environment for drivers, highly automated trucks, and work zone workers alike. One company operating highly automated trucks in Texas provided a powerful anecdote of how a truck can often get trapped in the right lane when approaching an unanticipated lane closure. To navigate around the closure, the truck must merge into the left lane. However, the left lane is clogged with drivers who do not provide a gap for the truck to merge. Class 8 trucks are bulky and require considerable time to merge, brake, accelerate, or otherwise maneuver.

The solution to this challenge is maintaining accurate information about work zones and lane closures that the highly automated truck operators can easily access. With advance notice, the highly automated truck can move into the left lane earlier and avoid the congested merging point closer to the work zone.

Similar to work zones, forced merge points (e.g., a lane ending or becoming an exit-only lane) require highly automated trucks to merge, which is one of the more complex tasks for any truck to execute. Entirely eliminating merge points is not feasible, but they should be well signed and give time for vehicles to merge into the next lane. Conversations with highly automated truck companies can guide the development of new entrance and exit ramp configurations as well as enhance signage protocols associated with work zones.

Lane Striping

Pavement markings designed to help drivers orient themselves and stay within set boundaries to avoid collisions are also important to the operation of some highly automated trucks. Faded or missing striping makes driving at night and during adverse weather more hazardous for human drivers. Even though most highly automated truck companies plan to be capable of operating without high-quality lane striping, faded or missing striping makes operation more difficult. Significant work has been done to ensure that standards are set for minimum retroreflectivity, but these standards were not designed for automated activity. In 2018, California elected to switch from 4-inch-wide to 6-inch-wide stripes, citing the better visibility for AVs as one of the motivators (15). Other work is being done across the country to explore methods for improving pavement striping. Generally, high-quality striping is a change that can be implemented rapidly at a relatively low cost that will benefit highly automated trucks and human drivers alike.

Even when high-quality striping is implemented, it must be maintained properly to remain effective in the long term. The procedures currently in place for Texas rely on a combination of driver reports and inspections. Driver reports provide some information but should not be considered comprehensive. A subset of lane miles is inspected each year, but this system does not catch all degradation in a timely manner. Texas needs to find a way to fill the gap so that faded and missing striping can be identified and remedied appropriately. Some highly automated truck companies have come forward to offer data to state agencies in support of road maintenance efforts. Since the trucks have multiple cameras and other sensors pointed at the roadway, they can provide valuable information on road quality to the Texas Department of Transportation (TxDOT). This concept has been explored broadly, but it would be valuable to invest in the development of a robust system for reporting maintenance events because this reporting tool will only grow in value as the deployment of highly automated trucks rises.

Transfer Hubs

Highly automated trucks that are built to operate on the highway need access to facilities that connect to the highway. Highly automated truck developers have announced plans to build transfer hubs and convert existing facilities where cargo can be dropped off by human drivers and connected to highly automated trucks (16). This type of facility will be essential to the success of highly automated trucks that aim to tackle the middle mile. This framework also highlights a continued need for human drivers for many years. Many highly automated truck developers have chosen to tackle the middle mile distinctly because of the simpler operational design domain and are not looking to navigate complex urban environments using autonomy in the near future. Texas can support the transfer hub concept by identifying facilities that are already connected to the highway network and can be repurposed or redesigned to work as a transfer hub. Rest areas, weigh stations, park-and-ride areas, truck stops, and truck parking facilities have been identified as potential locations for transfer hubs. If the facility is no longer in use, it can be fully converted. Otherwise, the space could be shared between the two activities. An important consideration when developing transfer hubs will be the need to keep human activity away from any area where highly automated trucks are operating to maintain safety and avoid confusion.

Opportunities

In the short term, Texas should focus on working with companies to exchange information effectively. Texas is investing in CV technologies that can provide up-to-date, lane-specific information on work zones and lane closures. Highly automated truck companies have also demonstrated a willingness to work with state and local partners to provide information on faded and missing striping.

In the long term, highly automated trucks will need to be considered part of a broader ecosystem. Many standards and procedures can be adjusted to incorporate the presence of highly automated trucks. Developing an effective transfer hub network will be essential to the success of middle-mile highly automated truck operations. As highly automated trucks spend more time on the road, they may find new concerns to be addressed. In summary, the Texas CAV Task Force sees the following opportunities:

- Refine infrastructure standards for lane striping, work zones, and lane closures with the needs of highly automated vehicles in mind.
- Prioritize research to address challenging roadway environments such as forced merges and entrance/exit ramps.
- Identify potential locations for transfer hubs and work with industry to pilot this solution.

- Encourage TxDOT and industry partners to work together in sharing information to benefit the operations of both organizations.

Warehouses, Distribution Centers, and Intermodal Facilities

As automation is incorporated into the freight ecosystem, major actors in the supply chain are co-locating to create transportation-advantaged zones that can attract and grow automated freight companies.

The Challenge and the Opportunity

The journey of cargo from manufacturer to customer contains many connections (Figure 4). At warehouses and distribution centers, cargo is sorted and packed into a new vehicle. These connections do not take place directly on the roadway but are critical to the efficient movement of freight and come with their own challenges. Intermodal facilities consist of ports, rail yards, and airports where the movement of goods transitions from one mode of transport to another. As the role of autonomous technology grows in the freight sector, these facilities are changing how they tackle drayage and management of vast quantities of cargo. Companies are changing how they think about moving their goods. For example, to meet its tight delivery timeline, Amazon purchased 20,000 vans, which cover the last-mile journey to a customer's doorstep. Even the U.S. Postal Service is experimenting with automated freight, shown by its 2019 long-haul test run of moving mail in a highly automated Class 8 truck from Phoenix, AZ, to Dallas, TX.

As the journey evolves, the connection points will shift with it. The location and scale of warehouses may look different in the future. Distribution centers will be located strategically to tackle the increasingly challenging last-mile delivery. This period of transition means that regions that are home to large amounts of freight activity can experiment with how facilities are structured in the future. The creation of freight hubs may become more common as the benefit of centralizing activity grows.

Figure 4. Warehouses, Distribution Centers, and Intermodal Facilities.

Infrastructure Close-Up

Cargo transitions take place most often at warehouses, distribution centers, and intermodal facilities. Companies use **warehouses** to store large quantities of cargo, located outside urban centers because the cost of space within urban regions is prohibitive. Manufacturers must maintain warehouses because they cannot perfectly align their production with consumer demand. Warehouses are expected to expand vertically as automation makes it easier to log the location of inventory and quickly retrieve product as needed.

Distribution centers are smaller facilities where individual orders are prepared and loaded for delivery to a consumer. These locations are typically located within the urban environment so that smaller delivery vehicles can make more trips to and from the location within a given day. The function of distribution centers remains important, but their location will need to be decided carefully to enable the operation of last-mile delivery vehicles.

Intermodal facilities are unlikely to relocate but will likely invest in automated technologies that can support drayage. These facilities can receive and distribute massive volumes each day, but to keep up with demand, they will need to operate efficiently. Connectivity allows trucks to report an early or late arrival so the queue can shift with roadway conditions.

An interesting example is in Fort Worth, TX, where AllianceTexas is launching the Mobility Innovation Zone (MIZ) to provide a proving ground for unmanned aerial systems and automated freight. The large scale of the facility allows for automated freight companies to determine what intermodal interactions will look like in the future. The MIZ has an industrial airport and a rail yard along with close proximity to I-35, allowing easy access to the highway network. This means the companies operating here can navigate interactions with two of the three most common intermodal transitions. The MIZ is also home to warehouses for companies, so movement from warehouses to distribution centers can be tackled. Freight hubs like the MIZ will likely become a popular way to pilot new technologies since the private ownership allows for flexibility to test rapidly, and collaboration with the public sector supports future growth to broader deployment. The public sector should foster efforts like these because they provide test beds to learn from. Lessons learned in the MIZ may be broadly applicable as automated technologies continue to grow. Additionally, the success of the MIZ would be beneficial for the freight ecosystem and the economy.

As companies integrate automated technologies into their delivery system, there will be changes at connection points within the journey of cargo from manufacture to delivery. More warehouses will be located close to highways so highly automated trucks can access them without navigating complex urban environments. As the space that warehouses occupy becomes more valuable, they could transition to a more vertical footprint to make use of the land companies own. Ports have a proven system for creating a digital inventory where the location of everything is maintained so that sorting a delivery of inventory and preparing a shipment both run more smoothly. The location of distribution centers will need to be carefully selected to allow access to consumers and to consider the needs of last-mile delivery vehicles. Last-mile delivery vehicles operate on a subset of the full roadway network, so distribution center location is critical to the ability to efficiently make deliveries.

Lastly, until automated technology is ubiquitous, automated technology will operate alongside human-operated systems. This will provide an interesting set of challenges where most structures are neither designed with only human operators or automated operators in mind. The supply chain structure will persist, but the connection points will transform alongside the changes occurring on the roadways to accommodate new highly automated technologies.

Opportunities

Warehouses, distribution centers, and intermodal facilities provide vital connection points along the journey of cargo. To continue growth, the Texas CAV Task Force sees the following opportunities:

- Monitor the changes in location and structure of facilities to understand how automation may impact land use in the long term.
- Support warehouses, distribution centers, truck stops, and intermodal facilities in creation of more test beds for automated freight technologies.

Last-Mile Delivery

Traversing the last-mile delivery leg is complex and dynamic, but increasing demand is fueling growth and pushing the development of automated delivery vehicles.

