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The PennSTART Safety Standards Project

Current Safety Standards and Test Track Designs for Connected and Autonomous Vehicles

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FINAL REPORT

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Executive Summary

This report aims to provide RIDC with a comprehensive overview of the regulatory landscape, safety standards, and test track designs relevant to AV testing so as to inform the construction of PennSTART—a new AV test track in Pennsylvania.

Key Findings and Insights:

- ***Federal vs. State Authority in AV Regulations:*** With limited federal oversight, states play a pivotal role in shaping AV testing policies. This decentralized approach reflects the recognition that rigid national enforcement could stifle innovation in this rapidly evolving field. While the federal government does not mandate AV compliance, the NHTSA is still authorized to conduct recall, investigation, and suspension of activities for malfunctioning and unsafe motor vehicles. It is imperative for stakeholders, including RIDC, to actively engage with local policymakers and regulatory agencies to ensure alignment between testing policies and technological advancements.

- ***AV Testing in Pennsylvania:*** Pennsylvania mandates that highly automated vehicles (HAVs) must always have a human operator present in the driver's seat. Additionally, testers in the state must submit comprehensive risk mitigation plans for approval before conducting tests on public roads. RIDC can leverage existing frameworks, such as the 12 elements of safety outlined in federal guidance and specific sections of PennDOT's comprehensive plan, to formulate robust safety review procedures for PennSTART. This includes meticulous consideration of the vehicle's software, hardware, and cybersecurity systems to ensure adherence to local safety standards.

- ***Public Trust Remains Challenging:*** Analyses of the Cruise robotaxi incident and Tesla's recall illustrate the complexities and challenges inherent in testing AVs for safety pre-deployment. Most notably, negative perceptions stemming from these accidents may lead to heightened scrutiny, increased regulatory restrictions, and erosion of consumer confidence for the AV industry. PennSTART can serve as a crucial platform for fostering collaboration, transparency, and evidence-based safety evaluation in the AV industry.

- ***Diverse Technology for AV Safety:*** In examining safety procedures at other prominent test tracks, distinct approaches to AV safety testing emerge, reflecting the diverse missions and operational methodologies of each facility. For instance, MCity stands out for its innovative in-house testing methodology while Gomentum Station and ACM adhere to established standards to align their services with recognized industry benchmarks. RIDC may better narrow down the necessary technologies for PennSTART through clarifying the track’s main purposes and promising features.

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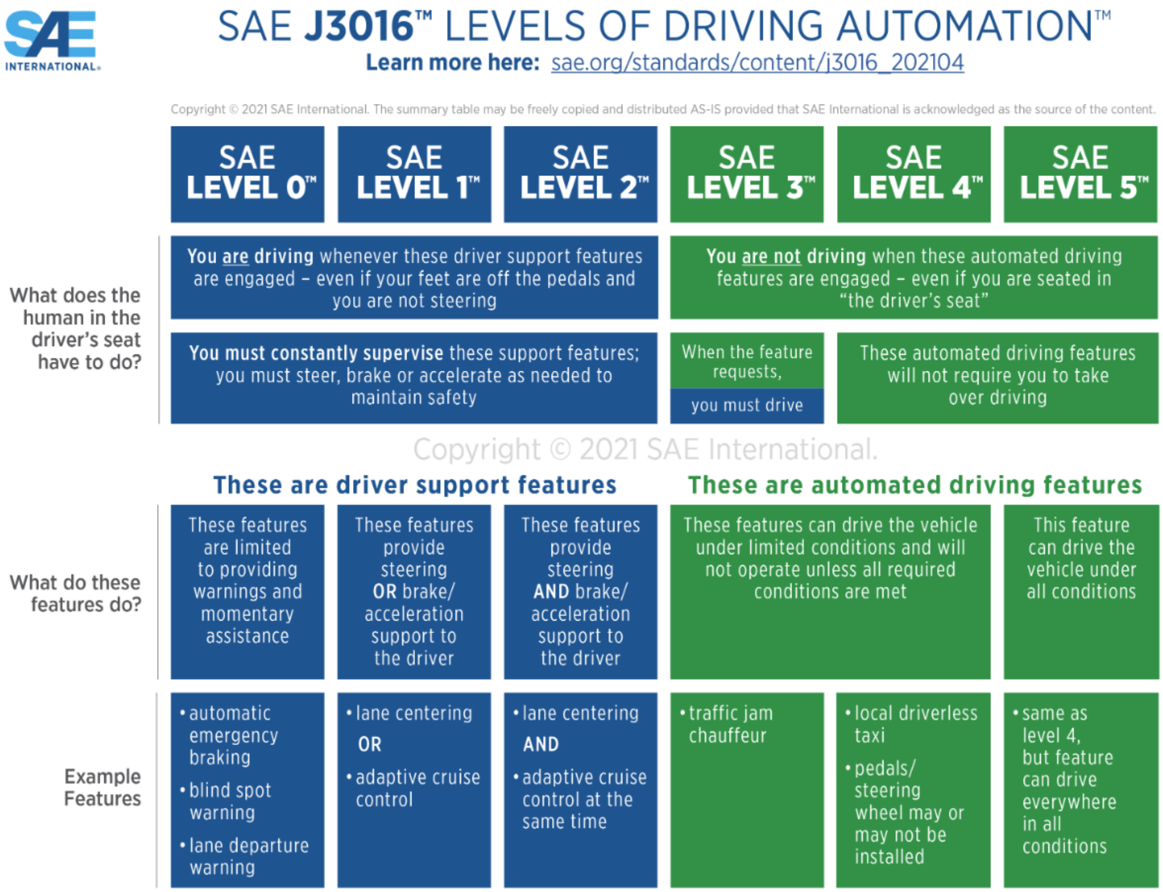
Definitions and Abbreviations

“Automated Driving System” (ADS): The NHTSA’s definition for “types of vehicles where a traditional driver would no longer be needed” (link). The term is more specific than AV because it denotes the automated system itself, not the entire vehicle.

“Autonomous Vehicles” (AVs): There are different frameworks to define AVs as well as different types of AVs. This report focuses on automated motor vehicles, specifically self-driving cars. Automation is a continuum. The Society of Automotive Engineers (SAE) designed the industry-standard scale to measure this continuum known as SAE J3016, which is also adopted by NHTSA.



SAE J3016™ LEVELS OF DRIVING AUTOMATION™

Learn more here: sae.org/standards/content/j3016_202104

	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver’s seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

“DOT”: Department of Transportation

“Highly Autonomous Vehicle” (HAV): NHTSA’s classification for AVs at SAE Level 3 and beyond (link). This report mainly focuses on these HAVs where the driver is not in control.

“NHTSA”: National Highway Traffic Safety Administration

“Object and Event Detection and Response” (OEDR): “... refers to the detection by the driver or ADS of any circumstance that is relevant to the immediate driving task, as well as the implementation of the appropriate driver or system response to such circumstance” (link, p. 7). OEDR is a key element for testing any HAV and its response to an imminent crash.

“Operational Design Domain” (ODD): “...defines all conceivable overlapping conditions, use cases, restrictions and scenarios that an AV might encounter, even the most esoteric edge cases” (link). ODD establishes situations and scenarios where the AV can and cannot be safe.

“Platooning” : two (2) or three (3) buses, military vehicles or motor carrier vehicles traveling in a unified manner at electronically coordinated speeds at following distances that are closer than would be reasonable and prudent without the coordination (link)

“Vulnerable Road Users” (VRU): includes pedestrians (including children), cyclists, motorcyclists, and people with disabilities or reduced mobility (including those who use motorized wheelchairs and scooters) (link). These individuals are of higher risk for encountering a road accident, especially at intersections.

AV Testing Policy Review

This section reviews federal, state, and local policies relating to AV testing. Because AV technology is still evolving, the federal government recognizes that enforcing safety compliance at the national level may hamper such development. Therefore, the field of autonomy is mostly regulated at the state level through tort laws. States operate on different standards and varying degrees of stringency for AV testing on public roads. Particularly in Pennsylvania, HAVs must never be operated without a person in the driver's seat. PA testers must also submit a comprehensive risk mitigation plan to receive testing permission on public roads. As the regulatory framework for AVs is rapidly evolving, RIDC should stay informed about state-specific legislation and federal guidelines to ensure compliance. Moreover, it is necessary to engage and collaborate with local policy makers to continue advocating for the field.

Primary sources quick access:

- Federal:
    - NHTSA Guidance for Safety: link
- Pennsylvania:
    - PennDOT's automated vehicle testing guidance: link
    - PennDOT Notice of Testing Form: link
    - PennDOT Semi-annual Data Collection Form: link
- Pittsburgh:
    - City of Pittsburgh Autonomous Testing Guidelines and Submission Process: link

Federal Guidance on AV Testing

The NHTSA is the main regulatory body for federal AV guidelines. While the use and production of AV must abide by safety standards for all motor vehicles, there exists no legislation that specifically regulates the automated driving systems.

Currently, the NHTSA's stance on the issue of AV Safety is outlined in a voluntary guidance document, entitled *Automated Driving Systems 2.0: A Vision for Safety* (link). The document contains two main sections: Voluntary Guidance and Technical Assistance for States. The former was designed to establish safety considerations before deployment of any autonomous systems for all designers. The latter clarifies federal and state roles in regulating ADS and suggests best practices for state-level officials.

Federal Enforcement Authority

In the document, NHTSA addresses its enforcement authority as follows:

1. *Vision for Safety* remains a **voluntary** safety guidance. There is "no compliance requirement or enforcement mechanism" (p. 2). The document only serves as a resource for designers and policy makers involved in the AV industry.
2. Companies may choose to publish a "Voluntary Safety Self-Assessment" (VSSA) to demonstrate their compliance with NHTSA safety standards (p. 16). The VSSA templates and examples are found here.
3. While the practices outlined in the guidance are not enforceable, NHTSA is authorized to recall, investigate, and handle complaints relating to any motor vehicle or motor vehicle equipment if it suspects a defect (p. 2). Resources on NHTSA's procedures for safety recalls are available here.
4. NHTSA is also responsible for setting Federal Motor Vehicle Safety Standards (FMVSSs) and can enforce compliance among manufacturers for all new motor vehicles or motor vehicle equipment. FMVSSs is detailed here.

In short, while *Vision for Safety* only provides suggestions on the elements of AV safety for policy-makers and designers to consider, NHTSA still has the legal authority to recall and investigate unsafe vehicles as it finds appropriate.

