REPORT OF THE MASSACHUSETTS AUTONOMOUS VEHICLES WORKING GROUP

DRAFT FOR DISCUSSION PURPOSES ONLY – ACTIVE POLICY DEVELOPMENT

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2 INTRODUCTION

On October 20, 2016, Governor Charles Baker signed *Executive Order (EO) 572* [To Promote the Testing and Deployment of Highly Automated Driving Technologies.] The Executive Order, which was signed concurrently with a similar order from Mayor Martin Walsh and the City of Boston, articulated the Commonwealth's support for innovating driver-assistive technologies, and expressed the Commonwealth's belief that autonomous vehicles (AVs) have the potential to transform personal mobility and road safety if developed prudently.

EO 572 established an Autonomous Vehicles Working Group to encourage the safe introduction of autonomous vehicles onto Commonwealth roadways and to provide input on potential policies, regulations, and legislation for consideration. The Working Group comprised members of MassDOT (including the Registry of Motor Vehicles and the Highway Division), the Executive Office of Housing and Economic Development, the Executive Office of Public Safety and Security, the Legislature and designees.

The Autonomous Vehicles Working Group convened 11 meetings between October 2016 and END DATE, and covered topics including: autonomous vehicle technologies; governance and federal guidance; approaches of other states and countries; the AV industry and testing process in Massachusetts; existing laws and regulations; insurance and liability; cybersecurity; and related research initiatives. The Working Group convened a meeting at the Massachusetts State House to hear from Legislators about bills filed pertaining to autonomous vehicles. In a subsequent meeting, the Working Group heard from nearly 20 stakeholders including AV companies and component suppliers, research institutions, and transportation advocacy organizations.

The following report provides a summary of key background information, and several recommendations for advancing the state of the AV industry in the Commonwealth. The Appendix contains additional information about autonomous vehicle technologies, governance, the industry in the Commonwealth, initiatives in others states and nations, and materials from the Working Group meetings.

In addition to establishing the AV Working Group, EO 572 defined a process for MassDOT to allow the testing of autonomous vehicles (SAE levels 3-5) on public roads. Among other requirements, the process included a memorandum of understanding with MassDOT and any affected municipality or state agency; an application to MassDOT including documentation of testing experience, testing and safety plans, insurance coverage, vehicle registration, and operator licensure; and a licensed driver in the vehicle with the ability to take immediate control as necessary.

To ensure that AVs are tested safely, the Commonwealth has developed a phased permitting approach. Whereas several states permit AV testing on public ways without limitation, the Commonwealth has developed an approach which facilitates testing in well-defined environmental conditions and roadways of gradually increasing complexity. Massachusetts similarly recognizes the important role of municipalities in effectuating safe travel of citizens and visitors, and thus the importance of municipalities' role in developing safe and effective policies and protocols for the introduction of new technologies to public roadways.

It will be necessary for automated vehicle developers to test and refine their AV hardware and software systems on public roads, and this testing is likely to occur for many years to come as the vehicles become increasingly capable of navigating all types of interactions with other road users, complex roadway sections, and adverse weather conditions. The iterative application structure which the Commonwealth has developed ensures that testing entities have demonstrated safe and effective operation in closed course and simulated environments prior to conducting testing on public roads in similar environments. It is important that developers of AV technologies be permitted to conduct safe testing in collaboration with municipal and state agencies to further both stakeholders' understanding of the technologies and their efficacy in real-world environments.

Massachusetts is not waiting for connected and autonomous vehicles to reduce traffic fatalities to zero or prevent all roadway crashes. There are many approaches and strategies which the Commonwealth is implementing to address road safety, such as constructing safe roads through the Complete Streets program, developing multi-modal network plans, updating capital investment strategies, and coordinating construction and mitigation plans. In late 2018, MassDOT will update its Strategic Highway Safety Plan, which outlines specific programs and opportunities for improving travel safety generally within the Commonwealth. Collaboration between State agencies, the Legislature, municipalities, and regional stakeholders to explore and understand AV technologies represents another way in which the Commonwealth is working to address overall travel safety for road users.

The recommendations developed by the AV Working Group build upon the Executive Order testing protocol and policies, and provide clear guidance for AV testing in the near term. After the Working Group was created, the Commission on the Future of Transportation began its work, which includes examining the longer-term deployment of autonomous vehicle technologies. The Commission will issue separate policy recommendations which may encompass C/AV deployment in its report in December 2018.

The Working Group would like to thank everyone who participated in its efforts, including industry experts and members of the public. The strategic planning research conducted by the University of Massachusetts at Lowell on behalf of MassDOT and the research into

regional AV issues by AECOM for the New England Transportation Center provided valuable insights for the Working Group's consideration. The Group would like to also acknowledge the City of Boston's Department of Transportation and Mayor's Office of New Urban Mechanics, and the Metropolitan Area Planning Council for their leadership and engagement on the testing of autonomous vehicles on public roads in the Commonwealth.