The Challenge and the Opportunity

Last-mile delivery involves transporting goods—everything from groceries and packages to meals and last-minute items—the final step to the customer's door. Last-mile delivery is both the most time-consuming and most expensive part of the delivery process, often costing over half of the delivery costs, because it involves multiple stops along a route that could be spread across several miles (17). Automating last-mile delivery offers significant value to Texas residents and businesses. First, the sector presents a tremendous boon to the Texas economy. Automated last-mile deliveries are forecasted to generate almost $50 billion in global revenue by 2030, according to a new report from Lux Research (18). Second, the COVID-19 pandemic has brought to light a public health benefit of contactless delivery. AVs are delivering groceries to seniors, meals to busy families, and medicine to those in need. Finally, automated last-mile delivery promises to reduce the per-parcel cost of last-mile delivery (19).

With increasing customer expectations for fast and free delivery, retailers and logistics partners are looking to new technologies such as CAVs to drive business improvements. However, these vehicles must navigate complex roadway environments that were not designed with the presence of CAVs in mind. Delivery robots operate in the street and on the sidewalk (Figure 5). It is challenging to operate on sidewalks without creating conflict between delivery robots and pedestrians. Operating on public roads requires higher speeds of travel and compliance with rules of the road. Delivery robots find signalized intersections particularly complex because of the interaction with pedestrians, bicyclists, and human-operated vehicles. While there is significant value in automating the last-mile journey, it is a difficult landscape to navigate and can be aided and accelerated with beneficial adjustments to infrastructure for more successful deployments.

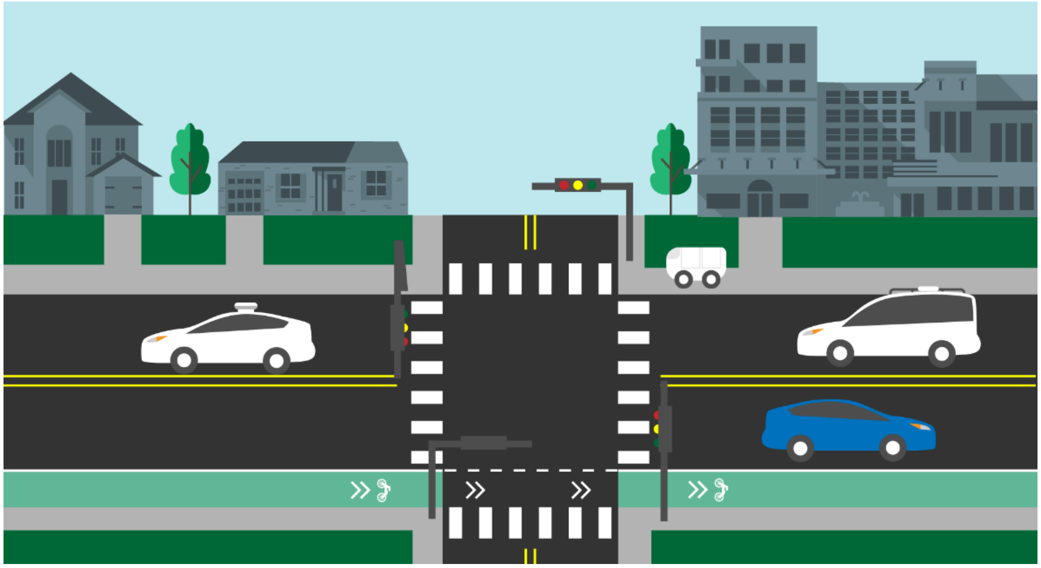

Figure 5. Challenging Roadway Environment for Last-Mile Delivery.

Infrastructure Close-Up

Personal Delivery Devices

PDDs typically use the existing sidewalk infrastructure to make small deliveries to the doorstep of a customer. The PDD, typically wheeled, must navigate around city infrastructure such as light poles and fire hydrants along with urban infrastructure such as benches, outdoor restaurant seating, menu boards, and others. In addition to static obstacles, sidewalks are a busy place in urban regions. The PDD may encounter pedestrians, dogs, bicyclists, or scooter users on a regular basis. While the PDD can govern its own behavior, it cannot control the behavior of humans with whom it must interact. PDDs must operate with an abundance of caution because they exist within a space designated for pedestrians. In many situations, the existing infrastructure may not be well suited for broad deployment due to challenges with accessibility, and interactions with humans have not been addressed.

Sidewalks are a critical part of the transportation infrastructure but can present a challenging operational environment. In urban environments, there are often missing sidewalks, curb cut variations, and obstacles that are difficult for wheelchair users and pedestrians alike. Companies operating PDDs on the sidewalk are programming their vehicles to navigate the complex environment; however, it is an evolving process.

During a pilot at the University of Pittsburgh, a PDD pilot was put on hold for a few days after a robot accidentally blocked a wheelchair user from accessing a curb cut. Recounted by Emily Ackerman in an article she wrote about her experience, “It didn’t move as the walk signal was ending. I found myself sitting in the street […] blocked by a non-sentient being incapable of understanding the consequences of its actions” (20). The company in charge of the pilot took quick action and made sure the robot would not loiter in curb cuts, but the event made clear that it is difficult to avoid potential conflicts in the existing infrastructure.

More generally, a PDD cannot anticipate every event that it will encounter when expected to operate alongside humans. Companies are investing in remote operation capabilities, which could enable an operator to take control of the vehicle in an unexpected situation. Cities are also exploring new ways to allocate their rights of way, including a dedicated lane concept, although such a designation is by no means mandated, and companies are actively working to develop operational premises for the infrastructure conditions that exist today. As vehicles and operating conditions continue to develop, the industry could see significant changes to infrastructure development and use.

If provided, a dedicated lane for delivery robots would function similarly to a bike lane. Space would be set aside within the street or sidewalk specifically for PDD operations. Cities could also create slow lanes, where PDDs could share space with bicycles, scooters, skateboards, runners, and other slower-moving vehicles (21). While remaining vigilant, the PDD would be able to operate in the protected lane more comfortably without needing to share space with pedestrians or navigate unexpected obstacles. The challenge lies in identifying available space within the right of way to develop a network of dedicated lanes. This would require a shift in planning but could make the broad deployment of PDDs more feasible. In the future, a network of sidewalks could be designated for pedestrians and delivery robots. Creating a painted marking or sign could identify the presence of these delivery robots so that pedestrians are not surprised when they come upon one.

Automated Delivery Vehicles

Another strategy for tackling last-mile delivery has been the development of automated delivery vehicles that operate on roadways, typically along neighborhood streets. These vehicles must share the roads with cars, bicyclists, and scooter users. At intersections, the vehicle must be aware of pedestrians. Additionally, they are challenged in navigating unprotected left turns and instances of road work. While companies are improving the left-turn capabilities, public agencies are focused on providing clear signage and maintaining an accurate database of ongoing road work.

One company, Nuro, has deployed in Houston, TX, to provide grocery delivery service. The company was awarded an exemption from NHTSA to operate its vehicle on public roads without having a steering wheel or brake pedal. However, federal legislation classifies the vehicle as a low-speed vehicle (LSV), and therefore it cannot travel over 25 mph without falling into a new vehicle classification. This restriction limits the geographic reach of these delivery vehicles. The exemption applies to the requirements that an LSV be equipped with exterior and/or interior mirrors; have a windshield that complies with FMVSS No. 205, “Glazing Materials”; and have a backup camera system that meets the requirement in FMVSS No. 111, “Rear Visibility,” limiting the length of time that a rearview image can remain displayed by the system after a vehicle’s transmission has been shifted out of reverse gear.

Texas deployments could consider strategically expanding the geographic reach of automated delivery vehicles to address food deserts and provide access to healthy foods without requiring a car. However, the network in which these vehicles can operate is limited. Due to federal legislation, LSVs cannot go over 25 mph and, due to state legislation, are only allowed to travel on roads with a posted speed limit up to 10 mph above their maximum speed. In other words, LSVs cannot travel on roadways with a posted speed limit greater than 35 mph in Texas.

States can consider enabling LSVs to travel on roads with higher posted speeds in order to access more households. In the case of Houston, key roadways could be identified to create a network for the automated delivery vehicle. Appropriate signage could be posted so that drivers are aware of the delivery vehicle operating at a lower speed. By expanding access to customers, automated delivery vehicles could provide a way to learn about implementing CAVs on neighborhood streets that can provide valuable insights for infrastructure enhancements and additional services.

Opportunities

Last-mile delivery is complex, which means that Texas should be proactive in addressing concerns that prevent automated delivery vehicles from navigating the urban landscape. Rather than slowing down the adoption of these new technologies, Texas infrastructure owners and operators are seeking to accelerate their ability to integrate them. The Texas CAV Task Force has identified the following opportunities:

- Collaborate with last-mile delivery vehicle companies and cities to plan for future infrastructure needs, including designating a network of automated delivery roadways to address food deserts and establishing dedicated lanes for PDDs.
- Consider posting signage along automated delivery routes to create awareness of the automated delivery vehicles and support updates to the *Manual on Uniform Traffic Control Devices* where applicable.
- Support the development of policy that allows AVs to operate in state without inapplicable equipment requirements.

A Changing Workforce

Automation is disrupting the transportation workforce, but it does not have to mean that jobs will disappear. Preparing now for the changing workforce demands can enable Texas to mitigate worker displacement, create new jobs, and bolster its economy.

The Impacts of Automation

Several theories are predicting how and when automation will hit the transportation sector. One outcome is that transportation will follow the same fate as the manufacturing industry, permanently replacing jobs with more cost-effective machines. Or transportation may follow the path of the banking industry, transmuting workers into new positions and creating jobs that require new skills. When one in sixteen jobs in the state is directly supported by the freight sector, it is essential that Texas get it right. By investing now in workforce development programs, Texas can mitigate displacement and upskill its workforce.

The Current Driver Shortage

With over 172,000 people employed as truck drivers, Texas has more truck drivers than any other state—and yet there is a significant driver shortage. In 2018, the American Trucking Association estimated a shortage of 60,800 drivers with the potential to reach 160,000 by 2028 (12). Several factors contribute to the shortage; in its simplest form, fewer qualified drivers are applying while experienced drivers continue to retire, and more and more drivers are needed to fulfill the increased demand.