NHTSA's Voluntary Guidance

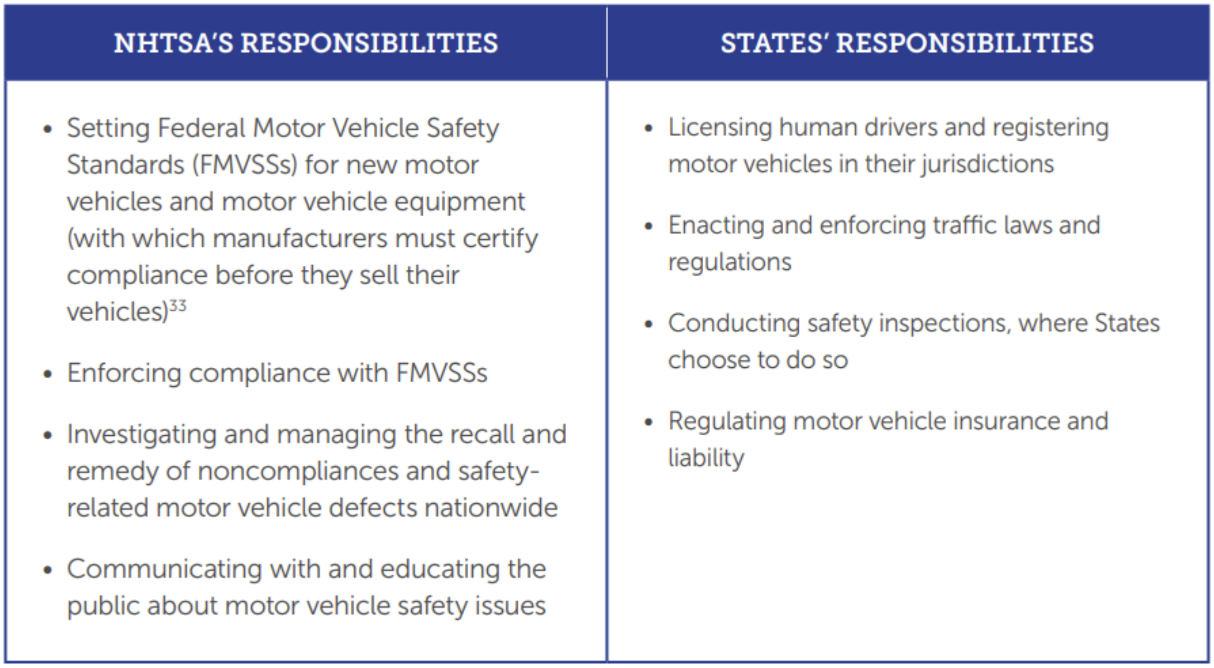
The guidance first defined automation levels according to SAE J3016: six levels of automation, ranging from zero to five with Level 5 representing full automation. HAVs are vehicles of Level 3 and above (see definition above). Then, it listed 12 elements of safety compliance for AVs. From these elements, organizations can develop more specific safety standards that better serve their purposes. The following table provides a summary description of each element according to the guidance.

Elements	Considerations
System Safety	● "... follow a robust design and validation process based on a systems-engineering approach" (p. 5) ● Adopt industry standards and evaluation metrics for designing and testing ADSs ● Consider a hazard analysis and safety risk assessment for the ADSs, for the overall vehicle, and, when applicable, for the broader transportation system ● Assess risks related to safety-critical system functionality ● "All design decisions should be tested, validated, and verified as individual subsystems and as part of the entire vehicle architecture." (p. 5)
Operational Design Domain (ODD)	● Design and document the ODD for each ADS in the vehicle in every testing scenario ● At minimum, the ODD should include: ○ Roadway types (interstate, local, etc.) on which the ADS is intended to operate safely; ○ Geographic area (city, mountain, desert, etc.); ○ Speed range; ○ Environmental conditions in which the automated system will operate (weather, time of day, etc.); ○ Other domain constraints. ● If a vehicle is forced outside of its ODD, it should transition to a "minimal risk condition" (p. 6). This may mean converting to a lower level of automation where the driver regain control of the vehicle.
Object and Event Detection and Response (OEDR)	● "...an ADS is responsible for performing OEDR while it is engaged and operating in its defined ODD" (p. 7) ● Document the process of testing a vehicle's OEDR capabilities with different objects ● Ensure the vehicle can detect objects in a normal driving scenario as well as address pre-crash scenarios such as control loss, crossing-path crashes, lane change/merge, etc.
Fallback (Minimal Risk Condition)	● Document the safety assessment and testing for when the ADS must revert to a minimal risk condition when it cannot operate safely (outside of ODD) ● "Fallback strategies should take into account that, despite laws and regulations to the contrary, human drivers may be inattentive, under the influence of alcohol or other substances, drowsy, or otherwise impaired" (p. 8) ● For HAVs, ADS must be able to fall back without human intervention

Validation Methods	● Develop validation methods that diversify testing approaches (include a combination of simulation, test track, and on-road testing). ● Collaborate with other entities to conduct more robust and comprehensive validation
Human Machine Interface (HMI)	● "At minimum, an ADS should be capable of informing the human operator or occupant through various indicators that the ADS is: ○ Functioning properly; ○ Currently engaged in ADS mode; ○ Currently "unavailable" for use; ○ Experiencing a malfunction; and/or ○ Requesting control transition from the ADS to the operator." (p. 10) ● Accommodate people with disabilities (e.g., through visual, auditory, and haptic displays) in vehicles that are expected to not have driver controls. ● "In vehicles where an ADS may be intended to operate without a human driver or even any human occupant, the remote dispatcher or central control authority, if such an entity exists, should be able to know the status of the ADS at all times." (p. 10)
Vehicle Cybersecurity	● Consider cybersecurity risks when designing the vehicle's ADS ● Document testing and report to the Auto-ISAC all discovered incidents, exploits, threats and vulnerabilities from internal testing, consumer reporting, or external security research as soon as possible, regardless of membership
Crashworthiness	● In the event of a crash, the occupant protection system should be performed at its intended level ● Consider methods to enhance the occupant protection system through ADS while considering countermeasures to protect all occupants ● "Unoccupied vehicles equipped with ADSs should provide geometric and energy absorption crash compatibility with existing vehicles on the road" (p. 12)
Post-Crash ADS Behavior	● Consider methods for returning the ADS to a safe state immediately after a crash such as shutting off the fuel pump, removing motive power, moving the vehicle to a safe position off the roadway (or safest place available) ● Share relevant data to help reduce the harm of the crash

Technical Assistance to States

The second part of this document provides policy recommendations for states in regulating ADS. Within this section, the most relevant information for RIDC is NHTSA's differentiation between state and federal roles in regulating AV. NHTSA encourages states to not enforce compliance for *Vision for Safety*'s voluntary guidance (such as codifying these standards into state statutes) so as to avoid inconsistencies between Federal and State laws.



NHTSA'S RESPONSIBILITIES	STATES' RESPONSIBILITIES
• Setting Federal Motor Vehicle Safety Standards (FMVSSs) for new motor vehicles and motor vehicle equipment (with which manufacturers must certify compliance before they sell their vehicles)[33] • Enforcing compliance with FMVSSs • Investigating and managing the recall and remedy of noncompliances and safety-related motor vehicle defects nationwide • Communicating with and educating the public about motor vehicle safety issues	• Licensing human drivers and registering motor vehicles in their jurisdictions • Enacting and enforcing traffic laws and regulations • Conducting safety inspections, where States choose to do so • Regulating motor vehicle insurance and liability

Testing Regulations in Pennsylvania

According to PennDOT's guidance on AV, Pennsylvania law allows testing of ADS but enforces more stringent requirements for HAVs (link). These standards include:

- A licensed driver who is capable of intervening when the automated system malfunctions must be seated in the driver's seat of the HAV at all times.
    - If the HAV hits a vehicle while the autonomous system is disengaged, the licensed driver in the driver's seat will be "presumably [liable] as they were driving a non-HAV" (link).
    - If the autonomous system was engaged when the crash happened, liability will be determined based on traditional state tort and product liability laws.
    - In cases of ethical dilemma, the HAVs must be programmed to bring the vehicle to a state of minimal risk as swiftly as possible.
- While testing on public roads is recommended alongside simulations and test tracks, unoccupied and/or remote testing on trafficways is prohibited.

- If testing on Pennsylvania traffic ways, HAV testers must submit a Notice of Testing, which includes uploading a Safety and Risk Mitigation Plan to PennDOT or NHTSA's Voluntary Safety Self-assessment, to provide details of the test and a risk mitigation plan. This document can be found in the guidance or on PennDOT's website (link).
    - PennDOT based the Safety and Mitigation Plan on the 12 elements of safety from NHTSA's *Vision for Safety* previously discussed in "Federal Policy Review."
- These applications are reviewed for approval, and PennDOT will decide on authorization within 10 days of receiving a notice.
- Testers are encouraged to participate in data collection semi-annually and report crashes if necessary. PennDOT currently does not require identification of whether a vehicle involved in a crash is an AV (link).

PennDOT's Safety and Risk Mitigation Plan might be informative for designing PennSTART's safety procedure (link, p. 2-4). This plan requests the following details:

1. Description of the ODD for testing
2. Description of a "killswitch" (e.g. how the ADS will be disengaged)
3. Description of methods to maintain functionality of the ADS hardware and software
4. Description of background check procedures conducted for driver(s) in the testing vehicle
5. Description of how the driver(s) for the testing vehicle has been trained and informed of the vehicle's operational features and limitations
6. Description of safety measures that deploys when the ADS is disengaged
7. Description of how the tester's drivers are reinforced or refreshed of their trainings