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3 CONNECTED AND AUTONOMOUS VEHICLES – TECHNOLOGY OVERVIEW

There are several innovative hardware and software systems that are fundamental to connected and autonomous vehicles. A new vocabulary has been established to define and regulate the nascent industry.

Connected vehicles employ vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) technologies that allow vehicles to send and receive critical safety information about their surroundings to improve awareness of potential crashes or other hazards. V2I technologies can support environmental and safety goals by providing traffic signal phase information, red light violation warnings, reduced speed/work zone warnings, and pedestrian in crosswalk warnings. V2V technologies can share information such as a vehicle's speed and bearing to provide warnings or intervention in the case of an impending collision. V2I and V2V communications can detect developing threat situations up to a few hundred yards away and in situations in which the driver and on-board sensors alone may not be able to.

An autonomous vehicle (AV) is generally described as a vehicle which can conduct all dynamic driving tasks for at least some period of time within a designated operating domain (e.g. weather, road type, etc.). These dynamic driving tasks include steering, acceleration/deceleration, monitoring of the environment, and object and event detection and response. An autonomous vehicle is also commonly described as a "highly automated vehicle" (HAV), or "self-driving" vehicle, though particular definitions can vary.

The most commonly accepted terminology is based on the SAE International standard J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. For the purposes of this report, the term "autonomous vehicle" includes those classified by SAE standards as level 3-5. Level 1-2 vehicles are included within the term "automated vehicles," which covers levels 1-5.

- **Level 0 – No Automation**: No automated systems, full human driver operation.
  Example: Traditional cruise control systems.
- **Level 1 – Driver Assistance**: Automated steering *or* acceleration/deceleration, otherwise full human driver operation.
  Example: Dynamic cruise control or lane-keep or lane-centering (used individually, not in combination).

- **Level 2 – Partial Automation:** Automated steering *and* acceleration/deceleration, with the human driver responsible for monitoring the environment and taking full control of steering and acceleration/deceleration instantaneously as needed. A variety of driver-state monitoring systems may be employed to ensure the human driver is monitoring the environment, such as driver-facing cameras and actuators within the steering wheel. Systems are designed to disengage and lock out the autonomous mode if a driver is not actively monitoring the environment.
  Example: Several automakers including Tesla and Cadillac have deployed level 2 systems which combine traffic-aware cruise control and lane centering. Cadillac specifies the road segments on which its level 2 system "Super Cruise" may be used.

- **Level 3 – Conditional Automation**: Steering, acceleration/deceleration, and monitoring of the environment all conducted by autonomous vehicle systems. A human driver must be seated and available for fallback takeover within ~2-10 seconds. If a human driver fails to takeover when necessary, the AV system must enter a minimal risk condition (i.e. safely stop). The requirements for a safe transition from an autonomous system to a human driver are unclear, and are a primary challenge for AV developers and regulators. A level 3 vehicle must still have manual operator controls for when a driver must take over, and for operational design domains the vehicle is not capable of. Some experts do not consider a level 3 vehicle to be an "autonomous vehicle" given the necessity for a human operator.
  Example: None yet in deployment, but several manufacturers claim to release such vehicles in the next year or two in which drivers will not need to actively monitor the environment on specified roadways and in well-defined environmental conditions.

- **Level 4 – High Automation**: No human operator is needed for the vehicle to operate within its defined design domain and driving modes. The system can operate entirely autonomously on some roads, and in some environmental conditions, but not all. A level 4 vehicle may not require a steering wheel or other manual operator controls, but may be rendered inoperable if environmental conditions, such as heavy rain or snow, exceed the design limitations of the system.
  Example: Autonomous shuttles that operate within closed environments (such as large industrial complexes) or on public low-speed routes and campus environments.

- **Level 5 – Full Automation**: The system can operate entirely autonomously in all conditions and on all roads. Many experts anticipate it will take several decades to fully develop a level 5.

The distinction between an autonomous and non-autonomous vehicle is primarily based on whether the human operator or AV is responsible for monitoring the driving environment and providing object and event detection and response. An autonomous vehicle should navigate around an unanticipated object in the roadway, or reach a safe and minimal risk operating condition, without human intervention. A vehicle with lower-level automation functions, such as lane-keeping assistance and/or dynamic cruise control (levels 1-2), requires immediate human intervention if an object is encountered.