The current driver stock is aging out as the industry is growing. The industry is struggling to attract younger drivers, often pointing to the arduous lifestyle. The long stretches of travel take their toll, making it difficult to spend time with family, exercise, or eat healthy, and lead to high turnover rates. In addition, the pay structure is far behind the curve. While drivers' salaries have increased, they are still as much as 50 percent lower than they were in the 1970s when adjusted for inflation. Additionally, regulating drivers to 11 hours per day for driving and the more recent mandate requiring an electronic logging device (ELD) has continued tension between safety advocates and the trucking industry. Safety advocates consider ELDs to be a technology platform that prevents the falsification of records, minimizes violations of federal hours-of-service limitations, and improves safety by reducing driver fatigue. On the other hand, the mandate has exacerbated an already tightening labor market, and many truckers have left the business. The full safety and labor effects of the ELD mandate are still being studied, particularly the impacts to small carriers who are most affected by the mandate (22). At this critical inflection point, Texas has an opportunity to turn the driver shortage around by investing in the development of its workforce and looking for ways to attract a new generation.

Disrupted but Not Displaced

While the concern of job loss from automation is very real, the truck-driving profession is far from obsolete (23). First, the future of freight operations will continue to rely on the experience and expertise of truck drivers. Trucking companies are transitioning from a driver to an operator model where the human performs fewer and fewer driving tasks; currently, the human operator typically drives the first and last mile, takes over the vehicle if it encounters an unfamiliar situation, and loads/unloads the vehicle at its destinations. In the long term, drivers will likely retain responsibility for first- and last-mile segments, with highly automated trucks operating without a driver across the middle mile. Another model under development is remote operations, where a fleet would be monitored by humans and, if necessary, controlled from a central command center. In any scenario, companies will continue to rely on truck drivers with roadway experience to support operations in various ways.

Second, the changes in the trucking industry have the potential to attract a new generation of workers. Fully automated trucking will still rely on human drivers for short haul and driving in urban environments, creating more trucking jobs that allow drivers to stay close to home. Additionally, the opportunity to be a remote operator is a fundamental change to the truck-driving lifestyle that makes the profession more appealing. With the rise in e-commerce and population growth, Texas anticipates an increased demand for goods and therefore goods delivery.

Third, the pathway to full automation will be a gradual transition, and some tasks may never be automated. Within the near future, the truck driving experience will be enhanced with advanced driver assistance systems that assist with driving tasks like lane keeping and adaptive cruise control. The next wave of automation focuses on automating driving tasks in simple environments: the middle mile of long-haul trips, guided movements within warehouses, and last-mile deliveries in designated zones. Meanwhile, more complex tasks such as navigating through inclement weather, conducting safety inspections, handling freight, refueling, managing customer relationships, or changing a flat tire will still require a human touch. Disaster response is a specialized area that will continue to require manual operations. During strong storms or in the aftermath of a hurricane, Texas depends on experienced truck drivers to restock grocery shelves, deliver medical supplies, and evacuate residents. To accommodate the transition, Texas has an opportunity to proactively support truck drivers and other supporting industries with new skills and training.

A Growing Gig Economy

With the advent of smartphone technology, the way that people view and perform work has altered over the past decade. For example, DoorDash is a smartphone-app-based platform that lets customers order food to be delivered. The customer inputs an order from an area restaurant, and DoorDash offers the gig to its workers, who can choose to accept, deliver the food, and get paid. What is different about this model is that a gig worker is paid by the task, not by the hour or by a salary. Some of these companies, including DoorDash, are testing automated delivery. While there are concerns that companies are using more automated systems to reduce their reliance on human delivery drivers, the technology also presents the opportunity to support retail outlets by expanding customer deliveries and create new jobs. Automation has the potential to accelerate the need for and size of the gig economy (24). As the gig economy continues to grow, Texas can support workforce education and training programs to equip truck drivers and gig workers alike with new skills.

Education and Training

The future of trucking will offer new employment opportunities for today's drivers but will require a new set of skills.

Partnerships in Education

With a shared interest to invest in local talent, companies are forging partnerships with educational institutions and launching new training programs. For example, automated trucking companies are working with community colleges and vocational schools to create curricula, teach courses, and provide hands-on training with highly automated trucks. Then, the companies prioritize hiring graduates of the program to work at their testing and development centers. Texas can similarly encourage companies that are testing and operating in the state to partner with its school system to cultivate a talent pipeline in a growing industry.

The Bigger Picture

Automation will affect many areas of the transportation industry beyond truck drivers—other drivers such as bus drivers and taxi drivers but also other sectors such as repair shops, manufacturing, and automobile insurance. There are several opportunities to create jobs in industries that support trucking; and as trucking becomes more efficient, the economy grows. Drayage, for example, is a potentially complex environment where human jobs can be created. Texas needs to be proactive in its approach and to think holistically about the shifts that are under way. Existing workforce development programs may be leveraged to prepare for automation. In particular, the Texas Workforce Commission manages a Skills Development Fund and an Apprenticeship Program that could support transportation workers who are interested in acquiring new skills related to CAV technologies. As the state emerges from the COVID-19 pandemic, Texas can ease reentry for workers by providing training opportunities.

Opportunities

The progression of AV technology development is expected to accelerate over the next decade. The Texas CAV Task Force has identified the following opportunities:

- Prioritize upskilling for truck drivers and others who may potentially be displaced.
- Encourage companies that are testing in Texas to partner with local educational institutions.
- Integrate training in CAV technologies into existing workforce development programs.

Connected Freight

Information provided by CV technology is valuable to current human truck drivers and has the potential to enhance highly automated truck operations in the future.

The Challenge and the Opportunity

The freight ecosystem thrives on good information, and CV technology can provide better, more accurate information. Historically, truck drivers have gathered their information "through the windshield" and adapted their delivery schedule with changing road conditions. As companies rely more on just-in-time deliveries and consumers expect timeliness, the value of accurate and up-to-date information has grown, and companies are updating their practices to keep up. Increasing connectivity in the trucking arena has been transforming the availability of information that is available at the right time and place. As in the automotive industry, connectivity can be as simple as a 4G LTE cellular connection, which enables in-vehicle applications and information sources to provide information to drivers.

However, in the area of safety-critical applications, CV infrastructure enables trucks to communicate with infrastructure and other equipped vehicles on the roadway. This allows a crowdsourcing of updates on important conditions such as queues of stopped traffic, hazardous weather conditions, or work zones ahead. Texas already has extensive information on the location and timing of work zones, low-clearance bridge locations, and other infrastructure challenges. Deploying CV technology allows for the broadcast of this information, which will improve operations and subsequently boost the economy. Once more vehicles are equipped, there is potential to power the implementation of safety enhancement technologies, such as emergency electronic brake lights. CV technology has economies of scale, and it will take time to realize the full potential of the technology. It is important that Texas invests early on and does not fall behind. Additionally, some new intersection control innovations that may be necessary for enhancing CV operations include freight signal priority and the ability for PDDs to trigger pedestrian walk calls in order to cross intersections safely.

While Texas has begun investing in CV infrastructure, challenges exist to widespread adoption of the technology. Enabling this type of connectivity in the freight ecosystem has relied on instrumenting trucks with onboard units (OBUs) and installing roadside units (RSUs), with a corresponding challenge for the public sector in deciding how fast to deploy RSUs. Fleet owners have been hesitant to install OBUs because of the cost and the time required for installation with little return due to the lack of CV infrastructure. At the same time, public agencies want to deploy CV technology that will be used immediately.

Simultaneously, the spectrum is controlled at the federal level, and recent rulings by FCC have led to changes in the spectrum allocation. Existing DSRC licenses are able to continue operating in the upper 30 MHz; however, existing operations in the lower 45 MHz are required to cease operations after the one-year transition period. FCC is seeking comments on the appropriate transition paths for existing DSRC operations. FCC has embraced C-V2X and allocated bandwidth for those communications. Moving forward, the public and private sectors will need to work together to deploy CV technology at a similar pace so that there are adequate returns for both entities and with due consideration to the areas of information versus safety applications. CV technology ties back to automated developments, too. CV technology enables AVs to communicate with the road and other traffic. As of yet, it is unclear whether connectivity is essential to the success of automated freight or tangential. Automated freight developers have generally described connectivity as a “nice to have,” not a “must have.”

Infrastructure Close-Up

Texas has started building the CV ecosystem across a number of deployment projects. Cities have done small pilot deployments on local roadways to understand how CVs might fit into the existing network. TxDOT has developed standards for smart work zones, enabling them to broadcast information.

The largest CV freight project in the state is the Texas Connected Freight Corridors (TCFC) project, which will instrument the Texas Triangle. In addition, freight partners have joined the project and will equip their vehicles to communicate with the deployed RSUs. This project sets up a foundation for CV technology that Texas can build on to realize the potential benefits. Through these efforts, the state can develop standards, collect lessons learned, and identify high-value deployment locations. The adoption rate of OBUs will take time to increase, but the presence of RSUs makes acquiring a CV more appealing. Texas should continue to invest in building the network of RSUs and educate consumers on the benefits of CV technology.

RSUs and OBUs operate by transmitting and receiving information, which must be done over a common frequency for the two to make a connection. DSRC and cellular communications (C-V2X) have been the two most popular solutions for communications with implementations of both. While DSRC was operating on a 75-MHz spectrum in the 5.9-GHz band, a recent FCC ruling allocated the lower 45 MHz of the safety band to unlicensed usage and reserves the upper part of the bandwidth for C-V2X. Existing DSRC licenses are able to continue operating in the upper 30 MHz; however, existing operations in the lower 45 MHz are required to cease operations after the one-year transition period. FCC is seeking comments on the appropriate transition paths for existing DSRC operations (7).