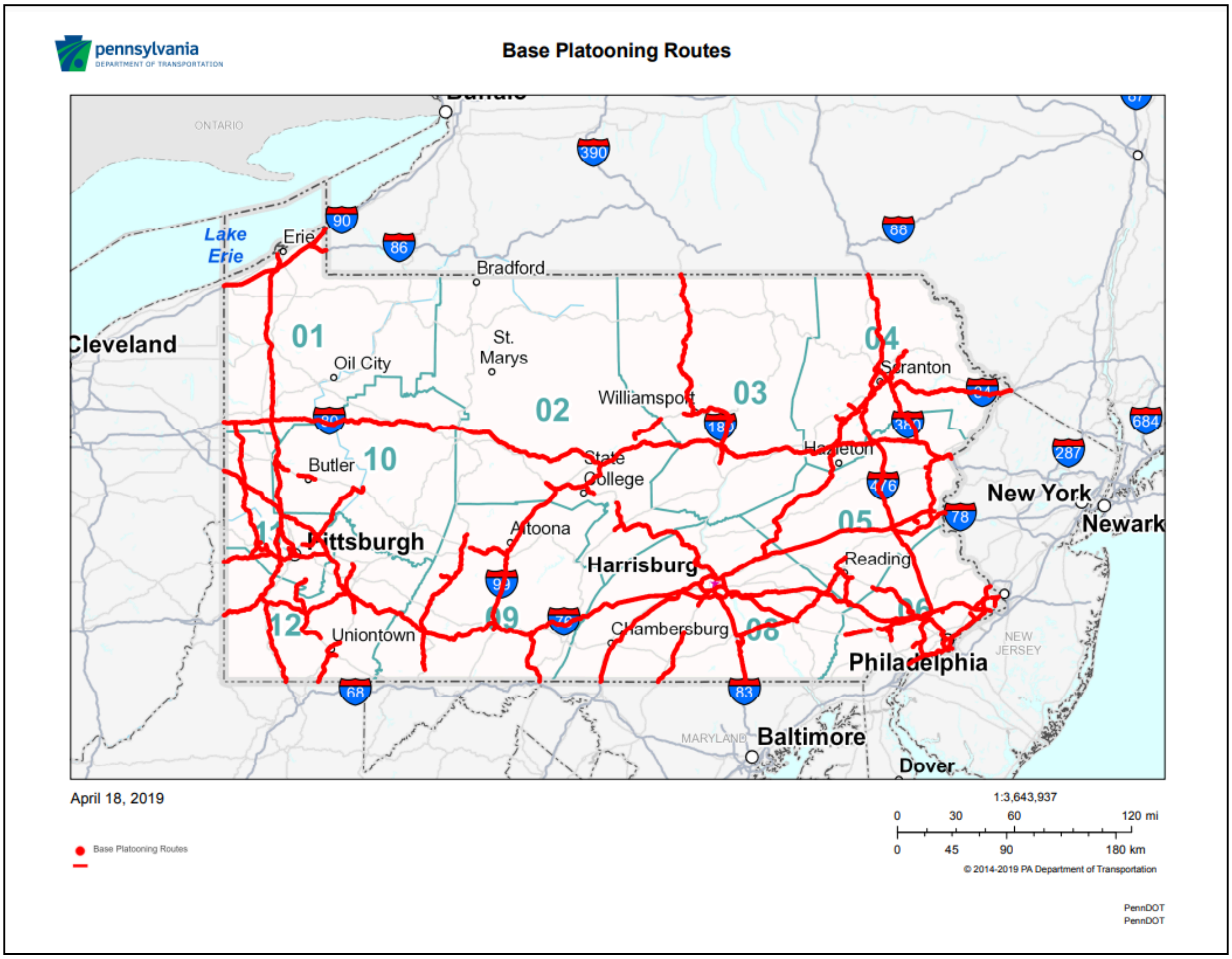
In place of this plan, testers can upload NHTSA's Voluntary Safety Self-assessment discussed previously.

While this report mainly focuses on autonomous cars, PennDOT prohibits the following vehicles from being controlled by an ADS, which might be relevant for PennSTART:

1. Vehicles carrying hazardous materials as defined in the Federal Motor Carrier Safety Regulations (49 CFR Subchapter B);
2. Vehicles carrying oversize or overweight loads;
3. Vehicles carrying fluids (e.g., tankers, concrete trucks);
4. Vehicles carrying pipes, lumber, or similar types of loose loads;
5. Vehicles carrying livestock;
6. Automobile and boat transporter combinations (traditional and stinger‑steered);
7. Truck and pole combinations;
8. Double and triple trailer combinations;
9. Lowboy tractor/trailer combinations (loaded and unloaded); and
10. Saddlemount or saddlemount with fullmount combinations.

Another potentially relevant testing procedure is platooning. Pennsylvania passed Act 117, effective in 2023, to allow "platooning" on public highways. Platoon operators must submit a Platoon Operations Plan through the GlobalSCAPE system to demonstrate that the platoon is safe to operate and utilize Driver-Assistive Vehicle Platooning (DAVP) technologies (link). Restrictions for platooning include:

1. Operate only on designated highways (see image below).
2. Prohibited in work zones when workers are present, tunnels, or through toll plazas.
3. Prohibited on lanes where trucks are prohibited.
4. Maintain a reasonable minimum headway defined by the operator and PennDOT and of at least 40 feet when traveling over bridges.
5. Have a method to disengage the platooning technology when necessary, such as at a weigh station.
6. The types of vehicles prohibited for ADS (listed above) is also prohibited for platooning.



Testing Regulations in the City of Pittsburgh

City of Pittsburgh Autonomous Testing Guidelines and Submission Process (link) outlines the requirements and procedures for companies intending to test autonomous vehicles on Pittsburgh's traffic ways. Testers must comply with PennDOT's requirements, such as submitting a Notice of Testing and Safety and Mitigation Plan, and receive authorization before submitting an additional notice to Pittsburgh's Department of Mobility and Infrastructure (DOMI). The city's submission requirements are less intensive, given that the tester already received authorization from the state, and purely serves informational purposes.

In general, DOMI requires the following:

1. Company and fleet information
2. ODD details
    - Such as testing neighborhoods, anticipated weather conditions, and testing dates
3. Safety details
    - Testers can reupload the Safety and Risk Mitigation Plan or Voluntary Safety Self-Assessment and briefly provide additional information specific to the Pittsburgh testing locations
4. Acknowledgement of Pittsburgh's *Shared + Autonomous Mobility Principles* (link)

Post-submission requirements for data sharing is more compulsory where companies must report miles driven, operational deviations, and crash information on a semiannual basis.

State-by-State Comparison on AV Testing Policies

Beyond federal and Pennsylvania, this report also concerns AV regulations in other states. In all, states vary significantly in stringency for AV testing. For instance, some states require a human driver in an AV at all times (Pennsylvania, Ohio, etc.) while others do not (Michigan, Texas, etc.). Most states enforce safety compliance with federal and state statutes but not all states have insurance requirements for AVs. These inconsistencies reflect the federal government's intention of only providing general technical guidance. Providing flexibility will allow states to better adapt policies to varying levels of advancement in AV technology. The table below provides state-to-state comparisons in AV testing policies.

State	Permit Requirements	Safety & Compliance	Driver Requirements	Public Safety & Law Enforcement	Collaboration & Innovation
Michigan	SAVE Act for AVs; no human operator required for testing	Advanced safety standards for AVs, remote control or autonomous stop required	Remote control or autonomous stop capabilities instead of a physical driver	Actively developing exclusive AV roadways; emphasis on public-private collaboration	Leading in AV deployment, flexible regulations
Ohio	DriveOhio initiative for AV testing; permits required	Designated operator responsible for safety; compliance with traffic laws	Licensed driver required to be in the driver's seat, ready to take control	Focused on diverse testing environments; collaborative approach with stakeholders	Varied testing environments, including urban, suburban, rural
California	Detailed testing and deployment permits required from the DMV	Complies with FMVSS; detailed safety and cybersecurity standards	Presence of a driver in certain testing scenarios; extensive training required	Strong focus on data privacy and public safety; extensive public hearings; California's requirement for annual disengagement and collision reporting provides a more structured approach to monitoring AV performance compared to Pennsylvania.	Comprehensive and detailed regulations, strong emphasis on innovation

New York	Testing or demonstration permits required; set to expire in 2024	Compliance with federal and state standards; $5 million insurance policy	Licensed driver must be in the driver's seat during testing	Specific testing route requirements; detailed law enforcement interaction plan	Collaboration encouraged but with specific testing limitations (such as avoiding construction or school zones, which is not explicitly mentioned in Pennsylvania's policies)
Pennsylvania	Specific legislation for AV testing; human driver required except platooning	Focus on safety guidelines and comprehensive safety plans; insurance coverage equal to at least $1 million	Human driver required behind the wheel except platooning	Safety-focused; collaboration with local authorities and stakeholders	Proactive stance in AV technology with an emphasis on aligning with transportation frameworks
Arizona	Primarily regulated through Executive Order 2018-04	Compliance with federal laws, Arizona State Statutes, Title 28 of revised Arizona State Statutes, Arizona Department of Transportation (ADT). Laws reflect forward-thinking approach	Human driver not needed if vehicle is fully autonomous, written letter needed to be submitted to ADT	Law enforcement covers Traffic collisions, disabled vehicles, and Arizona Revised Statute-Title 28 Violations	First state to support self-driving vehicles through an executive order. Witnessed the launch of Waymo's commercial self-driving taxi service. Over 600 automated test vehicles on its roads and the involvement of numerous companies.

Texas	Vehicles are required to have insurance, and manufacturers are considered responsible for any broken laws or collisions.	Compliance with applicable federal rules, including the National Highway Traffic Safety Administration’s (NHTSA’s) requirements, state traffic and motor vehicle laws	Self-driving vehicles can operate without a driver inside, allowed on highways if they adhere to traffic laws and are equipped with video recording equipment.	CAV Task Force	Aurora and Kodiak Robotics are testing self-driving trucks in Texas, including the Dallas area and between Houston and El Paso. The Texas Department of Transportation plans a 21-mile smart freight corridor near Austin with Cavnue technology.
Florida	Florida has created a single statewide standard for AVs. It has no additional permitting or licensing demands.	-	No need for a human operator in autonomous vehicles, allowing remote alerts for technology failure and the capability to stop the vehicle remotely.	-	The Central Florida Automated Vehicle Partnership, approved by the U.S. Department of Transportation, is a leading proving ground for automated vehicle technology. Orlando, in collaboration with various entities, spearheaded this premier initiative.

AVs vs. Traditional Vehicles Safety Policies Comparison

This final subsection discusses differences between policies for testing AV and traditional gas-powered vehicles. It seems that policies for AVs are more stringent compared to traditional vehicles, possibly due to the complexity and evolving nature of autonomous technology. AV policies may require a comprehensive approach that addresses not only the mechanical aspects of the vehicle but also the software, communication, and cybersecurity components crucial for safe and reliable autonomous operation. The following table summarizes these differences in three items: safety policies, inspection requirements, and post-crash requirements.

Criteria	Traditional Gas-Powered Vehicles	Autonomous Vehicles (AVs)
Primary Focus	Emission standards, vehicle safety features	Safe operation of autonomous technology, system reliability
Regulatory Bodies	National Highway Traffic Safety Administration (NHTSA), Environmental Protection Agency (EPA)	State Departments of Transportation (e.g., PennDOT), National Highway Traffic Safety Administration (NHTSA), Federal Motor Carrier Safety Administration (FMCSA)
Testing Requirements	Emissions testing during specific driving cycles; Safety features such as airbags, brakes, etc.	Rigorous software and hardware testing; Safety features for autonomous operation; Real-world driving scenarios for system evaluation
Inspection & Maintenance	Regular state inspections for emissions and safety compliance; Maintenance as per manufacturer guidelines	Regular checks and updates of software systems; Maintenance of sensors and hardware components relevant to autonomous operation
Emission Standards	Strict standards to control pollutants like carbon monoxide, nitrogen dioxide, particulate matter	Not directly applicable, electric AVs contribute to reduced emissions
Legislative Framework	Clear Air Act Amendments for emission standards; State and federal safety regulations for vehicle design and operation	Emerging state-specific legislation for AV testing and operation (e.g., Pennsylvania's AV laws); Federal guidelines for AV deployment and testing
Liability and Insurance	Liability generally on the driver/owner; mandatory vehicle insurance	Evolving insurance models to account for autonomous technology; Proof of insurance coverage equal to at least $1 million is required (Pennsylvania's new autonomous vehicle law takes effect in 2023).