Autonomous vehicles currently operate within well-defined operational design domains (ODD) which describe the boundary conditions within which an autonomous vehicle is intended to operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/nighttime, etc.), and other domain constraints. Within its ODD, an AV is expected to be able to detect and respond to other vehicles, pedestrians, cyclists, animals, and objects both in and out of its travel path that could affect safe operation of the AV. Object and event detection and response (OEDR) refers to this detection by a driver or AV system of any circumstance that is relevant to the immediate driving task, as well as the response to such a circumstance. An AV's OEDR should be able to deal with a variety of conditions including emergency vehicles, temporary work zones, and other unusual conditions (e.g., police manually directing traffic, construction worker controlling traffic, emergency response workers) that may impact safe operations of an AV within its operational design domain.

An autonomous vehicle is equipped with many different hardware systems for localizing the vehicle on the roadway and perceiving its surrounding environment. Each type of sensor has strengths and weaknesses which must be accounted for. Autonomous driving is only feasible using a range of sensors which, when used in parallel, can reliably achieve precise localization and detailed perception of the environment. An autonomous vehicle generally relies upon detailed base maps, in addition to the sensors and hardware systems, which enable it to understand precisely where it is (localization), and what is going on in that particular environment (perception).

AV developers employ machine learning to process tremendous amounts of driving data which helps to develop and refine its operating systems. Developers must also subject their hardware and software systems to significant testing in simulations. Real-world tests can be combined with simulations to help reduce the number of miles required for validating performance. One of the most significant challenges in developing reliable autonomous (level 3-5) vehicles is being able to accurately identify objects.

Driver monitoring systems (DMS) are used to detect a human operator's level of awareness. DMS are instrumental in level 1-3 vehicles wherein a driver may be required to take control of a vehicle. Driver attention monitoring is also beneficial for reducing crashes caused by drowsy, distracted, or impaired drivers. Most DMS rely on biological and/or automotive indicators. Biological signals include face and eye tracking via driver-facing cameras or infrared sensors, and heart rate monitoring. In level 3 vehicles, DMS may be used to evaluate whether a driver is able to take over control of the vehicle any time such takeover becomes necessary. In vehicles with level 1-2 automation, DMS are critical to ensuring that a driver is consistently monitoring the environment and prepared to take over immediately.

Event Data Recorders (EDRs) can capture information such as a vehicle's performance and driver actions immediately preceding and following a crash, and the resultant collision dynamics. NHTSA's guidance and the Commonwealth's testing requirements state that AVs should record all available information relevant to the crash, so that the circumstances of the crash can be reconstructed.

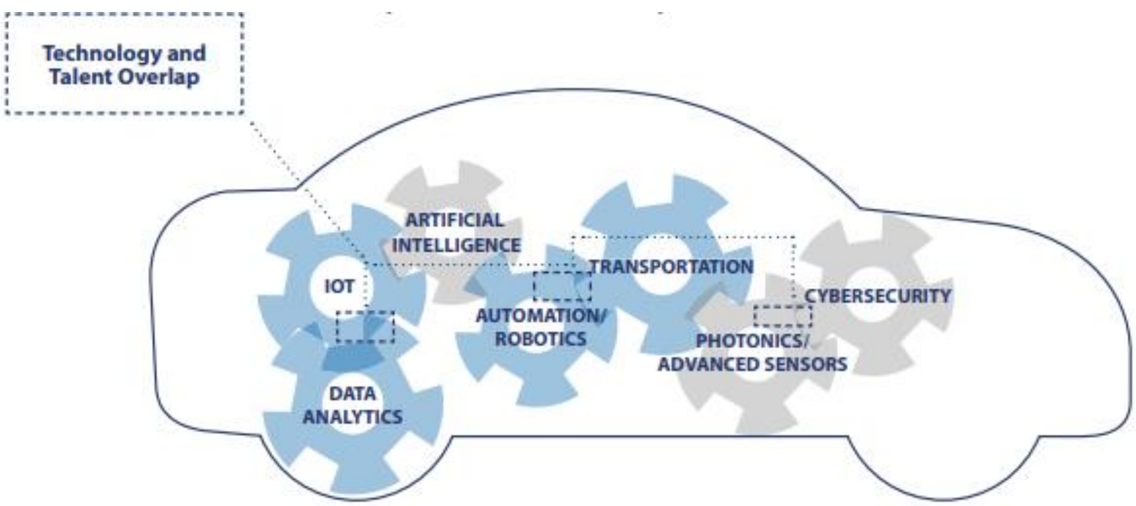
Connected vehicles are relevant to autonomous vehicles insofar as they may offer supplemental safety benefits through data provided from other vehicles or physical infrastructure, such as traffic lights. An autonomous vehicle does not need be a "connected" vehicle in order to operate in autonomous mode; however connected vehicle technologies can be an integral supplement for both human operators and autonomous systems. There are several benefits to connected vehicle technologies, most notably that they offer a longer effective range than current AV sensors, can communicate a wide range of information from multiple sources, and do not require an unobstructed line of sight (as AV sensors generally do). Combining connected and autonomous vehicle technologies could offer great potential for improving vehicles' awareness of roadway conditions and other road users (3).