The option of using the cellular network (C-V2X) is the most immediate alternative in any situation where DSRC is no longer viable. The network has existing coverage for a broad majority of the country and provides another option for quickly transmitting information. However, there are concerns about the ability for cellular communications to perform with the same low latency that DSRC can achieve, which enables high-value safety applications. The development of dual-mode devices has been explored and may provide a short-term bridge while DSRC is still allowed to operate. This shifting landscape has made the recent conversations surrounding CV technology more complex, but the FCC ruling provides a clear direction for the marketplace to advance in the future.

Opportunities

Texas has made great strides in putting together CV deployment projects early on and should continue to support the growth of this technology. CV technology is not among the highest priorities for highly automated truck companies because it only supplements operations, but there is still value in CV investments. The Freight and Delivery Subcommittee of the Texas CAV Task Force has identified the following opportunities for Texas:

- Expand the Texas connected freight network to include local roads, using the TCFC project as an opportunity to develop critical applications, gain experience in CV technology, and formulate best practices for deployment.
- Continue to discuss information-sharing opportunities with the private sector, including items related to geometry, signage, and safety.
- Work with the private sector to identify opportunities for increased CV connectivity and technology, and work with partners to identify high-priority applications and locations for future efforts.
- Provide information on executed and planned CV deployments to the public and educate them on the benefits of adopting the technology.

Summary of Freight and Delivery Subcommittee Opportunities

In summary, the Freight and Delivery Subcommittee of the Texas CAV Task Force has identified the following opportunities for Texas:

- Prioritize roadway maintenance along CAV corridors, focusing on lane striping, pavement quality, and signage.
- Sponsor research into gaps in common infrastructure challenges such as work zones, forced merges, and transfer points.
- Expand the Texas connected freight network to include local roads, using the TCFC project as an opportunity to develop critical applications, gain experience in CV technology, and formulate best practices for deployment.
- Continue to examine the potential needs for infrastructure enhancement and/or refinement, including items such as transfer points, changes to sidewalk design, and ways that multiple vehicle types can travel safety and cooperatively on the same infrastructure at different speeds.
- Continue to discuss information-sharing opportunities with the private sector, including items related to geometry, signage, and safety.
- Work with the private sector to identify opportunities for increased CV connectivity and technology and work with partners to identify high-priority applications and locations for future efforts.
- Provide information on executed and planned CV deployments to the public and educate them on the benefits of adopting the technology.

- Invest in workforce development programs that upskill workers and create new educational pathways.

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APPENDIX F

Connected and Automated Vehicle Licensing and Registration

Texas CAV Task Force White Paper
Subcommittee on Licensing and Registration

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Acknowledgments

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Disclaimer

The contents of this white paper reflect the views of the Texas CAV Task Force members, who are responsible for the information presented herein. The contents do not necessarily reflect the official views or policies of the State of Texas or any Texas state agencies. The white paper does not constitute a standard, specification, or regulation, nor does it endorse standards, specifications, or regulations. This white paper does not endorse practices, products, or procedures from any private-sector entity and is presented as a consensus broad opinion document for supporting and enhancing the CAV ecosystem within Texas.

Texas CAV Task Force Charter

The Texas CAV Task Force was created at the request of Texas Governor Greg Abbott in January 2019. The Texas CAV Task Force is responsible for preparing Texas for the safe and efficient rollout of CAVs on all forms of transportation infrastructure.

The primary functions are:

1. Coordinating and providing information on CAV technology use and testing in Texas.
2. Informing the public and leaders on current and future CAV advancements and what they mean in Texas. This process includes reporting on the current status, future concerns, and how these technologies are changing future quality of life and well-being.
3. Making Texas a leader in understanding how to best prepare and wisely integrate CAV technologies in a positive, safe way, as well as promoting positive development and experiences for the state.

The Texas CAV Task Force is composed of a voting group of no more than 25 members and represents the full spectrum of CAV stakeholders.

Terminology Note

The Texas CAV Task Force addresses the full spectrum of connected, automated, and autonomous vehicles. An *automated vehicle* refers to a vehicle that may perform a subset of driving tasks and require a driver to perform the remainder of the driving tasks and supervise each feature's performance while engaged. A *fully autonomous vehicle* refers to a vehicle that can perform all driving tasks on a sustained basis. These definitions are still blurred in common discussions and language. Currently, the industry is developing automated vehicle capability while pursuing fully autonomous vehicles. The white papers generally use the term *autonomous* to refer to the vehicles with fully autonomous capabilities and the term *CAV* to refer to the grouping of connected, automated, and autonomous vehicles. Please see the "CAV Terminology" white paper for a full listing of terms and definitions used in this developing technology ecosystem.

List of Terms and Acronyms

ADS	automated driving system
ADS 2.0	*Automated Driving Systems: A Vision for Safety 2.0*
AV	automated vehicle
AV 3.0	*Preparing for the Future of Transportation: Automated Vehicles 3.0*
CAV	connected and autonomous vehicle; also, connected and automated vehicle
CDL	commercial driver license
CMV	commercial motor vehicle
CV	connected vehicle
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulation
FMVSS	Federal Motor Vehicle Safety Standard
GVWR	gross vehicle weight rating
NHTSA	National Highway Traffic Safety Administration
OEM	original equipment manufacturer
PDD	personal delivery device
TDI	Texas Department of Insurance
TNC	transportation network company
TxDMV	Texas Department of Motor Vehicles
TxDOT	Texas Department of Transportation
TxDPS	Texas Department of Public Safety
USDOT	U.S. Department of Transportation
VSSA	Voluntary Safety Self-Assessment

Executive Summary

In 2017 and 2019, the 85th and 86th Texas Legislatures enacted legislation to create a regulatory framework to allow for connected and automated vehicles to be tested and deployed in Texas. In 2017, the Texas Legislature passed laws changing vehicle following distances to allow for truck platooning and adding rules for automated vehicles (AVs) to operate within Texas. In 2019, the Texas Legislature passed a bill to allow personal delivery devices (PDDs) to operate on sidewalks and crosswalks. This paper examines how these laws have led to a recent wave of innovation and experimentation—on roads, streets, and sidewalks; in cities; and on rural highways—operating within a range of public- and private-sector agencies and operators with state regulations that focus on regulating drivers and operators and on regulating vehicles.

A range of automated vehicles have been deployed and tested in Texas:

- Large and small freight vehicles (some with safety drivers, some in automated operation).
- Zero-occupant delivery vehicles on roadways.
- Shuttles and robotaxis carrying passengers on roadways.
- Personal delivery devices (PDDs) operating on sidewalks and crosswalks.

The Texas Department of Public Safety (TxDPS) has responsibility for licensing drivers for automobiles and light trucks and for commercial vehicles. TxDPS also regulates vehicle inspection stations that offer annual safety inspections (that enforce state laws establishing vehicle safety standards) as well as emissions testing in 17 counties in nonattainment areas. TxDMV is responsible for the registration (vehicle operation) and titling (vehicle ownership) of vehicles and commercial fleet services in Texas. Proof of insurance is required before vehicles can be registered. TxDMV is also responsible for regulating the sale of motor vehicles by licensed dealers. In Texas, manufacturers may not sell vehicles directly to customers, and all vehicles must be purchased from a licensed dealer. The Texas Department of Insurance (TDI) regulates insurers providing mandatory auto insurance policies for all drivers, personal and commercial. State, county, and local law enforcement agencies are authorized to enforce state laws on motor vehicle operations on roadways in their respective jurisdictions. At the Federal level, the National Highway Traffic Safety Administration sets the Federal Motor Vehicle Safety Standards (FMVSS) aimed at increasing safety on roadways and reducing vehicular accidents. The FMVSS stipulate specific design, construction, performance, and durability standards for all motor vehicles, personal and commercial. The Federal Motor Carrier Safety Administration (FMCSA) sets national commercial drivers licensing standards and sets hours-of-service regulations for interstate truck drivers. The FMCSA also issues certificates of operating authority for commercial motor vehicle (CMV) fleet owners; and the Texas Department of Motor Vehicles (TxDMV) also registers CMV fleets transporting passengers or cargo on CMVs with over 26,000 pounds or more gross vehicle weight.

Texas law authorizes operation of automated motor vehicles without human operators. This 2017 law establishes that an automated driving system is considered to be licensed to operate a motor vehicle when the automated driving system is engaged. This section also makes the owner of the automated driving system responsible for compliance with traffic or motor vehicle laws, with or without a test driver present. State laws requiring state inspections to enforce vehicle equipment standards do not make any allowances for specially equipped and manufactured AVs. The FMCSA is working to adapt current CMV regulations to accommodate automated driving systems, but those regulations are not being adjusted for incremental adoption of advanced driver assistance systems that might enhance operational safety without eliminating driver control of the vehicle. Texas laws do not currently exempt AVs from TxDMV registration requirements if the vehicles are operated on public highways, nor do they exempt AVs from compliance with motor vehicle dealer sales and lease regulations administered by TxDMV. Transportation of passengers for hire requires operating authority certification from TxDMV regardless of vehicle size. AVs operated by transportation network companies are subject to insurance requirements set by law for those firms. State law has authorized operation of PDDs on city sidewalks, but the state establishes no registration or inspection requirements of the vehicles.