Public Road Testing	Not applicable (vehicles are assumed safe post compliance with federal safety standards)	Extensive on-road testing required under specific conditions (e.g., presence of safety engineers); Testing permits issued by state authorities
Innovation and Adaptation	Relatively stable regulatory environment; Incremental advancements in vehicle safety and emissions control	Rapidly evolving with technological advancements; Continuous updates to regulations and guidelines to accommodate new AV technologies

Inspection Item	**Traditional Gas-Powered Vehicles**	**Autonomous Vehicles (AVs)**
Software and Firmware	Not applicable	Regular updates and functionality checks
Sensors and Cameras	Not applicable	Condition and functionality checks
Communication Systems	Not applicable	Inspection of vehicle-to-vehicle and infrastructure communication systems
Mechanical Systems	Brakes, steering, tires, wheels, suspension	Similar inspections, plus any AV-specific mechanical systems
Battery and Electrical Systems	Battery health, charging system (for EVs)	Same as traditional, plus any AV-specific electrical systems
Safety Features	Seat belts, airbags	Same as traditional, plus AV-specific safety systems like emergency stop mechanisms
Data Recording Devices	Not typically inspected	Checks on data recording and storage systems
Cybersecurity	Not typically a focus	Cybersecurity measures and protections
Compliance with Local Regulations	Emission standards, vehicle registration	Same as traditional, plus specific AV regulations
Emergency Protocols	Not applicable	Ability to handle emergencies autonomously or switch to manual control

Lighting and Electrical Systems	Headlights, brake lights, turn signals, etc.	Same as traditional
Body and Chassis	Inspection for damage and rust	Same as traditional
Exhaust System	Condition and emissions	Not applicable for electric AVs
Tires and Wheels	Tread depth, condition, pressure	Same as traditional

Aspects	Traditional Gas-Powered Vehicle	Autonomous Vehicles (AVs)
Responsibility for Stopping	Human driver stops the vehicle and assesses the situation.	The ADS automatically stops the vehicle.
Notification of Authorities	Human driver calls the police or emergency services.	The ADS can automatically notify authorities and emergency services.
Exchange of Information	Drivers exchange contact and insurance information.	Information exchange is managed by the vehicle's operator/owner or ADS.
Documenting the Scene	Human driver takes photos and gathers witness information.	The ADS records detailed data pre-, during, and post-crash for analysis.
Insurance Claim Process	Driver files a claim with their insurance company.	Claims may involve the AV manufacturer, software provider, or operator.
Legal Liability	Liability is often based on driver actions and decisions.	Liability can involve the ADS, manufacturer, software provider, and cybersecurity factors.
Regulatory Reporting	Depends on local laws, usually involves reporting to insurance and possibly police.	NHTSA has issued a Standing General Order (the General Order) requiring identified manufacturers and operators to report to the agency certain crashes involving vehicles equipped with ADS or SAE Level 2 advanced driver assistance systems (link).

Conclusion

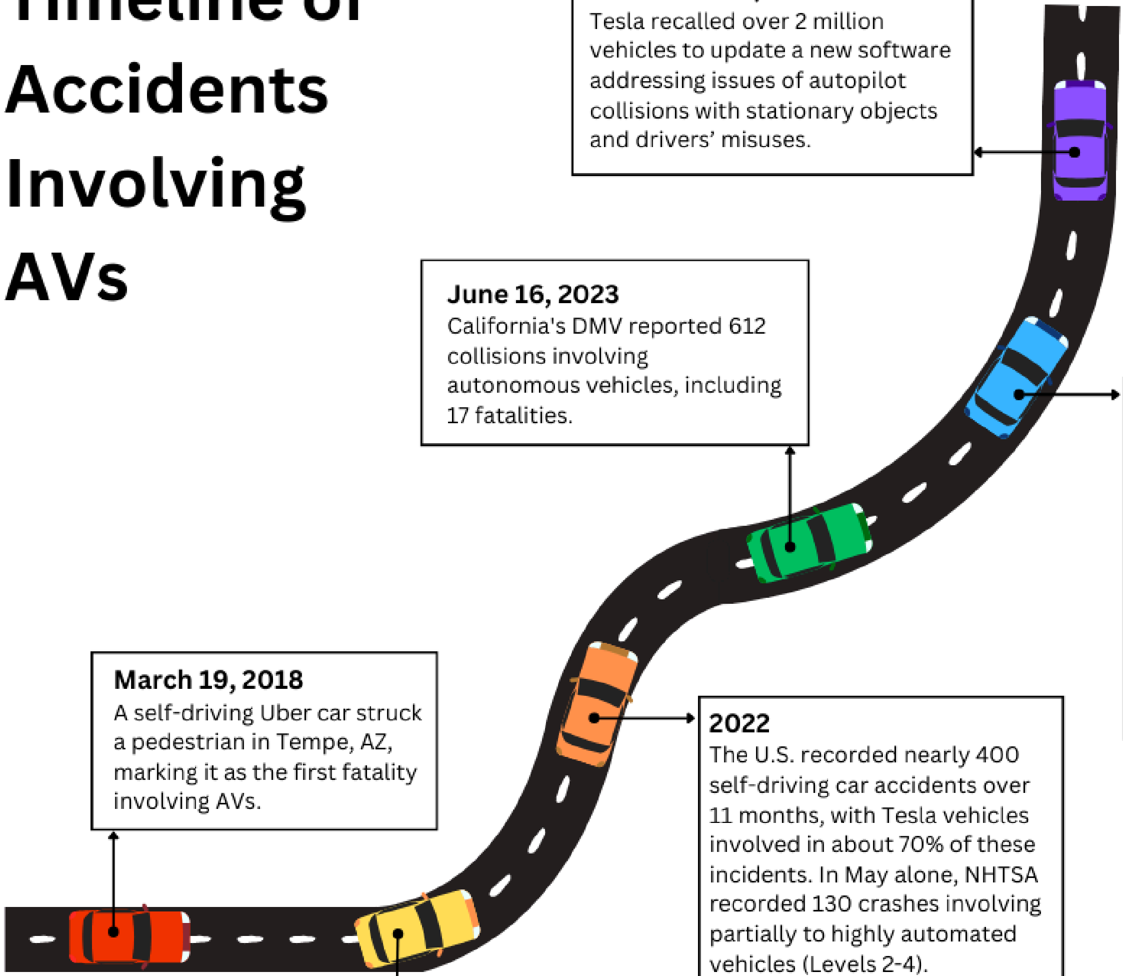
It is clear that the AV industry faces irregular stringency and much uncertainty in complying with testing policies (link). The lack of a binding federal legislation means states must fill in the regulatory roles with different standards and requirements; thus, collaborating with local regulatory agencies is crucial for keeping policies up-to-date with the field's development. In Pennsylvania, PennDOT requires submission of a comprehensive safety review and risk mitigation plan before testing HAVs on public roads. Moreover, a person in the driver's seat is required at all times as well as at least $1 million in insurance. Appendix B provides specific information about different insurance providers. RIDC can adopt the 12 elements of safety in the federal guidance and/or certain sections of PennDOT's comprehensive plan to draft PennSTART's safety review procedures, including considerations of the vehicle's software, hardware, and cybersecurity systems.

Accidents Involving AVs

This section provides case study analyses of accidents involving AVs to understand how an unsafe AV malfunction is resolved through current laws. The RAND Corporation estimates that an AV must be driven hundreds of billions of miles for it to demonstrate its reliability against fatalities and injuries (link). In other words, test-driving alone cannot ensure the vehicle's safety. Testers will need to develop ingenious testing methods to fine-tune the AV's safety features. An understanding of how AV accidents occur and their legal repercussions pave the way to deriving more comprehensive testing procedures for PennSTART.

There exists some data on autonomous vehicle accidents. The California Department of Motor Vehicles (DMV) reported 612 autonomous vehicle collisions in California alone as of June 16, 2023, including 17 fatal incidents. In 2022, nearly 400 self-driving car accidents were recorded in the U.S., with approximately 70% involving Tesla vehicles. These accidents mainly involved the use of Autopilot, Full Self-Driving, Traffic-Aware Cruise Control, and other driver-assist systems (link). This section focuses on two specific incidents: (1) start-up company Cruise's fatal incident where its robotaxi struck a pedestrian in San Francisco and (2) Tesla's recall of two million vehicles for a software update on its Autopilot system. The two case studies suggest significant challenges in testing AVs for safety before deployment. Public trust for AV technology is an ongoing issue that must be addressed through rigorous safety testing procedures and assurance policies as well as ongoing collaboration with local regulators.

Timeline of Accidents Involving AVs



March 19, 2018
A self-driving Uber car struck a pedestrian in Tempe, AZ, marking it as the first fatality involving AVs.

2020
The National Highway Traffic Safety Administration (NHTSA) establishes the first motor vehicle safety standards for AVs.

2022
The U.S. recorded nearly 400 self-driving car accidents over 11 months, with Tesla vehicles involved in about 70% of these incidents. In May alone, NHTSA recorded 130 crashes involving partially to highly automated vehicles (Levels 2-4).

June 16, 2023
California's DMV reported 612 collisions involving autonomous vehicles, including 17 fatalities.

October 2, 2023
In San Francisco, a negligent driver struck a pedestrian and threw her into the route of a driverless robotaxi designed by Cruise (AV startup in California). The AV was unable to stop, dragging the person 20 feet as its pull over and causing serious injuries.

December 13, 2023
Tesla recalled over 2 million vehicles to update a new software addressing issues of autopilot collisions with stationary objects and drivers' misuses.

Case Study 1: Cruise Robotaxi Incident on October 2, 2023

Incident Description

This case happened in San Francisco on October 2nd, 2023. Around 9:30 PM, a negligent driver struck a pedestrian, throwing her into the lane of a driverless robotaxi designed by Cruise. The AV failed to stop in time and dragged her 20 feet before coming to a stop on top. The San Francisco Fire Department used rescue tools to free the victim, who was gravely injured and had to be transported to a trauma center(link).

Permit Process before the Incident

The California DMV has a three-step process for obtaining a permit to operate an AV business in the state. Companies must obtain three types of permits in order: permit for testing an AV with a driver (valid for two years), permit for testing an AV without a driver (valid for two years), and then the permit for deployment of the AV (unsure of expiration). Each permit includes an extensive application and quality assurance. Currently, the DMV only accepts deployment for three companies in designated areas (link).