For additional information about C/AV technologies and the related industries, please consult the Appendix.

3.1 C/AV Industry in Massachusetts

This overview represents the best efforts of the Working Group to provide its understanding of the connected and autonomous vehicle industry in Massachusetts based on publicly available information. It is not a fully comprehensive review of the C/AV industry in the Commonwealth, which is developing rapidly. The Acts of 2018 Chapter 228 Section 54, signed by Governor Baker in August of 2018, directed the Massachusetts Technology Collaborative to conduct a more holistic study of the AV industry by the end of 2019, and issue recommendations on how to advance the state's competitiveness in the emerging industry.

Autonomous vehicles represent one industry within the rapidly growing intersection of robotics, automation, 'big data,' and machine learning. The Commonwealth is a leading development hub for artificial intelligence, robotics, automation, and key sensor components which comprise the enabling elements of C/AVs. Within the Commonwealth, there are a growing network of companies engaged in robotics, data processing, and artificial intelligence initiatives for use in fields from healthcare to advanced manufacturing and underwater or airborne vehicles.



The MIT Computer Science and Artificial Intelligence Laboratory (CSAIL) is a research institute at the Massachusetts Institute of Technology located within the Stata Center. Founded in 1963, the institute was one of the first to begin researching AI. The 1960s were a formative decade for organizations supporting the development of artificial intelligence (AI). The first two major academic laboratories were at MIT and Carnegie Mellon (then Carnegie Tech), with AI laboratories at Stanford and Edinburgh established soon after. MIT remains today one of the world's premier universities pioneering research and development of AV technologies. In 2015, MIT-CSAIL announced a $25 million research center funded by Toyota to further the development of autonomous vehicle technologies.

In addition to the MIT CSAIL laboratory, Massachusetts has rich intellectual and research assets involved directly and indirectly with autonomous and connected vehicle technologies. Academic institutions involved in such research include several of the University of Massachusetts campuses, Boston University, Northeastern University, Worcester Polytechnic Institute, MIT, Harvard University, and others. The Commonwealth is also home to several renowned non-profit, defense, and company-based research institutions. MIT's Lincoln Laboratory (Lexington) and the MITRE Corporation (Bedford) are two of the nation's 42 federally funded research and development centers, which are public-private partnerships that conduct research on behalf of the United States government. The United States Department of Transportation (USDOT) Volpe Center (Cambridge) is a center of transportation and logistics expertise operating under USDOT. Draper Labs (Cambridge) is focuses on multidisciplinary engineering, positioning, navigation and timing microsystems, and autonomous systems.

AV system developers located in the Commonwealth include nuTonomy (an Aptiv company), Optimus Ride, NextDroid, and Toyota Research Institute. Several firms in Massachusetts specialize in hardware and software systems, including Analog Devices, Autoliv, Neurala, Sensata, Analog Photonics, Aptiv, and more. In addition, many related companies like Zipcar, Amazon Robotics, Lyft, Uber, and Google have a presence in the Commonwealth.

The Commonwealth is also home to several industry-based organizations. MassRobotics is the collective work of a group of Boston-area engineers, scientists, and entrepreneurs. The goal of the organization is to create an innovation hub and startup cluster focused on the needs of the robotics community. MassRobotics develops common-need technology services, offers prototyping facilities, and promotes cost efficiencies by sharing services and testing space.

Closed-course testing facilities are necessary for the development of autonomous vehicles for operator training, validation of vehicle behavior and systems, calibration of hardware, and stress testing edge-case scenarios (such as adverse weather). One site used by several AV developers and academic institution is the former Fort Devens campus. Devens was used for 79 years as the U.S. Army's New England headquarters before being closed in 1996. The site contains both public and private roads, with 4,400 acres of mixed-use development. The site currently permits closed-track testing for various vehicle types and functions on some of its extensive runways and closed track facilities. There is a nominal daily charge for facility use.

The Commonwealth's support for AV development is focused on several key enabling technologies: photonic sensors, robotics, and cybersecurity. The Massachusetts Manufacturing Innovation Initiative (M2I2) provides capital cost shares for projects and discovery centers located within the Commonwealth's borders, as part of the state's on-going commitment to the Manufacturing USA program put forth by the federal government. Since 2016, the Commonwealth has invested more than $14M via M2I2 program in AIM Photonics and ARM Manufacturing USA institutes supporting Massachusetts companies and research institutions focusing on photonics and robotics technologies and applications.

Among several technology sectors within the Commonwealth, a significant focus has been placed on cybersecurity, leading to the creation of the MassCyberCenter. Currently housed as an initiative within the Massachusetts Technology Collaborative (MassTech), the MassCyberCenter is a government-backed initiative to advance the regional cybersecurity ecosystem.