By enacting AV legislation in 2017, the Texas Legislature created an environment that has allowed the AV industry to expand its testing and development in Texas. By clarifying the legal obligations of AV developers and vehicle owners, Governor Greg Abbott and the Texas Legislature have increased the regulatory certainty for these firms to consider deployment and development opportunities in Texas. This white paper identifies opportunities for adding regulatory clarity for more AV innovation:

- AV developers and the TxDPS could collaboratively discuss compliance with state motor vehicle equipment standards and current AV configurations, particularly for PDDs and zero-occupant vehicles.
- AV developers and manufacturers, TxDMV and the Texas Automobile Dealers Association could discuss how current dealer licensing/sales laws and registration rules affect the range of commercial relationships between original equipment manufacturers and AV developers.
- If some AV developers are considering alternatives that include AV operation entirely by remote operators (rather than by onboard software that controls vehicle driving tasks), the AV industry may want to interact with applicable state agencies to determine how the current regulatory structure addresses such operations.
- The AV industry and national associations of state transportation and motor vehicle agencies can develop guidelines for best practices for identifying AV vehicles and responsible parties for meeting licensing and operating requirements of state law

Introduction

Connected vehicles (CVs) are vehicles capable of communicating with other objects through wireless data platforms. Automated vehicles (AVs) are vehicles that use sensors, computers, and other tools to take over driving tasks from a human driver. Since 2017, regulatory and legislative guidance and activity have largely pertained to AVs, which are the focus of this paper. SAE International outlines a taxonomy with five levels of automation for vehicles that range from no automation, where a human operator must perform all driving tasks, to full automation, where all driving tasks are performed by the vehicle itself with no need for a human driver. Testing of AVs is being actively pursued in Texas across many platforms, such as personal delivery devices (PDDs), motor vehicles, shuttles, and commercial motor vehicles (CMVs). The purpose of this paper is to highlight the licensing and registration implications related to AVs operating within Texas.

Public Agency Roles and Responsibilities

Many public agencies can impact AV policy. This section highlights the public agencies that will play an important role in developing and implementing AV policy in the years to come.

U.S. Department of Transportation

The U.S. Department of Transportation (USDOT) is tasked with making sure that America's transportation system operates in a safe and efficient manner. USDOT houses many agencies that also play significant roles in their own rights. In these early stages of AV development, USDOT has not enacted regulations so that the emerging technology can be developed in a way that encourages innovation. However, USDOT has urged state and local governments, original equipment manufacturers (OEMs), research and safety institutions, and other stakeholders to be actively engaged in the development of the guidance that it produces (1).

USDOT has produced three documents that provide guidance related to AV activities:

- ***Automated Driving Systems: A Vision for Safety 2.0*** (ADS 2.0) was published in September 2017 by the National Highway Traffic Safety Administration (NHTSA) and provides voluntary guidance for stakeholders to develop AV technology (1).
- ***Preparing for the Future of Transportation: Automated Vehicles 3.0*** (AV 3.0) was published in October 2018 by USDOT and expands the guidance developed in ADS 2.0 to reduce the uncertainty surrounding AVs and outline a process for stakeholders to engage with USDOT on AV policy (1).
- ***Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0*** was published in January 2020 by USDOT and further expands AV guidance and seeks to develop a consistent high-level policy approach to AV development and deployment (1).

In March 2018, President Trump signed the Consolidated Appropriations Act 2018 into law. This act provided $100 million in funding for the research and development of AVs (2).

USDOT has taken a cautious approach in terms of actual policy development for AVs but has remained active in engaging with stakeholder groups and providing high-level guidance and oversight.

Among USDOT's first steps in creating a framework around AVs was to develop the concept of Voluntary Safety Self-Assessments (VSSAs). VSSAs entail 12 sections—ranging from system safety and validation methods to consumer education and government engagement—where companies document and explain how they approach and ensure safety. The level of detail in these reports continues to advance as companies' technologies and safety management evolve.

In AV 3.0, USDOT expanded its guidance to incorporate CMVs. Notably, USDOT and the Federal Motor Carrier Safety Administration (FMCSA) concluded that SAE Level 4 operation for commercial vehicles was allowable under existing trucking regulations, noting that "FMCSA regulations will no longer assume that the CMV driver is always a human or that a human is necessarily present onboard a commercial vehicle during its operation." Furthermore, FMCSA asserted preemption authority over state or local legal requirements that interfere with the application of federal motor carrier safety regulations, including as they pertain to automated driving system (ADS) development, testing, and deployment in interstate commerce.

National Highway Traffic Safety Administration

NHTSA is the USDOT agency charged with developing and issuing Federal Motor Vehicle Safety Standards (FMVSSs) aimed at increasing safety on roadways and reducing vehicular accidents. The FMVSSs stipulate specific design, construction, performance, and durability standards for motor vehicles and are codified in Title 49 §571 of the U.S. Code of Federal Regulations (3).

NHTSA's authority has two main implications for AVs. First, because FMVSSs have not yet been updated for vehicles that are designed to operate without a human driver, any AV would either have to be compliant with all relevant existing FMVSSs required of any other vehicle or receive an exemption if some aspect of the AV were not compliant. Depending on the intended use case of an AV, some existing FMVSSs that are important for human-driven vehicles end up being largely irrelevant for AVs. One example is Title 49 §571.103 of the U.S. Code of Federal Regulations, which requires windshield defrosting and defogging systems. In the case of a fully autonomous passenger vehicle where there is no driver, for example Waymo's One, a passenger would not need to be able to see the roadway, and the need would be negated. However, this equipment would still be mandatory unless the AV developer successfully petitioned for an exemption to §571.103. Similarly, fully autonomous delivery vehicles, such as Nuro's R2, where only cargo is in the vehicle, would not require traditional safety standards; Nuro was able to receive an exemption that did not require the vehicle to have windows. However, many AV developers, especially those developing automated commercial vehicles, are building on top of FMVSS-compliant vehicles and therefore would not need FMVSS exemptions.

The second potential NHTSA impact on FMVSSs is that given NHTSA's authority to regulate vehicle equipment, NHTSA would be the lead agency to define any ADS equipment or performance requirements. To date, NHTSA has not yet provided any regulations exclusively pertaining to AVs. NHTSA will continue to play a vital role in the development of safety standard policy for AVs for the foreseeable future. A 2016 enforcement guidance bulletin reiterated NHTSA's broad enforcement authority under existing statutes and regulations to address existing and emerging automated safety technologies to protect the safety of the driving public against unreasonable risks of harm.

NHTSA recently also implemented the AV TEST program to help educate the public on where and how ADS testing and development take place. In response to many state and local jurisdictions asking for more information on nearby testing, NHTSA created an interactive Test Tracking Tool where the public can view up-to-date information on each company's testing activity. This tool launched in September 2020 of this year with a limited set of test participants, but NHTSA will allow all ADS developers to publish data in the tool in late 2020.

Federal Motor Carrier Safety Administration

FMCSA regulates interstate commercial vehicle operations, including setting licensing standards, hours-of-service limits, and safe operation practices through Federal Motor Carrier Safety Regulations (FMCSRs). FMCSA also provides guidance to state enforcement agencies on CMV inspection and enforcement activities. Unlike passenger vehicles, federal regulation of interstate commercial vehicle operations, such as large trucks and buses, is much more extensive given their role in interstate commerce. A wide range of FMCSRs relate to driver requirements, behaviors, or activities, making them highly relevant to connected and automated CMVs. In AV 3.0, FMCSA asserts its authority to take enforcement action if an automated system inhibits the safe operation of a CMV, while concluding that automated CMV operation is allowable under existing FMCSRs, assuming it can be compliant with the same operational requirements as a human-driven CMV. Furthermore, AV 3.0 notes FMCSA policy would no longer assume that the driver of a CMV is always human or that a human is necessarily on board, and that human-specific FMCSRs, such as drug testing and hours of service, would not apply to SAE Level 4 or 5 CMVs operating without a human driver.

Addressing the impact of differing state AV testing and deployment policies on automated CMVs engaged in interstate commerce, AV 3.0 notes that "if FMCSA determines that State or local legal requirements may interfere with the application of FMCSRs, the Department has preemptive authority."

Texas Department of Public Safety

In Texas, the Texas Department of Public Safety (TxDPS) is responsible for issuing commercial and motor vehicle driving licenses. TxDPS officers also enforce the motor vehicle regulations and FMCSRs to maintain safe roadways. While TxDPS does not issue vehicle registrations, TxDPS officers are charged with enforcing the requirements (4). TxDPS also regulates vehicle inspection stations that offer annual safety inspections and emissions testing in 17 counties in nonattainment areas.

Texas Department of Motor Vehicles

The Texas Department of Motor Vehicles (TxDMV) is responsible for titling and registering vehicles in Texas. The revenue from motor vehicle registrations is used to build and maintain Texas roadways. TxDMV is also responsible for issuing oversize/overweight permits for CMVs and issues operating authority credentials for motor carrier firms (not just vehicles). Prior to a vehicle being registered in Texas, it must pass an inspection and have proof of insurance (5).

Texas Department of Transportation

The Texas Department of Transportation (TxDOT) is responsible for building and maintaining Texas roadways and for providing state and federal funding for transportation infrastructure, operation, and safety needs (6). TxDOT is responsible for a range of federal planning requirements and reporting, including performance measurement, asset management, infrastructure condition, strategic highway safety planning, and long-range planning. At the direction of Governor Greg Abbott, TxDOT also created the Texas Connected and Autonomous Vehicles (CAV) Task Force in 2019 comprised of industry representatives, government officials, and other key stakeholders. The Texas CAV Task Force was designed to be an information portal for all things CAV in Texas and promote opportunities for CAV growth and understanding (7).

Texas Department of Insurance

The Texas Department of Insurance (TDI) is responsible for the oversight of the insurance industry within Texas. To register a vehicle in Texas, the vehicle owner must provide proof that the vehicle is insured. In Texas, drivers are responsible for paying for accidents in which they are found liable. Insurance can pay for automobile repairs and medical bills if there is an accident (8). The Texas Legislature sets insurance requirements, and TDI regulates the insurers that offer the policies.

