Automated Vehicle Safety Validation, Data, and Metrics

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

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Table of Contents

List of Figures

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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).

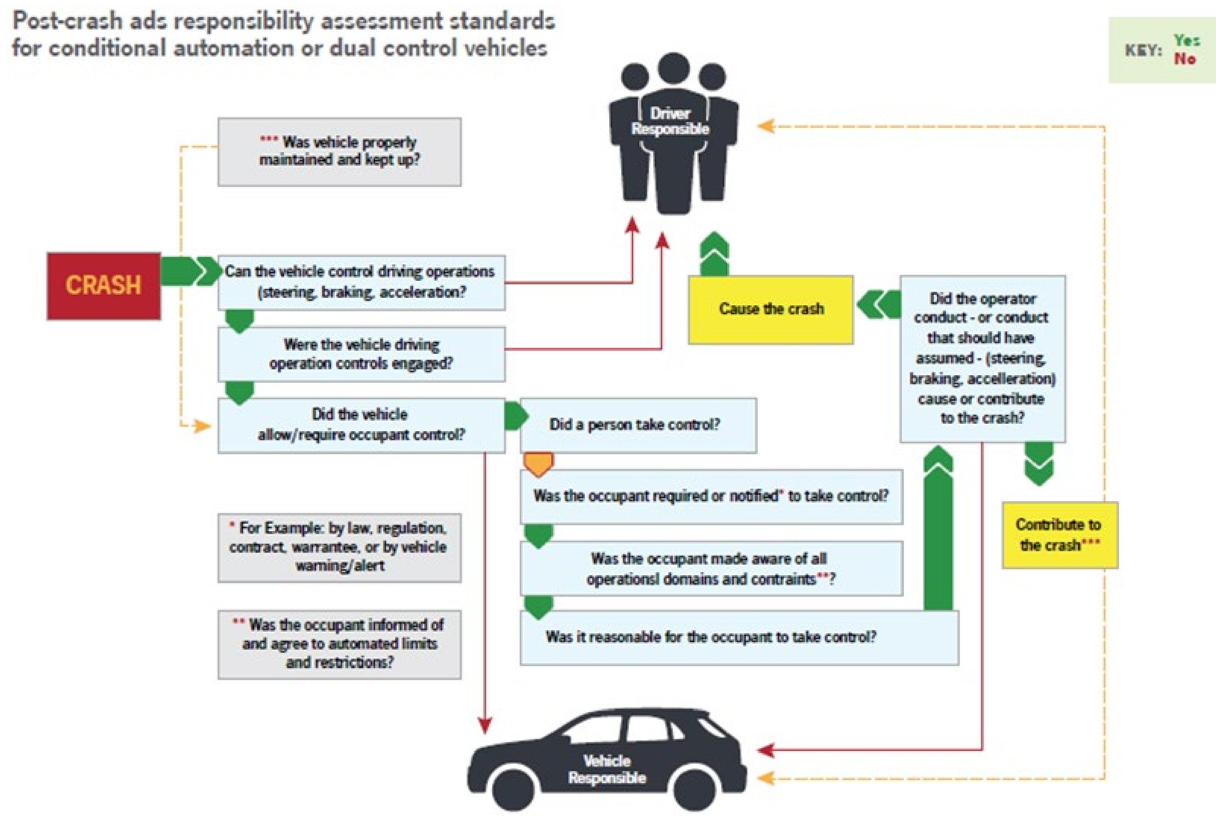
ANSI/UL 4600

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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