Cruise first started their business with a focus on creating a fully autonomous transportation operation. They began modifying existing vehicle models like the Chevrolet Bolt, integrating advanced technologies such as LiDAR, radar, camera sensors, sophisticated drive control algorithms, and artificial intelligence. The permit process required that Cruise conducted real-world testing on public roads in various locations, including San Francisco, Arizona, and the metropolitan Detroit area. Cruise's malfunctions despite these complex tests raised challenges for regulators to fully assess an AV's safety.

Legal Repercussions and Company Responses

The day after the incident, representatives from the Department of Motor Vehicle (DMV) and California Highway Patrol met with Cruise representatives to discuss the incident. Cruise provided officials with video footage from the AV, showing the initial hard-braking to demonstrate that the vehicle attempted to "minimize impact." However, the footage did not include the robotaxi's pullover maneuver nor other movements after the initial braking (link). This mishap would later result in Cruise's suspension and further distrust in AV companies.

After the meeting, Cruise initially attempted to fix the issue by recalling all of its cars nationwide and initiating a third-party safety review, but the company ultimately expanded the business (link). On October 16th, NHTSA opened an investigation into Cruise's incident. Cruise emphasized on X, formerly Twitter, that the crash was an "extremely rare event" (link). On

October 24th, the DMV subsequently ordered Cruise to stop all operations, suspending its license to operate in the state due to “safety concerns” (link). Cruise’s CEO and co-founder resigned in less than a month after the incident. In six months, Cruise received a notice for a hearing for a penalty up to $1.5 million for providing misleading evidence to regulators (link).

Cruise argued that it had shown the full video and hired an external law firm to examine whether its executives were hiding evidence from regulators. The review concluded that the shortened video was due to “internet connectivity issues” and that Cruise did “play or attempted to play” the full video when meeting with regulators (link). At the same time, Cruise leadership failed to appropriately respond when regulators showed evidence of the robotaxi failing to identify the pedestrian. They attempted to alter the narrative to highlight that the hit-and-run driver caused the accident, not the Cruise vehicle, without acknowledging the AV’s contribution to causing the pedestrian’s injuries. Therefore, Cruise still failed to cooperate with regulators and address the AV’s malfunctions in a productive manner.

Case Study 2: Tesla’s Recall on December 13, 2023

Incident Description

Tesla recalled more than two million vehicles on December 13, 2023, due to concerns with its Autopilot or Full Self-Driving (FDS) system. The NHTSA initiated an investigation after 750 complaints of Tesla vehicles equipped with this system stopping the vehicle while driving, even on the highway. The investigation concluded that the current design of Tesla's Autopilot might not adequately ensure driver engagement, where drivers are frequently “unprepared” to control the vehicle when Autopilot was engaged (link). Tesla agreed with the recall and committed to deploying a software update, which included increasing visual alerts, simplifying the engagement and disengagement of Autosteer, and adding more checks for Autosteer activation.

Permit Process before the Incident

Initially, Tesla's FDS system was not classified under the DMV's autonomous vehicle regulations because it required human intervention (link). Tesla argued that its FDS is only at Level 2 automation and, therefore, can operate without a special permit from the DMV. This decision was later revisited as federal agents investigated Tesla vehicle crashes. Specifically, the California DMV indicated that if Tesla's features met the definition of an AV as per California law, Tesla would need to operate under the appropriate AV permits (link). Tesla currently holds a permit for testing an AV system with a driver and may continue to pursue the remaining permits for its FDS (link).

Legal Repercussions and Company Responses

Tesla was involved in multiple lawsuits (most are private right of actions) relating to this Autopilot system, alleging that it was defective and that the company was negligent in allowing the system to be used on public roads without adequate safeguards (link). Notably, there was class action claiming that Tesla "misled" consumers about its vehicle's self-driving abilities–where the Autopilot system was supposed to bring the vehicle to full automation without the driver's attention (link). While Tesla won this case, the plaintiffs' arguments are worth taking into consideration because they highlight the importance of human intervention to ensure safe operations of an AV system.

Tesla's liability in these lawsuits was determined on a case-by-case basis. In some cases, Tesla successfully argued that the accidents were caused by human error rather than a defect in the Autopilot system (link). After Tesla's mass recall in December, however, plaintiffs were arguing that such action proves the company knew its Autopilot system was dangerous, bolstering their claims that the system was defective and contributed to the accidents (link). The company might have taken the responsible action to fix their unsafe ADS, but the unfavorable consequences of such action might deter other companies from following suit.

In conclusion, the ultimate outcome of Tesla's lawsuits and the extent of the company's legal liability will depend on the specific facts of each case, the arguments presented by the parties, and the decisions of the courts.

Implications for the Industry

These case studies highlight a major challenge for the deployment of AV technologies: public trust. Reported crashes and accidents, not to mention lawsuits, relating to an AV significantly affect public perception of AV safety, leading to more restrictions in testing and deploying new technology. Once an accident occurs, companies' reactions are highly scrutinized in the media. For Cruise, lack of collaboration with policy makers contributed to not only the revocation of their deployment permit but also their customers' trust in the robotaxi (link). At the same time, Tesla' recall might have been the most optimal decision to make, but plaintiffs saw such action as evidence of the ADS being unsafe (link). Therefore, public trust must be handled in a multi-faceted approach where stakeholders in the autonomous industry comprehensively provide the public and policy makers with both quantitative and qualitative evidence of an "acceptable level" of safety for any AV (link). A rigorous evaluation process is a reasonable starting point for collecting such evidence—an important goal and use case for PennSTART.

Safety Standards at Different Test Tracks

This section reviews safety procedures at different test tracks to provide a practical overview of how these facilities apply ideas of AV safety into their designs. We focus on three major tracks–MCity, Gomentum Station, and American Center for Mobility (ACM)–due to their robust and publicly available information on safety procedures at the tracks. MCity's approach to safety testing seems to be more unique than the others with an in-house testing methodology and innovations with humanetics. Gomentum Station and ACM offer testing services in accordance with international or national standards (Euro NCAP, IIHS, ISO, etc.). This difference may be because MCity is more of a research center for AV technology as opposed to Gomentum and ACM, which also operate as proving grounds for AV technology. PennSTART's primary purposes may better align with those of Gomentum and ACM, while research tracks like MCity provide insights into new testing technologies that are cost-effective and comprehensive.

MCity

This 32-acre controlled test environment with 4.2 miles of roads on the University of Michigan's North Campus in Ann Arbor, Michigan, is used to research and develop connected and autonomous vehicle (CAV) technologies. MCity is equipped with state-of-the-art technology and infrastructure for rigorous, repeatable testing.

MCity recently introduced the concept methodology of an ABC Test for HAVs: **A**ccelerated evaluation, **B**ehavior competence, and **C**orner cases. Each type of test yields different evaluation metrics and is meant to assess the HAV's safety in a test track before deployment on public roads. "Taken together," Dr. Peng – Director of MCity wrote, "[the ABC tests] are random, valid, fair and comprehensive" (link).

Accelerated evaluation only concentrates on *risky* testing situations, speeding up the testing process (link). These tests are meant to provide insights into how well an HAV handles challenging, everyday situations, contributing to an early understanding of its safety capabilities. Specifically, because car following, lane change, and left turns are scenarios that caused 70 percent of all crashes, accelerated evaluation focuses on training and evaluating the HAV on these three scenarios only (link). The researchers will be able to spend more time training the ADS on predicting and reacting to these common accidents.

Behavior competence includes 50 testing scenarios that MCity compiled from literature review. While not all scenarios should be tested on an HAV, MCity recommends diversifying the testing environment depending on the vehicle's ODD. For example, some vehicles may be operating frequently under low-light conditions and rainy days, so their behavior competence tests should be conducted under these conditions (link). However, testing for all weather and lighting conditions is costly, so MCity proposes six guiding principles:

1. The selection of test cases should be reasonably based on the vehicle's ODD.
2. When selecting parameters for each test case, the behavior of other human road users should be sampled randomly.
3. The test case scenario should be based on naturalistic road user data that is applicable to the driving behaviors and conditions of the specific locality and region where the HAV will be deployed.
4. The tests' challenge levels (e.g. easy, moderate, hard) must be clearly defined so companies can test their vehicle on a wide range of difficulty levels.
5. All tests need to be executed "precisely."
6. Consider roadmanship –"refers to driving behavior that is statistically "normal," or similar to most human drivers" –as a test parameter. (link)

Appendix A contains a list of all 50 behavioral testing scenarios that MCity aims to develop at the test tracks.

Corner cases are more unique, deterministic tests than others and designed to "push the limits of automated vehicle performance and technology" (link). These tests are the most challenging for the HAVs, such as wrong-way drivers, flashing yellow lights, and cyclists' left turn in busy traffic (link). Certain scenarios are beyond the capabilities of current testing technology as they involve human test subjects which can pose significant risks to participants.

To fulfill the ABC tests, MCity needs facilities and historical data that naturally simulate real-world scenarios and road conditions. For instance, road signs are intentionally designed to be crooked instead of pristine to test the vehicle's recognition abilities (link). Other design elements such as the use of robotics to replicate different types of road users (link), analyses of natural driving data to model real-world driving in an augmented environment for repeatable testing (link), and diverse road types and traffic situations (link) also speak to the naturalistic standards of the ABC tests.

Gomentum Station

Gomentum Station is another prominent facility for testing CAV technologies in Concord, California. Operated by the American Automobile Association branch in Northern California, Gomentum offers a range of features and environments for comprehensive testing of autonomous vehicles and advanced driver assistance systems (ADAS). These include:

- Structured scenario test: simulations of real-world scenarios that can be administered repeatedly for testing ADS Level 2, 3 and 4
- Equipment rental: dummies of road users or obstacles such as pedestrians, deers, and bicyclists for crash testing purposes

- Real-time kinematic (RTK) corrected GPS: navigation technology with higher accuracy positioning down to 2 cm or 0.7 inch
- Digital twin simulator: 3D simulated environment to virtually test drive the ADS system (link)

Gomentum tests selected competencies from the NHTSA, the Insurance Institute for Highway Safety (IIHS), and the Euro NCAP, which will be listed in an upcoming comparison table (link). Their researchers also designed and applied the Collision Avoidance Capability (CAC) metric, published in SAE's journal, to assess a vehicle's ability to predict and avoid collision at any point in time without priori knowledge about the conflict scenario (link). This paper is available through Carnegie Mellon University's libraries.