Municipalities and Other Local Authorities

According to Title 2 §51.001 of the Texas Local Government Code, municipalities have the power to adopt and enforce regulations that are "(1) for the good government, peace, or order of the municipality or for the trade and commerce of the municipality; and (2) necessary or proper for carrying out a power granted by law to the municipality or to an office or department of the municipality" (9). Cities and counties have responsibilities for roads, streets, and the complete right of way in their jurisdictions and for partnering with TxDOT on state highway projects, but only cities have the authority to adopt ordinances regulating land use and commercial activities. Cities also regulate taxis and limousines (passenger transportation for hire). Municipalities have the authority to enforce statutes applicable to motor vehicles operating on roads within the city's jurisdiction. Local authorities may also regulate the operation of PDDs under Title 7 §552A.009 of the Texas Transportation Code, provided their regulation is in a manner that is consistent with §552A for highways and pedestrian areas.

Other Roles and Responsibilities

Other individuals and organizations can also impact AV policy. This section highlights the other entities whose roles and responsibilities will affect AV policy in the years to come.

Original Equipment Manufacturers and Automated Vehicle Developers

Most cars and trucks are designed and manufactured by companies that FMVSSs refer to as OEMs. Many OEMs are testing and deploying driver assistance technologies that incrementally increase the driving functions that are being automated. Some OEMs are also testing AV systems to consider how to incorporate increasing levels of driver assistance and replacement in vehicles sold to customers.

In addition to OEM AV development, a range of technology firms referred to here as *automated vehicle developers* are testing systems of sensors, cameras, software, and artificial intelligence that offer levels of vehicle automation, usually as an aftermarket adaptation of existing vehicles and often with the cooperation of an OEM. Some of these AV developers are also offering commercial services (freight or passenger carriage) to consumers.

Vehicle Owners and Operators

As vehicles become increasingly automated, many Texans purchase cars and trucks with driver assistance technologies for personal use and will be responsible for operating those vehicles in compliance with all applicable state and local laws and regulations. When vehicles are operated for hire to transport freight or passengers, companies that own these vehicles and employ drivers are likewise responsible for complying with applicable laws and regulations. Current AV deployments also involve vehicle manufacturers and developers that provide services to customers.

Property Owners and Developers Supporting Experimentation

Some AV deployments have involved property owners and venues seeking to expand their brand through innovation. Automated shuttles have been tested at entertainment venues (Arlington, TX), universities (Texas A&M University and Texas Southern University), and mixed-use developments (Hillwood/Frisco Station). PDDs have been tested on the University of Houston campus. Some of these demonstrations have included transportation management associations or interlocal agreements with transit agencies.

Customers and Passengers

For those AV developers offering freight services (e.g., Kodiak, TuSimple, and Embark) as part of their testing operations, shippers and receivers are involved in the transaction and may participate in the interest of supporting innovation. Passengers choosing to board an automated shuttle are directly involved in AV testing and demonstrations. As more such services are offered, shippers and passengers will indicate their acceptance of the new technologies by their patronage. The market acceptance of such services may be critical in the continued commercial viability of AV developers and the public considering these services.

Types of Automated and Connected Vehicles Active in Texas

In 2017, Texas became one of 10 regions USDOT selected to test AV technologies. This opportunity became known as the Texas AV Proving Grounds Partnership (10). While USDOT has withdrawn all Proving Grounds designations, AV research is a continuing strength in Texas.

Large and Small Freight Vehicles Operating on Roadways with Safety Drivers

In August 2019, Kodiak Robotics announced that it was testing a commercial route of an autonomous truck with a safety driver between Dallas and Houston as an example of AV truck testing in Texas (11). Kodiak has collaborated with Texas law enforcement to provide training to officers on the trucks and how they operate. The trucks have safety drivers but computer brains that use cameras, lidar, and sensors to navigate the way. Kodiak has ensured that safety drivers meet impeccable safety and regulatory requirements, such as:

- Possessing a commercial driver license (CDL).
- Completing three years of commercial driving experience.
- Maintaining a high safety record.
- Passing a drug and background check.
- Passing an interview and road test for the autonomous vehicle (12).

Other firms testing AV trucks in Texas include TuSimple, Aurora, and Embark (testing in Texas until early 2020). These firms were attracted to Texas by the state's AV law enacted in 2017. While AV trucks are currently being tested with safety drivers, they are not required to do so under Texas law.

Autonomous Freight Vehicles on Roadways

In August 2020, Waymo announced that it had begun testing autonomous trucks along I-10, I-20, and I-45 in Texas. The current testing will use Peterbilt trucks with and without cargo, but they will not be used for commercial purposes just yet (13). Because the testing is just getting under way, it may be some time before any information is available about licensing and registration. Under AV 3.0, FMCSA has indicated that it would not apply human-oriented regulations to driverless trucks but could potentially provide rulemaking action that could be carried out by local law enforcement, for such things as motor vehicle inspections. FMCSA has taken no final action at this time.

Zero-Occupant Delivery Vehicles on Roadways

In December 2019, Nuro announced that it had begun testing a zero-occupant delivery vehicle in Houston, TX (14). Nuro has partnered with Kroger, Domino's, Walmart, and CVS in the Houston area. The vehicles are smaller and lighter than conventional vehicles, operate at lower speeds, and do not require an in-vehicle operator. Remote drivers continually monitor operation of the vehicles (15).

Shuttles and Robotaxis Carrying People on Roadways

Autonomous shuttle pilot projects have been popping up across Texas, with notable deployments under way in Arlington, Bryan/College Station, Frisco, and Houston.

Arlington

EasyMile operated an autonomous shuttle project on city sidewalks briefly in 2017. Drive.ai completed an autonomous shuttle pilot project in Arlington's Entertainment District in 2019. During the pilot project, the shuttle service completed 760 trips for 1,419 passengers, driving more than 440 miles (16). On March 16, 2020, the City of Arlington was awarded just under $1.7 million to incorporate autonomous vehicles into its on-demand carsharing program. The funding will provide wheelchair-accessible service and service for students at the University of Texas at Arlington (at no cost) (17).

Bryan/College Station

In 2019, Navya partnered with Texas A&M University to deploy an 11-passenger autonomous shuttle on campus. The shuttle operated on weekdays on a designated route on the main campus, with two designated stops. The shuttle was available to students, faculty, staff, and the local community (18).

Frisco

In 2018, Drive.ai partnered with the City of Frisco and other parties to complete an on-demand autonomous shuttle project, available in a geofenced area. During the pilot project, the shuttle service completed more than 3,000 trips for almost 5,000 passengers (19).

Houston

In 2019, EasyMile partnered with First Transit and the Metropolitan Transit Authority of Harris County to operate an autonomous shuttle on the Texas Southern University campus. The 12-passenger, fully autonomous shuttle operates on a pre-programmed, 1-mile pedestrian trail on the campus. The shuttle is available to students, staff, and visitors on weekdays, and a consent form is required for transport (20).

Personal Delivery Devices and Mobile Carrying Devices

The Arlington City Council approved a resolution that would allow the testing and deployment of PDDs. In 2018, Marble was the first company to begin mapping sidewalks in order to deploy the delivery devices (21). Not much information is publicly available on the current status of the project.

PDD tests in the City of Frisco included both the Starship Technologies PDD robot in May 2020 and the FedEx PDD branded Roxo in October 2019 (FedEx and Frisco entered into a memorandum of understanding for the tests, but no formal agreement was made with Starship). The Starship PDD offered food and grocery deliveries in certain neighborhoods for 10 weeks, and the FedEx PDD operated on predetermined routes on one city street for two weeks. The University of Houston also sponsored PDD tests in fall 2019 on its campus using the Starship PDD.

During the Starship deployment, two incidents were reported. Title 7 §552A.007 of the Texas Transportation Code requires PDDs to have a marker with the owner's name and contact information. After one of the incidents, a public citizen was concerned about not being able to locate a phone number to contact the owner of the device. In another incident, the device left the scene before law enforcement arrived. This brings to light issues of how to determine compliance with Title 7 §552A.005 of the Texas Transportation Code, which requires PDDs to obey applicable motor vehicle laws; if law enforcement officers are unable to determine ownership, they may not be able to properly apply the law. The visibility of the PDDs, due to their small size, was another concern raised during the deployment, especially when the devices were crossing a roadway. Some devices were stuck at crosswalks or in other roadway crossings.

Regulation of Drivers and Operators

TxDPS is responsible for licensing drivers and (along with other local law enforcement agencies) enforcing the rules of the road.

Current Licensing Requirements

To become a licensed driver in Texas, a driver must complete the following steps to obtain a driver license:

- Submit an application form and provide all necessary forms of identification and residency.
- Pass a vision test.
- Pass a knowledge and driving skills test.

A CDL is required for large commercial vehicles and buses. The three types of CDLs are:

- **Class A**: any combination of vehicles with a gross combination weight rating of 26,001 pounds or more, provided the gross vehicle weight rating (GVWR) of the vehicle or vehicles towed exceeds 10,000 pounds.
- **Class B**: any single vehicle with a GVWR of 26,001 pounds or more, any single vehicle with a GVWR of 26,001 pounds or more that is towing a vehicle with a GVWR that does not exceed 10,000 pounds, and any vehicle designed to transport 24 passengers or more, including the driver.
- **Class C**: any single vehicle or combination of vehicles that is not a Class A or B if the vehicle is designed to transport 16 to 23 passengers including the driver, or is used in the transportation of hazardous materials that require the vehicle to be placarded under Tile 49, Part 172, Subpart F of the U.S. Code of Federal Regulations (22).