4 GOVERNANCE

There are several layers of local, state, and federal governance that apply to traditional motor vehicles and human operators.

The Federal Motor Vehicle Safety Standards (FMVSS) were first introduced in 1966 and now include 73 separate standards that generally focus on crash avoidance, crashworthiness, and post-crash survivability. The current FMVSS do not explicitly address automated vehicle technology and often assume the presence of a human driver. The standards will have to be updated in order to accommodate changes to vehicle design and operation, but the timing of this is uncertain.

Traditionally, a manufacturer self-certifies that the vehicle being manufactured and sold meets the Federal Motor Vehicle Safety Standards (FMVSS). The National Highway Traffic Safety Administration (NHTSA), part of USDOT, is authorized by the National Traffic and Motor Vehicle Safety Act (49 U.S.C. Chapter 301) to issue FMVSS that set performance requirements for new motor vehicles and new items of motor vehicle equipment. Under the Safety Act, NHTSA does not provide approvals of motor vehicles or motor vehicle equipment and does not make determinations as to whether a product conforms to the FMVSS outside of an NHTSA compliance test. The Safety Act requires manufacturers to self-certify that their products conform to all applicable FMVSS that are in effect on the date of manufacture. Manufacturers also are responsible for ensuring that their products are free of safety-related defects. NHTSA checks compliance with the FMVSS by testing vehicles and regulated equipment. NHTSA also investigates safety-related defects and conducts related enforcement and recall actions. Finally, NHTSA can issue interpretations for how vehicles may comply with FMVSS.

NHTSA and the Environmental Protection Agency (EPA) may be required to issue exemptions or waivers to allow for AV tests. nuTonomy's Renault ZOE vehicles being tested in the Commonwealth are provided with EPA exemptions for nonconformity, as they are European cars not traditionally sold in the US. NHTSA must issue exemptions for any vehicle which does not meet FMVSS to be testing on public ways. NHTSA can provide a maximum of 2,500 FMVSS exemptions annually. Pending federal legislation in the House and Senate both seek to address this limited number of exemptions in addition to several other provisions intended to streamline AV testing and deployment.

The National Transportation Safety Board (NTSB), an independent federal agency, is charged with determining the probable cause of transportation accidents and promoting transportation safety. In the course of its investigations, NTSB regularly issues recommendations to federal regulatory agencies such as USDOT and NHTSA, Congress, and vehicle manufacturers and industry groups. NTSB has conducted several investigations of level 1-3 automated vehicle crashes, and will investigate future AV crashes as necessary.

In September 2017, USDOT issued an update to its Federal Automated Vehicles Policy, Automated Driving Systems 2.0. The document includes a 12-point Voluntary Safety Self-Assessment for AV manufacturers, and best practices guidance for state legislature and transportation departments regarding vehicle licensing and registration, traffic laws and enforcement, and motor vehicle insurance and liability regimes. NHTSA has defined a commitment to use existing regulatory tools to advance the testing and deployment of HAVs, including: interpretations, exemptions, notice-and-comment rulemaking, and defects and enforcement authority. A detailed review of the federal guidance is included in the Appendix section. [To be supplemented by ADS 3.0 – update accordingly]

At the state level, the Massachusetts Department of Transportation (MassDOT) Registry of Motor Vehicles (RMV) is charged with licensing operators through administration of a road test and written exam, and registering vehicles with proper titling and insurance documentation. In addition, the RMV requires annual vehicle inspections to ensure compliance with manufacture and performance standards, such as the functionality of seat belts and braking capacity. The state is also responsible for enacting and enforcing traffic laws and regulations, and regulating motor vehicle insurance and liability.

A manufacturer's certificate of origin or statement of origin (MCO or MSO) is used by most jurisdictions for titling and registering a new motor vehicle. The MCO document contains information such as the make, model, vehicle identification number (VIN), horse power, gross vehicle weight, etc. A vehicle Certificate of Registration is issued by the RMV for identification of a vehicle and its owner. Massachusetts General Laws (M.G.L) Chapter 90, Chapter 6C, and Code of Massachusetts Regulations 540 (C.M.R.) include the legislative authority, definitions of vehicle types and registration processes, operator licensure, vehicle use and operations, and insurance requirements.

MassDOT regulates the use of public ways under its jurisdiction, including the Massachusetts Turnpike and the Metropolitan Highway System. In addition, MassDOT is directed to administer a long-range statewide transportation plan which includes intermodal and integrated transportation, and develop and administer procedures for transportation project selection. Other responsibilities of MassDOT include to: establish transit facilities and related infrastructure; act as the central entity and coordinating organization for transportation initiatives on behalf of the Commonwealth and work in collaboration with governmental and other entities to advance transportation interests; disburse, appropriate, grant, loan or allocate funds for investing in transportation initiatives; provide assistance to local entities, authorities, public bodies for purposes of maximizing opportunities for transportation and development; and ensure regional equity related to transportation planning, construction, repair, maintenance, capital improvement.