American Center for Mobility

This 500-acre vehicular automation research center and federally designated AV proving ground is located in Ypsilanti Township, Michigan (link). ACM provides testing services for a wide range of vehicle types, not just AV. The test track specifically designed to test ADS technology of all levels is powered by Intertek–a company that offers Assurance, Testing, Inspection and Certification (ATIC) services to various industries (link). The track evaluates against certain standards from the Euro NCAP and International Organization for Standardization (ISO) for the following ADS:

- Adaptive cruise control
- Automatic emergency braking
- Automatic parking
- Automotive navigation system
- Blind spot monitoring
- Crash imminent braking
- Collision avoidance system
- Driver monitoring system
- Forward collision warning
- Lane departure warning system
- Lane keep assist system
- Traffic sign recognition
- Turning assistant
- Vulnerable road user (VRU) detection system

Conceptually, Intertek adopts the idea of functional safety and cybersecurity from other industries to define safety standards for AVs. "Functional safety concerns hazards that arise from the function of a vehicle… Functional safety is the identification and planned mitigation of these risks" (link). In other words, it means evaluating all the risks associated with the ADS (in both the vehicle's hardware and software) and weighting them based on severity so that resources can be concentrated on mitigating high-risk scenarios. These risk assessments also include cybersecurity risks where an outside agent interferes with the vehicle's operations.

In addition, the ACM also collaborates with the Center for Connected and Automated Transportation (CCAT) to integrate the Safe AI Framework for Trustworthy Edge Scenario Tests, or SAFE TEST, to the tracks' capabilities. The test includes augmented technology that allows researchers to virtually test an AV against background traffic with naturalistic maneuvers without incurring high costs of purchasing test vehicles (link). These environments are seamlessly loaded into the AV's camera system and allows for cost-effective, repeatable testing procedures.

Comparison and Conclusion

These three test tracks differ on a fundamental level in terms of AV safety testing. For a start, each track specifies different automation levels that are within their testing capabilities. MCity focuses purely on HAVs Levels 4 and 5, Gomentum can test AVs from Level 2 to 4, and ACM offer testing for all levels of automation. Moreover, the three tracks embrace different combinations of testing frameworks from both official standards and in-house research. Unlike the other tracks, MCity did not publish official standards that they test against but instead provide a list of test scenarios, a collection among which the ADS will be tested against. In terms of technology, appendix B of this report provides a comprehensive comparison of different technology at different test tracks including for these three tracks, but the table below provides focused comparisons on technology for testing against vulnerable road users (VUR) and for simulating traffic scenarios/conditions. These differences might be the result of not only resource constraints but also the tracks' missions where MCity focuses more on innovative research and the other tracks on being proving grounds for AV.

Elements	MCity / MCity 2.0	Gomentum	ACM
SAE Levels	Mostly AV Level 4 and 5	AV levels 2, 3, and 4	All AV levels
Evaluation Framework	● For scenario-based behavior competency: Mcity ABC test (developed in-house) ● For driving environment-based safety performance: CCAT SAFE	● Structured scenarios tests based on either preexisting standards test, naturalistic driving logs, or public databases ● In-house Collision Avoidance Capability (CAC) metrics	● Automotive Functional Safety Tests (Risk Mitigation scenarios) ● CCAT SAFE
Test Standards	1. Move out of the travel lane and park 2. Perform lane changes 3. Follow lane lines 4. Detect and respond to faded or missing roadway markings or signage 5. Drive on roads without lane lines 6. Adjust position for cones 7. Perform a U-turn 8. Lane change through a narrow gateway 9. Drive through tunnel 10. Detect and respond to speed limit changes and speed advisories 11. Detect and respond to traffic signals and stop/yield signs 12. Detect and respond to temporary traffic control devices for detours/change of pattern 13. Navigate around unexpected road	● NHTSA Forward Collision Warning ● NHTSA Lane Departure Warning ● NHTSA Crash Imminent Braking ● IIHS Autonomous Emergency Braking ● IIHS Pedestrian Autonomous Emergency Braking ● NHTSA Traffic Jam Assist ● Euro NCAP Automatic Emergency Braking Car-to-Car ● Euro NCAP Automatic Emergency Braking Vulnerable Road User ● Euro NCAP Lane Support Systems ● Euro NCAP Speed Assist Systems	● Euro NCAP Autonomous Emergency Braking Car-to-Car ● Euro NCAP Autonomous Emergency Braking Vulnerable Road User ● Euro NCAP Lane Support Systems ● Euro NCAP Speed Assist Systems ● ISO 11067:2015 – Curve speed warning systems ● ISO 11270:2014 – Lane keeping assistance systems ● ISO 15622:2010 – Adaptive Cruise Control systems ● ISO 15623:2013 – Forward vehicle collision warning systems ● ISO 16787:2017 – Assisted parking system ● ISO 17361:2017 – Lane

	closures 14. Navigate railroad crossings 15. Navigate narrow streets 16. Perform high-speed and low-speed merge 17. Detect passing and no passing zones and perform passing maneuvers 18. Adjust position for vehicles encroaching in lane 19. Detect and respond to encroaching oncoming vehicles 20. Perform car following (including stop and go) 21. Detect and respond to stopped vehicles and stationary obstacles 22. Detect and respond to lane changes (cut-ins) 23. Navigate intersections and perform (left and right) turns 24. Navigate roundabouts 25. Navigate a parking lot respond to reversing vehicles and locate spaces 26. Detect and respond to emergency vehicles, including at intersections 27. Detect and respond to school buses 28. Detect and respond to non-collision safety situations (e.g. Vehicle doors ajar) 29. Respond to vehicle breaking rules at traffic lights 30. Navigate environments with		departure warning systems ● ISO 17386:2010 – Maneuvering Aids for Low Speed Operation ● ISO 17387:2008 – Lane change decision aid systems ● ISO 19237:2017 – Pedestrian detection and collision mitigation systems ● ISO 22178:2009 – Low speed following systems ● ISO 22179:2009 – Full speed range adaptive cruise control systems ● ISO 22839:2013 – Forward vehicle collision mitigation systems ● ISO 26684:2015 – Cooperative intersection signal information and violation warning systems

	occluded view 31. Detect and respond to golf carts 32. Detect and respond to work zones and people directing traffic 33. Make appropriate right-of-way decisions at crosswalks (pedestrian + bicycle) 34. Detect and respond to pedestrians in road (not at intersection or crosswalk) 35. Keep safe distance from pedestrians and bicyclists on side of the road		
VUR Dummies	Collaborated with Humanetics to obtain crashable VUR robots (link)	Offer standardized 4ActiveSystems test props for adult and child articulated pedestrians and adult cyclists. Also collaborate with Humanetics but not for VUR (link)	Offer 4activePS static adult and child pedestrian targets and surfboards. Also collaborate with Humanetics but unsure for which equipment (link)
Traffic Simulations	Live testing is scenario-based and conducted on the test tracks with realistic props. Augmented testing (the AV is connected to a virtual reality) is based on naturalistic driving data collected in-house and follows CCAT SAFE standards.	Live testing is scenario-based and conducted on the test tracks with standardized props. Augmented testing is through GoMentum's digital twin simulator (in-house technology) that allows testers to conduct a virtual drive-through with the ADS in a 3D environment.	Live testing includes high speed and low speed testing on public roads, closed tracks, and rough roads. Currently developing the capability for augmented testing with digital twin simulators.

Features and Technologies

Features are elements that characterize a track's capabilities and use cases while technologies are the specific systems that allow tracks to operate a feature. For example, the feature "Internet of Things" requires 5G, Private 4G/LTE, V2X communication, and Fiber Optic Cable technologies. In this section, we first summarize the test features and technologies available on six existing U.S. test tracks, focusing on the use cases of MCity and GoMentum Station. Finally, we perform a mapping analysis between features and technologies. The goal of this section is to provide RIDC with an overview of existing technologies to consider incorporating into PennSTART's use cases.

Primary sources quick access:
- Mcity: link
- GoMentum Station: link
- SunTrax: link
- Alliance MIZ: link
- I-ACT: link
- ACM: link

Features at Different Test Tracks

The table below summarizes the features we found in these six tracks. It is important to note that I-ACT is still in its conception phase. The Data cloud system for Mcity is also being built in their 2.0 version of the track (cite). Since the start of this project, this table has been updated to reflect new additions. The latest updates include: Gomentum now has a 6 lane intersection; Mcity built a roundabout and is building a data cloud with new funding; and MCity, GoMentum Station, and SunTrax added Suburban simulation ability.

Features	Mcity	GoMentum Station	SunTrax	Alliance MIZ	I-ACT	ACM
On/Off Ramps	X		X			X
Railroad Crossing	X	X				
Underpass	X	X				
Rural	X	X	X		X	X
Bikes	X	X				X

Crossings	X	X				X
Blind Curves	X		X			X
Straight Away	X(100 ft)		X(1 mi)		X	
Traffic Lights	X	X	X			X
Simulated Tree Canopy	X					
Targets	X	X	X			X
Merges		X				
City Blocks	X	X	X	X		X
Construction Sites		X	X			
Overpasses		X				X(3 levels)
Tunnels		X				X(curved)
Undulating Topography			X			
High-Speed Oval			X			X
Personalize Urban			X		X	X
Pick-up/Drop -Off Zones			X			X(parking)
Suburban	X	X	X	X	X	
Roundabouts	X		X			X
Resilience Testing			X			
Driveways			X			
Weather Simulator			X		X	

Drone Space				X	X	
Off-Road						X
6 Lane Intersection		X				X
Configurable Test Area	X		X			X
Data Cloud	X	X				X
Airport Runways					X	
Grid System Village					X	

A Focus on Mcity and Gomentum

We took a closer look at MCity and Gomentum as these tracks provided more information on the use cases of their technology. We then suggest a list of use cases that PennSTART should consider in its design to become a rigorous AV testing center in Pennsylvania.

Mcity Use Cases

1. *Connected and Automated Vehicle Testing:* Mcity provides a controlled environment for testing the performance and safety of CAVs under realistic urban and suburban conditions. This includes evaluating how these vehicles interact with various road features, traffic signals, and signs.

2. *Remote Testing Capabilities:* With Mcity 2.0, researchers can remotely access the test facility, enabling them to send algorithms and programs to Mcity, plug them into the facility's operating system, and participate remotely in testing scenarios. This is especially beneficial for researchers and institutions without their own testing resources.

3. *Augmented Reality:* The facility's augmented reality technology allows for testing physical test vehicles with virtually connected vehicles. This technology creates a unique environment where real and virtual vehicles can interact, providing a comprehensive testing scenario.

4. *Testing in a Naturalistic Driving Environment:* Mcity's environment allows for testing against safety-critical scenarios, such as hard braking and cut-ins, in a setting that closely resembles real-world conditions.