To obtain a CDL, a driver must submit an application, prove identity and residency, and pass a vision test. The knowledge and driving skills tests are more advanced than for a standard driver license. Driver requirements include passing a safety inspection, knowledge of skills related to the specific commercial vehicle type, and any necessary endorsements. Endorsements are required for certain types of transportation needs. For example, a passenger endorsement is required if the driver will be transporting more than 16 people. CDL drivers are also required to indicate if they will be driving within the state only (intrastate) or if they will be driving across state lines (interstate). CDL holders must maintain a valid medical certification that is validated every two years. Licensed commercial vehicle operators are also subject to hours-of-service regulations established by FMCSA.

Current Certification/Registration Requirements of Vehicle Fleet Operators

Motor carriers are defined in Title 7 §643.001 of the Texas Transportation Code as "an individual, association, corporation, or other legal entity that controls, operates, or directs the operation of one or more vehicles that transport persons or cargo over a road or highway in this state" (23). Yet much of the regulation of motor carriers in terms of operating authority is linked to larger vehicles. Motor carriers operating vehicles over 10,000 pounds in gross vehicle weight in interstate commerce are required to obtain certificates of operating authority from FMCSA. Motor carriers operating within Texas are required by Title 7 §643.051 of the Texas Transportation Code to register with TxDMV if they operate CMVs—defined by Title 7 §548.001 of the Texas Transportation Code as motor vehicles used on a public highway to transport passengers or cargo if the vehicle has a GVWR of 26,000 pounds or more.

Expectations of Automated and Connected Vehicles in Texas

Chapter 545, Subchapter J of the Texas Transportation Code sets out authorization for operation of automated motor vehicles without human operators. Title 7 §545.453 states that an ADS is considered to be licensed to operate a motor vehicle when the ADS is engaged. This section also makes the owner of the ADS responsible for compliance with traffic or motor vehicle laws, with or without a test driver present. This overall authorization seems limited to the operation of the motor vehicle and does not affect other state laws that are related to the size of the vehicle or the nature of the services provided by the AV. AVs used in commercial motor carrier operations (carrying freight for hire, not just for testing) are subject to regulations requiring operating authority certification at the federal or state level (depending on intrastate or interstate operations). Many of those motor carrier regulations regarding operating authority for freight carriers are limited to larger trucks (over 26,001 pounds GVWR). FMCSA is already taking steps to adapt current CMV regulations to ADSs. In AV 3.0, the agency concluded that SAE Level 4 operation for commercial vehicles was allowable under existing trucking regulations and that human-centric regulations like drug testing and hours of service will not apply to driverless trucks. FMCSA will continue to adapt trucking regulations to AVs as issues arise, and is already working with law enforcement and developers to address evolving issues like vehicle inspections. State or local agencies are not allowed to impose a franchise or other regulation related to AV operation.

Current state laws in Chapter 547 of the Texas Transportation Code, which specifies motor vehicle equipment standards, and Chapter 548, which governs mandatory vehicle safety inspection requirements, do not make any particular exemptions for AVs.

Transportation of passengers for hire requires operating authority certification from TxDMV regardless of vehicle size. AVs used in passenger transportation affiliated with a public transit operator may be subject to the safety regulations of the Federal Transit Administration that apply to the transit operator. AVs operated by transportation network companies (TNCs) are subject to insurance requirements set out in Title 10 §1954.053 of the Texas Insurance Code.

Gaps in Driver/Operator Regulation Requirements for Automated Vehicles

The current definition of automated motor vehicles requires that the ADS be capable of performing all aspects of the entire dynamic driving task without a human operator—that is, a person in the vehicle who controls the entire dynamic driving task. The current law allows for a vehicle to operate on Texas roads. AV stakeholders are continuing to work with government agencies to develop and deploy the technology within the confines of current law and to ensure a robust working relationship to discuss any changes to operator requirements that could be necessary as AV technology continues to develop.

As more trucks are operated with advanced driver assistance systems that assume more control over certain elements of the dynamic driving tasks, FMCSA may consider flexibility or waivers of hours-of-service regulations for truck operations with these advanced technologies.

Regulation of Vehicles

TxDMV is responsible for the registration and titling of vehicles and commercial fleet services.

Current Registration and Titling Requirements for Vehicles

To register and title a vehicle in Texas, the vehicle owner must show proof of insurance and a passing safety inspection for the vehicle. The registration sticker includes the registered vehicle license plate number and the county in which it is registered. These two pieces of information assist in theft and fraud prevention. Registrations are not transferable. To apply for a title, the applicant must show proof of ownership (24).

Title 7, Chapter 643 of the Texas Transportation Code requires that CMVs operating on Texas roadways be registered. The registration application is $100 plus $10 for each registered vehicle and must include the following information:

- "the name of the owner and the principal business address of the motor carrier;
- "the name and address of the legal agent for service of process on the carrier in this state, if different;
- "a description of each vehicle requiring registration the carrier proposes to operate, including the motor vehicle identification number, make, and unit number;
- "a statement as to whether the carrier proposes to transport household goods or a hazardous material;
- "a declaration that the applicant has knowledge of all laws and rules relating to motor carrier safety, including this chapter, Chapter 644, and Subtitle C;
- "a certification that the carrier is in compliance with the drug testing requirements of 49 C.F.R. Part 382, and if the carrier belongs to a consortium, as defined by 49 C.F.R. Part 382, the names of the persons operating the consortium;
- "a valid identification number issued to the motor carrier by or under the authority of the Federal Motor Carrier Safety Administration or its successor; and
- "any other information the department by rule determines is necessary for the safe operation of a motor carrier under this chapter" (25).

CMVs, like conventional vehicles, must also provide proof of insurance. TxDMV sets this liability insurance coverage based on the size and class of the CMV and the persons or cargo that is being transported. Title 43 §217.46 of the Texas Administrative Code states that any motor vehicle used for the primary purpose of delivering goods, including a passenger vehicle, must be registered as a CMV. Title 43 §217.54 of the Texas Administrative Code states that in cases where one entity owns 25 or more motor vehicles, the entity's vehicles may be registered as a fleet, instead of individually.

Current Regulations for Vehicle Sales and Operations

In Texas, any person that buys, sells, or completes any business of exchanging motor vehicles must have a general distinguishing number, or a dealer license, that TxDMV issues under the provisions of Chapter 2301 of the Texas Occupations Code. In Texas, manufacturers may not sell vehicles directly to customers, and all vehicles must be purchased from a licensed dealer. A 6.25 percent sales tax is levied on vehicles sold in Texas, based on the sale price of the vehicle and not including trade-in allowance (24), or vehicles relocated and subsequently registered in Texas based on their net present value. This is true for cars, trucks, and buses—all are sold by licensed dealers. Chapter 2301 currently has no provisions for special considerations for CVs or AVs.

Expectations of Automated and Connected Vehicles in Texas

While Chapter 545, Subchapter J of the Texas Transportation Code authorizes AV operations, those statutes do not exempt AVs from registration requirements if the vehicles are operated on public highways, nor do they exempt AVs from compliance with sales and lease regulations in Chapter 2301 of the Texas Occupations Code. This is also the case for trucks operating in platoons with connected braking systems with shorter following distances under Title 7 §545.062(d) of the

Texas Transportation Code. AVs requiring registration to operate on state highways may find the completion of mandatory safety inspections set out in Chapter 548 of the Texas Transportation Code (related to equipment standards in Chapter 547) a challenge, given the unique design features of some zero-occupant delivery vehicles, which are not necessarily exempted. There are currently no requirements that a PDD be registered or inspected, but the name and contact information for the owner must be visible as required in Chapter 552A of the Texas Transportation Code.

Gaps in Vehicle Regulation Requirements for Automated Vehicles

The most prominent gaps in vehicle regulation are related to how sales and lease regulations and the interaction with registering vehicles may limit AV manufacturers (individually or in partnership with OEMs), and how state inspection requirements linked to vehicle equipment specifications affect certain kinds of AVs.

The regulations for AVs and PDDs are different. AVs and PDDs alike, when built to operate without a human driver or a human occupant, may also face challenges with inspection compliance because they are specifically built and not standard for vehicle inspections. TxDOT/TxDMV can look at what reasonable accommodations/amendments should be made to inspection requirements, as authorized to do so, to ensure these vehicles can still be successfully registered in the state.

Additionally, Chapter 552A of the Texas Transportation Code requires the owner's name and contact information to be visible on the device, but not all municipalities may be familiar with the requirements. During one incident involving the Starship deployment in Frisco, TX, a citizen was concerned that there was no phone number on the device, only a website address. The industry could work with the Texas Municipal League to develop best practices for product identification. Public and private cooperation could also develop best practices for incident response for the public, PDD operators, law enforcement, and municipalities.

Other Regulations and Issues

Current federal regulations and local policy need to be reviewed for applicability to AVs. This section highlights some of these regulations or other concerns that may become problematic with AVs.

Current Federal Safety Standards

Title 49 §571 of the Code of Federal Regulations (26) establishes the safety standards required for motor vehicles. These standards can require equipment to be on or in the motor vehicle or certain testing to be completed. The code includes the exact specifications for equipment and placement. While the current federal safety standards should not be repealed, they may not be relevant to the safe operation of AVs, especially when there is no human driver. Some AV developers choose to build their technology on FMVSS-compliant vehicles and retain all equipment that maintains FMVSS compliance. For these types of AVs, there is no conflict with existing FMVSSs. Other AV developers choose to develop novel vehicle designs or make modifications that are not compliant with current FMVSSs, such as removing the steering wheel for a vehicle never intended to be driven by a human. For those AVs, FMVSS exemptions would need to be granted for such vehicles to be deployed. Table 1 highlights but a few of the federal safety standards that may not apply to AVs, requiring AVs to have either extraneous equipment installed simply for compliance purposes, or an FMVSS exemption in order to take such equipment out.