M.G.L. Ch. 40 § 22 permits municipalities to regulate certain forms of vehicles on local roadways, and set municipal licensing or registration fees. However, municipalities cannot bar the use of "passenger or station-wagon type motor vehicles" registered for commercial use where non-commercial passenger-type vehicles operate (1). A city or town may also regulate the parking of vehicles by restricting certain areas within its control, including through the installation and operation of parking meters.

The Massachusetts Port Authority (Massport) is empowered to and has promulgated rules and regulations governing the conduct of its business and affairs and the use of its roadways and facilities, including some areas within the South Boston Seaport, the Logan International Airport, and other Massport properties. Title 740 of the C.M.R. provides Massport regulations regarding general public safety, vehicular operations, and commercial ground transportation services.

Similarly, the Department of Conservation and Recreation (DCR) has distinct regulatory authority which may impact the operation of motor vehicles on DCR roadways (M.G.L. Ch 92 §37 and 132A §7). DCR may make rules and regulations for the government and use of all property under the control of DCR, including all roads, driveways, parkways, boulevards and bridges. Such rules and regulations may provide for the payment of fees and other charges for the parking of vehicles and for other privileges within DCR territory. DCR requires an annual permit for commercial non-construction vehicles which access DCR roadways (2).

Existing motor vehicles laws neither expressly allow nor expressly prohibit the testing of highly automated vehicles on public roadways in the Commonwealth. To facilitate testing, Executive Order 572 defined a process which requires companies to submit an Application to MassDOT in addition to executing a memorandum of agreement (MOA) with MassDOT and any municipalities or other State agencies whose road facilities will be utilized. MassDOT developed an initial Application document in November of 2016, and signed the first memorandum and Letter of Approval in December.

In June of 2018, MassDOT signed an agreement with thirteen municipalities and the Department of Conservation and Recreation to streamline and standardize testing in participating jurisdictions through a regional application and template MOA process. The Working Group provided its feedback and considerations to MassDOT on the initial and revised application documents. A general summary of these documents is included in the

Appendix, and more information can be found on the mass.gov website under "How to test autonomous vehicles in Massachusetts".

5 POLICY CONSIDERATIONS

The autonomous and connected vehicles industry and associated regulatory frameworks are rapidly evolving. It is important for policymakers and members of the public to understand the technical context in which autonomous vehicles are being developed and the operational environments in which they are being tested. States and municipalities have a significant role in connected and autonomous vehicles testing and deployment, including but not limited to: operator licensure; vehicle inspections; insurance and liability; enforcement of operational and business-related laws and regulations; and general road design, construction, maintenance, and travel safety.

There are numerous potential benefits that may be realized through the strategic testing and deployment of autonomous vehicles.

1. Improve travel safety for all road users by reducing the occurrence of human errors
2. Reduce transportation emissions and encourage low emissions travel options, shared mobility, and transit
3. Improve transportation affordability and accessibility, including through "first/last mile" connections to transit
4. Support mobility and equitable transportation options for all demographics
5. Balance competing land use demands for road right of way space and parking facilities
6. Reduce costs due to crashes, congestion, and pollution mitigation
7. Support workforce transitions and education for new automated industries
8. Promote economic development and encourage AV hardware and software innovation, research and development, and supply chain manufacturing
9. Standardize road map data including curb access, egress points, shoulder and easement areas, signage, etc. to digitize road rules and infrastructure assets
10. Standardize data-sharing protocols for performance and operations of AVs to support research and transportation planning efforts

As the industry is still in its infancy, it is uncertain if and when these benefits will be realized. There is an inherent risk in permitting AV testing on public roads, as the use of unproven technologies or unsafe testing can undermine the potential long-term safety of AVs. However, with nearly 400 roadway fatalities in Massachusetts in 2017, there is an existing risk of using a roadway for walking, biking, or driving.

It is necessary and prudent for the Commonwealth to maintain a deliberative and iterative process for permitting the testing and eventual deployment of AVs on public ways. An informed and structured application and permitting process can help to mitigate the safety risks of AV testing while allowing the Commonwealth to actively shape the deployment and utilization of AVs to equitably serve its residents and reduce crashes due to human error. A defined strategy and policy approach to testing and deployment of autonomous and connected vehicles will also support long-term investments in development of the technologies within the Commonwealth.