5. *5G and V2X Communication Testing:* With a fully connected 5G network and vehicle-to-everything communication capabilities, Mcity facilitates testing the latest communication technologies in CAVs.

6. *Data Collection and Analysis:* The facility's advanced data collection system, including sensors and a control network, enables the collection and analysis of traffic activity data. This data is crucial for understanding vehicle behaviors and interactions in various traffic scenarios.

7. *Safety Assessments:* Mcity offers specific programs like the Mcity Safety Assessment Program, which includes the Mcity ABC Test and the CCAT SAFE TEST, to evaluate the safety performance of autonomous vehicles.

8. *First-mile/Last-mile Testing:* The facility includes features like a house and garage exterior with an accessibility ramp, allowing for testing related to deliveries, ride-hailing, and first-mile/last-mile solutions.

9. *Testing New Technologies:* Mcity provides a safe and controlled environment for testing new CAV technologies before they are deployed on public streets. This includes evaluating the interaction of these vehicles with various road features, traffic signals, and signs.

10. *Remote Testing and Simulation:* With the implementation of Mcity 2.0, researchers can remotely access the test facility. This feature is particularly beneficial for those without their own testing resources, enabling them to send algorithms and programs to Mcity for testing in real-world scenarios.

11. *Augmented Reality and Virtual Testing:* Mcity's augmented reality technology allows for the interaction between physical test vehicles and virtually connected vehicles. This enables testing in a more comprehensive set of scenarios, combining real and virtual environments.

12. *Smart Road Infrastructure Testing:* Mcity's facilities, including smart intersections and pedestrian crosswalks, are suitable for testing intelligent transportation systems and smart road infrastructure. This is further supported by Mcity OS, a cloud-based operating

system that enables the creation and execution of complex, repeatable testing scenarios for connected, automated, or both types of vehicles.

13. *Data Collection and Analysis:* The facility is equipped with state-of-the-art sensors and control networks for collecting and analyzing traffic activity data. This data is crucial for understanding vehicle behaviors and interactions in various traffic scenarios.

14. *Consumer Acceptance Research:* Mcity also conducts research to gauge consumer acceptance of driverless technology, providing insights into the societal impact and readiness for such technologies.

GoMentum Station Use Cases

1. *Diverse Testing Environments:* The facility includes urban and rural environments, underpasses, overpasses, tunnels, and railroad tracks, offering a variety of real-world scenarios. This makes it ideal for testing a range of vehicle behaviors and responses in different settings.

2. *Advanced Infrastructure:* GoMentum Station features over 19 miles of roadways, including intersections, one-way and two-way lanes, merge areas, and roundabouts. It also has shared and separated bike lanes, adding to the complexity of the testing environment.

3. *Technology Integration:* The facility is equipped with remotely programmable traffic signals with V2X capabilities, allowing for comprehensive testing of vehicle-to-infrastructure communication.

4. *Targeted Scenario Testing:* GoMentum Station provides pedestrian, bicycle, animal, and vehicle targets for scenario-based testing, along with high-precision testing equipment. This is crucial for assessing how autonomous vehicles respond in dynamic environments.

5. *Accuracy and Data Collection:* The full RTK (real-time kinetic)-corrected GPS service throughout the site ensures high accuracy in data collection, which is essential for validating test results.

6. *Digital Twin Simulator:* The facility offers a digital twin simulator of various testing zones, enabling virtual testing and validation in the real world.

7. *Collaborative Ecosystem:* GoMentum Station actively seeks partnerships with public and private sectors to advance mobility technologies. This collaborative approach helps in fostering innovation and safety in autonomous vehicle development.

Recommendations: Potential Features and Use Cases to Include for PennSTART

1. *Urban and Suburban Environments:* Simulate city and residential areas to test navigation and interaction with various road layouts, traffic densities, and pedestrian areas.

2. *High-Speed and Highway Conditions:* Include long straightaways and gentle curves for testing at higher speeds, plus ramp entries and exits.

3. *Intersection and Roundabout Scenarios:* For testing vehicle responses to complex traffic scenarios and decision-making at intersections.

4. *Diverse Road Surfaces and Markings:* To assess vehicle sensors and algorithms under varying conditions.

5. *Controlled Weather Environments:* Such as wet roads or foggy conditions, to test vehicle performance in adverse weather.

6. *Pedestrian and Cyclist Simulations:* For testing detection and response to VRU.

7. *Connectivity Features (V2X):* For testing vehicle-to-vehicle and vehicle-to-infrastructure communication.

8. *Obstacle and Collision Avoidance Tests:* With dynamic, unpredictable scenarios for safety testing.

9. *Parking Scenarios:* For testing automated parking technology.

Technologies at Existing Test Tracks

Understanding the different features of these tracks, we now look into the technologies that allow for these capabilities. We provide three tables to understand how these technologies relate to the aforementioned features and their ubiquity across tracks: (1) a summary of the technologies offered at six tracks, (2) a feature-technology mapping analysis, and (3) a detailed description of each technology.

Summary of Technologies

Technology	**MCity**	**Gomentum**	**Alliance MIZ**	**I-ACT**	**ACC**
Video Sensors	X	X			
5G	X	X	X		X
EV Charging	X			X	X
Fiber Optic/High Speed	X		X		X
Kinematic Positioning	X				
Edge Computing	X	X			
Test Track OS Control	X				
RTK Base (positioning)		X			X
Digital Twin		X			
Connected lights		X			
DSRC		X			
Roadside Unit		X			
On-Board Unit		X			
Detection		X			
Electric Grid				X	
Private 4G/LTE					X

Notes:

1. MCity did not specify types of sensors.
2. SunTrax focused on roadway features rather than technology.
3. Alliance MIZ is not a true track, so no technologies were advertised.
4. I-ACT was still in the conception phase when this list was drafted.

Technology-to-Feature Mapping

Technology	Features																
	IoT	V2X	5G & 4G/LTE Network	Video Surveillance	Data Storage & Cloud	Cyber Security	Lidar & Cameras	Smart Infrastructure	Charging	Simulation & Modeling	GPS & Positioning	Intelligent Traffic Management	Environmental Simulation	Safety Features	Connectivity & Integration	First-mile / last-mile Testing	Obstacle detection testing
5G	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Private 4G/LTE	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
EV Charging Station	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Vehicle-to-everything (V2X) communication	1	1	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Video Surveillance	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Cameras	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Video Sensors (for data collection)	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
Fiber Optic Cable	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Ethernet	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Data storage	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Data Cloud	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cyber 2.0 Security Network	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Lidar Solutions	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Smart Poles	1	1	1	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Smart Traffic Light/Signals	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Intelligent Street Lights	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Traffic Signal Controllers	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Connected Lights	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Traffic Signs	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Embeded sensing	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Power	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Electric Grid	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Digital Simulation	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
Test Track OS Control	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Kinematic Positioning	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
RTK Base (positioning)	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Edge Computing	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
Digital Twin Simulator	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0
DSRC (Dedicated Short Range Communications)	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Roadside Unit	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
On-Board Unit	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Detection	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
RTK-Corrected GPS	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Augmented Reality	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
IoT Control Room	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
Wireless Charging Lanes	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Brake Soak & Slopes	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
On/Off Ramps	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Curves / Blind Curves	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Roundabout	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Traffic Circle	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Road Surfaces and Road Markings	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Crossing Types (pedestrian, railroad)	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Bridge deck, highway/ underpass, tunnels, guardrails, barriers, and crash attenuators	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0
Shared and separated bike lanes	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Urban and Suburban Streets Simulations	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Simulated tree canopy	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Parking Garage	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
House Exterior	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0

Construction sites simulation	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1
Undulating Topography	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
All-Terrain Vehicle (ATV) Course	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Weather simulator	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Drone Space	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Configurable test area	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0
Soft, synchronized moving pedestrian simulator	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
Soft vehicle for collision simulator	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
Cyclist Simulators	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1
Animals Simulators	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1

Technology Description

Technology	Description	Use Case for testing	Industry Provider	Potential Integration
5G	For high-speed data transmission and low-latency communication.	Testing AVs' ability to communicate in real-time with other vehicles, infrastructure, and cloud services.	Verizon, AT&T, Crown Castle	with V2X communication, IoT devices, and cloud services for seamless data exchange.
Private 4G/LTE	A private mobile network using 4G/LTE technology, offering controlled and secure connectivity	Testing AVs' communication in a controlled environment, especially in areas without public 5G coverage.	Verizon, AT&T and Sprint	with V2X communication and IoT devices for localized connectivity.
EV Charging Station	Infrastructure for charging electric vehicles.	AVs' ability to autonomously locate and use charging stations.	ChargePoint, Blink, ABB	with the AV's navigation system and energy management software.
Fuel Plaza?	commercially available and specialized blends of gasoline and diesel fuels.	May be used in hybrid AV testing scenarios.	Shell, Chevron, BP	
Vehicle-to-everything (V2X) communication	V2X technology enables vehicles to communicate to their surroundings including traffic signals, other vehicles, infrastructure, bicyclists and pedestrians. V2X leverages wireless protocols such as dedicated short range communication (DSRC) or cellular V2X (C-V2X) to enable this communication.	Testing AVs' ability to exchange safety and operational data with their surroundings.	Qualcomm, NXP, Cohda Wireless	with 5G, DSRC, and IoT devices for comprehensive connectivity.

Video Surveillance	Cameras and monitoring systems used for security and observation	Monitoring AV testing areas for safety and data collection.	Bosch, Hikvision, Axis Communications, Pelco	with data storage and analysis systems for real-time monitoring and post-test analysis.
Cameras	Imaging devices installed on vehicles used for capturing visual data.	Testing AVs' perception systems and their ability to interpret visual information.	Bosch, Mobileye	with AVs' sensor fusion systems and data analysis platforms.
Video Sensors (for data collection)	Sensors that capture video data for analysis, can be installed on different poles, traffic lights, etc	Collecting detailed visual data during AV testing for performance evaluation.	FLIR, Teledyne, Basler	with data storage and processing systems for comprehensive data analysis.
Fiber Optic Cable	dedicated fiber to support all IoT devices that will be tested or demonstrated.	Providing high-speed data connectivity for AV testing facilities and communication systems.	Corning, Prysmian Group, OFS.	with data centers, communication networks, and surveillance systems for fast data transfer.
Ethernet	A widely used technology for network connectivity.	Connecting various devices and systems in the AV testing facility for data exchange and communication.	Verizon, AT&T, Crown Castle	with data storage, surveillance, and control systems for reliable connectivity.
Data storage	Systems and devices for storing digital data.	Storing large volumes of data generated during AV testing for analysis and archiving.	Western Digital, Seagate Technology	with data analysis platforms, cloud services, and backup systems for data management.
Data Cloud	Cloud computing services for storing, processing, and managing data.	Scalable storage and processing of AV testing data, enabling remote access and collaboration	Amazon Web Services, Microsoft Azure, Google Cloud.	with data analysis tools, IoT devices, and security systems for comprehensive data management.