Table 1. Federal Motor Vehicle Safety Standards and Associated Concerns with AVs.

FMVSS	Requirement
Standard No. 101: Controls and displays	Driver warning and indicator system
Standard No. 102: Transmission shift position sequence, starter interlock, and transmission braking effect	Location and operability of the transmission shift lever
Standard No. 103: Windshield defrosting and defogging systems	Windshield defrost and defogging system
Standard No. 104: Windshield wiping and washing systems	Windshield wiping system
Standard No. 111: Rear visibility	Inside and outside rearview mirrors
Standard No. 204: Steering control rearward displacement	Location specification for the steering control system
Standard No. 207: Seating systems	Driver's seat

NHTSA has recently published an Advanced Notice of Proposed Rulemaking (Docket No. NHTSA-2020-0106) to apply to ADSs, which are defined by SAE International as driving automation Levels 3 to 5. This rulemaking would develop a framework for ADS safety that "would objectively define, assess, and manage the safety of ADS performance while ensuring the needed flexibility to enable further innovation." This framework might lead to development of new FMVSSs for ADS components if provided in a vehicle, not necessarily requiring ADS elements in all new vehicles. The applicability of FMVSSs to CVs and AVs is thus still in development.

Law Enforcement Issues with Automated Vehicle Licensing and Registration Regulations

Many AVs are distinctively designed or manufactured so that a law enforcement officer would be able to discern that some measure of vehicle automation was being deployed. Title 7 §545.456 of the Texas Transportation Code, which allows AV owners to identify their vehicles as such to TxDMV for registration purposes, does not necessarily specify how AVs are identified for law enforcement purposes. Title 7 §545.453 of the Texas Transportation Code makes the owner of the ADS responsible for complying with vehicle operation laws but also does not specify how such ownership is to be displayed or made accessible to law enforcement personnel. Defining the kind of visible marking to distinguish CV or AV vehicle operation may be best accomplished as best practices to be shared among state agencies participating in their national associations or as required by federal guidelines or regulations.

Case Studies Involving Licensing and Registration Requirements

As AV technologies grow and states continue to partner with the private sector to deploy them, lessons can be learned from the successes and failures of others. Case studies from Arizona, California, and Florida offer specific examples of experiences with licensing and registration. By 2017, 18 states had introduced AV legislation, with 11 states enacting legislation (27).

Arizona

In 2015, Governor Ducey of Arizona signed an executive order that allowed the elimination of regulations that hindered the deployment of self-driving vehicles, while still requiring them to comply with all state and federal safety standards and regulations. The executive order instructed law enforcement agencies to develop first responder action plans (28). This executive order opened the door for testing of fully autonomous vehicles without an operator within the state. In 2018, Governor Ducey updated the executive order to allow fully automated vehicles to operate on Arizona roadways without a human driver.

California

In 2014, California began the Autonomous Vehicle Tester Program, which allows OEMs to test autonomous vehicles with a human in the driver seat. The OEMs must apply to the program, which is administered by the California Department of Motor Vehicles. As of September 1, 2020, the program had 60 permit holders. The following steps are a summary of the extensive permit application required to apply to the program:

- Obtain an Employer Pull Notice Program number, which allows commercial and government organizations to monitor their employees' driving records and enroll test operators in the program.
- Submit an application for a Manufacturer's Testing Permit.
- Obtain an Autonomous Vehicle Manufacturer Surety Bond or an application for self-insurance.
- Submit an operator training program description.
- Submit a copy of the articles of incorporation, corporate minutes, or other document filed with the Secretary of State, which identifies the officers, shareholders, and managers (if filing as a corporation, limited liability company, or limited liability partnership owned business) (29).

In 2018, this program expanded to the Autonomous Vehicle Tester Program, which allows OEMs to test vehicles without a human in the driver seat. As of October 2020, the program had five permit holders. The following documents, among others, are required to apply to the program:

- Autonomous Vehicle Tester Program Application for Manufacturer's Testing Permit.
- Autonomous Vehicle Manufacturer Surety Bond or Autonomous Vehicle Tester Program Application for Certificate of Self-Insurance.
- A copy of the articles of incorporation, corporate minutes, or other document filed with the Secretary of State, which identifies the officers, shareholders, and managers (if filing as a corporation, limited liability company, or limited liability partnership owned business) (30).

Both programs require a $3,600 fee to participate in the program. This fee includes 10 vehicle permits and 20 operator permits. Additional fees are required to add vehicles and drivers. In the testing program, the vehicles must be registered in California or operate under manufacturer or distributor plates and have a California Certificate of Title. Operators must certify that they will only operate the vehicles for testing purposes (30).

California has not yet integrated CMVs over 10,000 pounds GVW into its Autonomous Vehicle Tester Program. This has created a high degree of regulatory uncertainty for CMV ADS developers. Long-haul shipping is now seen as one of the first likely deployments of automated driving, but with this regulatory uncertainty, the likelihood of its early deployment in California may be diminishing. Texas could avoid this fate by addressing AVs in a comprehensive manner that is vehicle agnostic when appropriate.

Florida

In July 2019, Governor DeSantis of Florida signed a law allowing fully autonomous vehicles at SAE Level 4 or 5 to operate within the state without a safety driver. The law also required shared service companies, such as Uber and Lyft, to provide $1 million in liability coverage for these fully autonomous vehicles. Passengers of these fully autonomous vehicles also became able to use wireless devices as a part of the law (31, 27).

Balancing Regulatory Posture and Economic Development

The successful deployment of AV policy will require a balance between regulatory posture and economic development. AVs will need to be regulated in a way that the policies of OEMs and local stakeholders are not hindered, and economic development can thrive.

Texas has been making great strides in becoming a leader in AV deployments. Austin has received some of the largest amounts in funding opportunities across the United States, and AV stakeholders continue to set their sights on Texas as one of the major playing fields to test their products. Both Aurora and Tesla have recently shared that they will be expanding their activities in Texas.

Texas Transportation Code Encouraging Deployment and Innovation

By enacting AV legislation in 2017, Governor Greg Abbott and the Texas Legislature created an environment that has allowed the AV industry to expand its testing and development in Texas. By clarifying the legal obligations of AV developers and vehicle owners, Governor Greg Abbott and the Texas Legislature have also increased the regulatory certainty for these firms to consider deployment and development opportunities in Texas. This has increased the number of AV-related jobs in Texas and has allowed Texas businesses and vehicle owners a wider range of choices for vehicle purchases and transportation services that may increase traffic safety and expand infrastructure capacity.

Texas public agencies can document the results of AVs and new driver assistance technologies, which decision makers and regulators can use to inform decisions about how to respond to specific regulatory issues or gaps. In the absence of clear guidance and regulations at the federal level, Texas and other states have the chance to tailor their regulatory responses to AVs to increase safety for all motorists, and to increase opportunities for Texas businesses and consumers to use new technologies to expand economic opportunity. Any regulations would need to be made at the state level in a way that provides regulatory consistency and maximizes opportunities for economic development.

Scenarios for Public Expectations for Regulation and Risk Management of Automated Vehicles on Roads

Sometimes public regulation seeks to respond to and prevent adverse outcomes of the past in a way that constrains future development of new technologies. As AVs are involved in crashes, many parties in the transportation policy environment—drivers, insurers, crash litigation firms, organized labor, and advocacy groups—will react in ways that can affect the operating environment for AVs. An AV-pedestrian fatal crash in 2018 in Arizona had significant implications for TNCs adopting AVs. As larger AVs are involved in crashes in Texas, elected officials and public agencies will need a broad range of information at their disposal to respond to the crashes in a way that balances the safety risks of AVs with the safety risks of other vehicles. Some of the education messaging discussed previously could help motorists, motor carriers, and law enforcement make informed decisions about how to modify the regulatory framework for AVs in Texas.

Opportunities in Texas

This document identifies a series of regulatory opportunities to clarify AV development in Texas and outlines a series of information/education opportunities to expand understanding of AVs in the state.

Regulatory Opportunities

This document identifies some opportunities for additional clarity in the interaction of current statutes and regulations and AV deployment:

- **Regulatory flexibility**: AV developers and TxDPS could collaboratively discuss compliance with state motor vehicle equipment standards and current AV configurations, particularly for PDDs and zero-occupant vehicles. TxDPS can determine how much regulatory flexibility it has to accommodate these unique AV designs.
- **Stakeholder collaboration**: AV developers and manufacturers, TxDMV, and the Texas Automobile Dealers Association could discuss how current dealer licensing/sales laws and registration rules affect the range of commercial relationships between OEMs and AV developers.
- **Alternative opportunities**: If some AV developers are considering alternatives that include AV operation entirely by remote operators (rather than by onboard software that controls vehicle driving tasks), the AV industry may want to interact with applicable state agencies to determine how the current regulatory structure addresses such operations.

Further Opportunities for Discussion among Stakeholders

This document also identifies a series of opportunities for the public and private sectors to cooperate in advancing AV development in Texas. As AV developments continue in the future, there is an opportunity for all stakeholders to continue the conversation to produce continued benefits for all. The following questions can guide this discussion:

- **Law enforcement engagement**: How can the AV industry engage with TxDPS and local law enforcement organizations to develop voluntary standards to provide law enforcement with readily available information on which entity meets the operating and licensing requirements of Chapter 545, Subchapter J of the Texas Transportation Code? Can this be developed nationally through associations of state transportation and regulatory agencies working with the AV industry?
- **Public transportation engagement**: How can the AV industry collaborate with public transportation agencies represented on the Texas CAV Task Force in addressing some of the education and messaging opportunities identified in other Texas CAV Task Force white papers for different segments involved in transportation?
- **Future regulations and planning requirements**: How can the Texas CAV Task Force share information on possible AV regulations or planning requirements that may be included in congressional action on surface transportation reauthorization?

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