The testing approval process developed through EO 572 has accomplished the goal of facilitating safe testing activities on public ways with a driver in the vehicle and support of participating jurisdictions. The Working Group recommends that MassDOT continue to take the lead role in facilitating testing under the conditions prescribed in EO 572 with a safety driver in the vehicle and able to take immediate control as necessary. To facilitate the review of future regional testing applications, and to implement the following recommendations and conduct related C/AV activities moving forward, the Working Group recommends that MassDOT formalize an inter-agency C/AV Committee comprising stakeholders of the AV Working Group in addition to representatives of participating municipalities, law enforcement agencies, and first responders (Recommendation #1). Prior to the approval of a regional testing application, the Committee should initiate engagement with first responders and law enforcement agencies in the participating jurisdictions (Recommendation #2).

Following the finalization of the regional application protocols, MassDOT should promulgate regulations which would supplant the testing process and requirements within the memorandum of agreement (Recommendation #3). Regulations for such testing should be limited to the conditions and requirements set forth in EO 572, including the need for a backup driver in the vehicle prepare to take immediate control. Drafting and filing regulations necessitates a public comment process, which will allow MassDOT and the Committee an additional opportunity to consider feedback to the process and requirements.

Legislative authority may be necessary in advance of regulating the testing of driverless vehicles and vehicles without standard operating equipment (steering wheel, gas, brake, etc). The Working Group has developed a set of considerations for the Legislature in the regulation of such testing (Recommendation #4). The C/AV Committee should support continued engagement with the Legislature on AV testing activities and considerations for the regulation of driverless testing and deployment.

5.1 Establishing a C/AV Committee

To support implementation of the following recommendations and future C/AV activities in the Commonwealth, MassDOT should establish and lead a C/AV Committee including representatives of the legislature, the Executive Office of Public Safety and Security (EOPSS), the Executive Office of Housing and Economic Development (EOHED), municipalities, law enforcement and first responders, and other stakeholders as determined by MassDOT. The Committee should hold internal meetings at least monthly among the representatives, and conduct public meetings at least once per year and additional stakeholder engagement as necessary.

The Committee should first prioritize outreach and engagement efforts with first responders in participating jurisdictions (Recommendation #2). The Committee should subsequently support MassDOT in the effort to transition from Executive Order 572 to a regulatory structure (Recommendation #3). This may include tasks such as the review of existing definitions and propose new definitions for key terms, including but not limited to "autonomous vehicle," "operator," "minimal risk condition," "dynamic driving task," and others as necessary.

The Committee should be generally tasked with supporting the evaluation of testing applications; monitoring in-state testing and reporting; proposing revisions to the testing application documents and permitting process; evaluating the progress of the C/AV industries and related technologies; assessing pilot programs, initiatives, and policies; disseminating information to relevant staff and agencies; considering whether and how to permit testing of other types of autonomous vehicles including trucks and sidewalk vehicles; identifying C/AV infrastructure needs and opportunities; and other general C/AV activities as deemed necessary.

The Committee should research metrics, standards, and processes which could help evaluate the functional safety of AV systems and operating protocols for purposes reviewing applications and reporting in quarterly progress updates. Such metrics, standards, and/or processes should help define whether the technology has achieved a minimum level of competency to perform the dynamic driving tasks within its design domain, and if the developer and its test drivers are conducting testing in a prudent manner to provide overall functional safety.

In addition, MassDOT and the C/AV Committee should explore if and how data recorded by an AV before and after a crash or failure of the automated system may be shared with law enforcement and/or relevant authorities for the purposes of conducting an investigation, documenting safety incidents, or other such needs. The Committee should further provide ongoing support to MassDOT and EOPSS in outreach about C/AV technologies and operations to first responders, driver license examiners, and motor vehicle inspectors. The C/AV Committee could also identify and pursue opportunities to support consumer training and education of C/AV functionalities and safe operations, including proposing any updates to driving manuals.

Efforts to collaborate with other states and in regional initiatives such as the New England Vehicle Consortium and I-95 Corridor Coalition should be coordinated with this Committee on issues including legal and regulatory structures, first responder training and crash investigations, consumer outreach and education, and roadway infrastructure and technologies.

The Committee should identify and pursue research and funding opportunities for connected and automated vehicle technology research and implementation, in partnership with academic and research institutions in the Commonwealth when possible.

5.2 ENGAGING FIRST RESPONDERS AND LAW ENFORCEMENT

In advance of permitting regional testing, the Working Group recommends that the C/AV Committee, led by MassDOT and the Executive Office of Public Safety and Security (EOPSS), provide educational outreach materials to first responders and law enforcement, and conduct workshops for the jurisdictions which have opted in to permit AV testing. Such workshops and outreach should be offered on a regular basis as the technology develops, and in collaboration with related organizations and stakeholders. The information provided should include:

1. The types of connected and automated vehicle technologies currently deployed on the roads today (in production vehicles)
2. Ongoing and planned AV testing activities in the region
3. Application documents including the first responders interaction plans for AV testing in the region
4. Frequently asked questions and considerations
5. Contact information for relevant members of the C/AV Committee

Outreach and educational information prepared for this purpose should be made available online, along with any active applications and respective first responder interaction plans.