Cyber 2.0 Security Network	Provides defense against the spread of cyber-attacks within organizational networks.	Ensuring the security of data and communication systems in the AV testing facility.	Cisco Systems, Palo Alto Networks	with data storage, communication networks, and control systems for comprehensive security.
Lidar Solutions	Light detection and ranging is the apex of mapping technology that uses eye-safe laser beams to see the world in 3D, providing machines and computers with an accurate representation of the surveyed environment.	Testing AVs' ability to perceive and navigate their environment using lidar sensors.	Ouster, Velodyne, Luminar	
Smart Poles	Multifunctional poles equipped with sensors, communication devices, and other technology.	Providing infrastructure for V2X communication, surveillance, and environmental monitoring in the testing area.	Philips Lighting, GE Lighting	with V2X communication systems, surveillance cameras, and IoT devices for comprehensive infrastructure support
Smart Traffic Light/Signals	Traffic lights equipped with sensors and communication technology for adaptive control.	Testing AVs' ability to interact with intelligent traffic management systems.	Siemens, Swarco	with V2X communication systems and traffic management software for coordinated traffic control.
Intelligent Street Lights	Street lights with integrated sensors and communication capabilities for adaptive lighting and data collection.	Enhancing visibility and safety in the testing area while collecting environmental data.	Philips Lighting (Signify), Cree Lighting	with smart poles, IoT devices, and energy management systems for efficient operation
Traffic Signal Controllers	Devices that control the timing and operation of traffic signals.	Testing AVs' ability to respond to dynamic traffic signal changes and coordination.	Trafficware, Siemens, Inteligent	with smart traffic lights and traffic management systems for synchronized traffic control.

Connected Lights	Lighting systems connected to a network for remote control and monitoring.	Providing adaptive lighting in the testing area for different scenarios and conditions.	Osram, GE Lighting	with intelligent street lights, smart poles, and IoT devices for coordinated lighting control.
Embeded sensing	Sensors embedded in infrastructure or vehicles for data collection and monitoring.	Collecting detailed data on AV performance and interaction with the environment.	Bosch, Continental AG	with data analysis platforms, IoT control rooms, and V2X communication systems for comprehensive monitoring.
Power/ High Power Outage	Systems and infrastructure for supplying electrical power.	Providing power for all components of the AV testing facility, including charging stations and lighting.	Siemens Energy, GE	with renewable energy sources, smart grid technology, and energy management systems for efficient power distribution.
Electric Grid	power generation, transmission, and distribution facilities.	Ensuring reliable power supply for the AV testing facility and its components.	ABB, Schneider Electric	with renewable energy sources, smart grid technology, and energy storage systems for stable and efficient power supply.
Digital Simulation	Use of computer models to simulate real-world scenarios and environments.	AV algorithms and systems in simulated environments before real-world testing.	ANSYS, Dassault Systèmes	with data analysis platforms, digital twin simulators, and virtual reality systems for comprehensive simulation capabilities.
Test Track OS Control	An operating system for controlling and managing the various components of the AV testing track.	Coordinating the operation of the testing track over phone, including traffic signals, surveillance systems, and data collection.	Custom solutions developed by PennSTART or outsource (National Instruments (NI), Siemens Digital Industries Software)	with all track components, including sensors, communication systems, and data management platforms.

Kinematic Positioning	A technique for determining the position of an object using motion data.	Testing the accuracy of AV positioning systems, especially in complex environments.	Trimble Navigation, Topcon Positioning Systems	with RTK systems, GPS, and sensor fusion systems for enhanced positioning accuracy.
RTK(real-time kinematic) Base (positioning)	A base station that provides Real-Time Kinematic (RTK) corrections for high-precision positioning.	Providing accurate position data for AV testing and calibration.	Leica Geosystems, Trimble	with AVs' positioning systems and kinematic positioning technologies for precise location data.
Edge Computing	Distributed computing that brings computation and data storage closer to the sources of data.	Processing data from AVs and sensors at the edge of the network for faster response times and reduced bandwidth usage.	Hewlett Packard Enterprise (HPE), Cisco Systems	with IoT devices, data storage, and communication networks for efficient data processing.
Digital Twin Simulator	A virtual model that replicates the physical testing track and its components.	Simulating and analyzing testing scenarios and outcomes before conducting physical tests.	Siemens Digital Industries Software, PTC	with digital simulation systems, data analysis platforms, and IoT control rooms for comprehensive testing and analysis.
DSRC (Dedicated Short Range Communications)	A wireless communication technology for enabling V2X communication.	Testing AVs' ability to communicate with other vehicles and infrastructure over short distances.	Cohda Wireless, Savari	with V2X communication systems, roadside units, and on-board units for seamless communication.
Roadside Unit	Infrastructure that supports V2X communication by transmitting and receiving data to and from passing vehicles.	Testing AVs' ability to communicate with infrastructure and receive real-time information.	Commsignia, Savari, TraffficCast, Siemens	with DSRC, 5G, and smart traffic management systems for coordinated communication.

On-Board Unit	A device installed in vehicles to enable V2X communication.	Testing AVs' ability to communicate with other vehicles and infrastructure.	Commsignia, Savari, TrafffficCast, Siemens	with DSRC, 5G, and sensor fusion systems for comprehensive communication capabilities.
Detection	Technologies and systems for detecting objects, vehicles, and pedestrians in the testing environment.	Testing AVs' ability to detect and respond to various obstacles and entities.	Iteris, Blue City Technology	with Lidar solutions, cameras, and sensor fusion systems for accurate detection.
RTK(real-time kinematic)-Corrected GPS	RTK (real-time kinematic) corrected GPS accuracy is used for applications that require higher accuracies, such as centimeter-level positioning down to 2 cm.		NovAtel, Hexagon	with AVs' positioning systems and kinematic positioning technologies for precise navigation.
Augmented Reality	allows for testing physical test vehicles with virtually connected vehicles	use of AR for creating dynamic and adaptable testing environments that can simulate a wide range of scenarios without the need for physical construction	Magic Leap, Microsoft	with digital simulation systems, IoT control rooms, and visualization platforms for immersive testing experiences.
IoT Control Room	A centralized hub for monitoring and controlling IoT devices and systems in the testing facility.	Managing and coordinating the various technologies and systems used in AV testing.	Cisco, IBM	with sensors, communication networks, and data management platforms for comprehensive control and monitoring.
Wireless Charging Lanes	Specialized coils laid down beneath the asphalt of the street that can charge vehicles as they travel over it	Testing the ability of AVs to charge wirelessly while driving (first case in Detroit in Nov. 2023)	Witricity, Qualcomm	with EV charging stations, power management systems, and AV energy systems for seamless charging.

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Appendix A: 50 Behavioral Competence Tests for HAVs at MCity

Ego-car test (25):

- Move out of the travel lane and park
- Perform lane changes
- Follow lane lines
- Detect and respond to faded or missing roadway markings or signage
- Drive on roads without lane lines
- Adjust position for cones
- Launching from a steep uphill
- Perform a U-turn
- Make appropriate reversing maneuvers
- Road with up/down elevation
- Lane change through a narrow gateway
- Drive over bridge
- Drive through tunnel
- Detect and respond to speed limit changes and speed advisories
- Detect and respond to traffic signals and stop/yield signs
- Detect and respond to access restrictions (one-way, no turn, ramps, etc.)
- Detect and respond to temporary traffic control devices for detours/change of pattern
- Follow local and state driving laws
- Navigate around unexpected road closures
- Navigate railroad crossings
- Detect and respond to vehicle control loss
- Detect and respond to unanticipated weather or lighting conditions outside of vehicle's capability
- Detect and respond to unanticipated lighting conditions
- Navigate cul-de-sacs
- Navigate narrow streets

Interact with a vehicle (18):

- Perform high-speed and low-speed merge
- Detect passing and no passing zones and perform passing maneuvers
- Adjust position for vehicles encroaching in lane
- Detect and respond to encroaching oncoming vehicles
- Perform car following (including stop and go)
- Detect and respond to stopped vehicles and stationary obstacles
- Detect and respond to lane changes (cut-ins)
- Navigate intersections and perform (left and right) turns
- Navigate roundabouts

- Moving to a minimum risk condition when exiting the travel lane is not possible
- Navigate a parking lot respond to reversing vehicles and locate spaces
- Detect and respond to emergency vehicles, including at intersections
- Detect and respond to school buses
- Detect and respond to non-collision safety situations (e.g. Vehicle doors ajar)
- Respond to unexpected maneuvers by other vehicles
- Respond to vehicle breaking rules at traffic lights
- Navigate environments with occluded view
- Detect and respond to golf carts

Interact with VRU and other non-vehicle player (7):

- Detect and respond to work zones and people directing traffic
- Make appropriate right-of-way decisions, including at crosswalks
- Follow police/first responder/worker/citizen controlling traffic
- Detect and respond to pedestrians in road (not at intersection or crosswalk)
- Keep safe distance from vehicles, pedestrians, bicyclists on side of the road
- Detect and respond to animals
- Detect and respond to motorcyclist

Appendix B: AV Insurance Providers

Insurance Provider	Pros	Cons	Availability	Rates
Tesla Insurance (link)	- Tailored for Tesla vehicles - Competitive rates for Tesla owners compared to other 3rd party providers as they have more data - Direct relationship with Tesla - Adaptable to Tesla upgrades through software.	- Limited to 12 states - Premiums may increase based on Tesla Safety Score	12 states in the US	Average rates for full coverage premiums for Tesla models can range from 69% to 117% higher than the national average, depending on the model.
Koop Insurance (link)	- Broad appetite for emerging technologies - Comprehensive protection for tech enterprises - Specialized in technology risks	- May not cater to individual vehicle owners. More suited for fleets.	Not specified	Quotes based on the unique needs of technology enterprises; Rates are not provided on the website.
Progressive (link)	- Offers more car insurance discounts - Usage-based insurance program (called Snapshot) - Rideshare insurance available - Gap insurance offered	- Rates tend to be higher than GEICO - Higher rates for seniors, young drivers, teens - Average collision repair rating	50 states + D.C.	Competitive rates, but often higher than GEICO. For some Tesla owners, around $70 more per month than GEICO. Specific rates are not there in website
GEICO (link)	- Typically offers cheaper rates - Simple online quote process - Easy to reach customer service - Offers mechanical breakdown insurance	- No gap insurance offered - Limited local agent network - Higher complaint levels than average	50 states + D.C.	Generally lower rates, but specific numbers are not provided. Rates vary based on age, driving record, coverage, and vehicle.

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