5.3 Moving From Executive Order to Regulation

MassDOT has developed an effective and collaborative approach for permitting autonomous vehicle testing with a backup driver, following the guidance of Executive Order 572. To build on the existing testing process, the Working Group recommends that MassDOT exercise its authority under Massachusetts General Law Chapter 90 §31 to draft and adopt regulations which encompass the terms of the Memorandum of Agreement. The C/AV Committee should support the efforts of MassDOT and the RMV to develop the regulations.

The regulatory structure should be limited to testing in conditions defined by EO 572, including the need for a safety driver present in the vehicle and able to take immediate control of the dynamic driving task. The regulatory process should allow for the carriage of passengers as part of a pilot test, provided such passenger tests do not conflate with any ride-for-hire mode. The C/AV Committee should consider whether regulatory process could allow for the testing of low-speed vehicles without standard driver controls. Finally, the framework should consider a sunset clause for the entire regulation, or particular elements that may be waived or eliminated in the future as the technology develops. The process for drafting and filing regulations will include a public comment phase, which will allow MassDOT and the Committee an additional opportunity to consider feedback to the permitting protocols and requirements.

In parallel with transitioning to a regulatory framework, MassDOT and the C/AV Committee should continue to iteratively develop the application and phased testing protocol, with a focus on public safety and engagement with state and local transportation officials and first responders.

5.4 Establishing Legislation

Legislative authority may be necessary in advance of permitting testing of driverless vehicles and vehicles without standard human operator controls (steering wheel, gas, brake, etc). Statutory revisions may also be necessary prior to the deployment of fully-driverless autonomous vehicles and related ride-for-hire services in the Commonwealth. The Working Group has developed a set of general considerations for the Legislature on the regulation of driverless testing and future deployment of AVs. The C/AV Committee should support continued engagement with the Legislature regarding ongoing and future AV testing activities, and input on when and how to regulate driverless testing and AV deployment.

1. Provide clear and defined authority for MassDOT and RMV to promulgate regulations for AV testing of driverless vehicles and vehicles without standard operator controls

2. Review existing statutory definitions relating to motor vehicles and operators, and develop new definitions for key terms including autonomous vehicle, operator, minimal risk condition, dynamic driving task, and others as necessary

3. Review vehicle codes, applicable traffic laws, terms and definitions, and similar items to determine if there are legislative or regulatory barriers that may unnecessarily restrict testing and deployment of autonomous vehicles on public roads. In particular, the following sections of the Massachusetts General Laws (MGL) and the Code of Massachusetts Regulations (CMR) may be most relevant:
    - MGL Ch 89: Law of the Road
    - MGL Ch 90 §1: Definitions
    - MGL Ch 90 §7: Vehicle Standards
    - MGL Ch 90 §8: Licensure
    - MGL Ch 90 §10: Right to Operate
    - MGL Ch 90 §13: Operations
    - MGL Ch 90 §20: Violations
    - MGL Ch 90 §22: Violation / Suspension
    - MGL Ch 90 §24: OUI, Reckless Driving
    - MGL Ch 90 §31: Registrar's Authority
    - 540 CMR 2.0: Definitions
    - 540 CMR 4.0: Inspections
    - 540 CMR 23.0: Licensing / Education
    - 540 CMR 24.0: Medical Qualification

4. Require proof of insurance prior to operation of an AV

5. Review liability of original equipment manufacturers (OEMs) for third party or after-market vehicle conversions

6. Establish clear liability for level 4-5 AVs

7. Review existing statutes pertaining to ride-for-hire services and consider revisions as necessary for future deployment of autonomous ride-for-hire services

8. Support further study or consideration of enforcement actions, insurance requirements for driverless vehicles, data sharing, cybersecurity, legislative and regulatory ‘best practices,’ or other C/AV research

6 CONCLUSION

Autonomous and connected vehicles offer many potential benefits for the Commonwealth. The ways in which these technologies are tested and introduced into the public domain will have an impact on their adoption, and the policy decisions of the Commonwealth may influence the extent to which benefits are realized. An effective permitting process to test AVs, as has been developed in the Commonwealth, helps to mitigate safety risks and improve public perception and trust as the technologies are being developed. Strategic policies for the future deployment and utilization of AVs can support development of C/AV technologies in the Commonwealth to enhance safety, promote equitable access, reduce congestion and emissions, and improve overall mobility.

The AV Working Group Report was prepared to establish a basis of AV technologies, the industry in the Commonwealth, governance of the sector, and examples of regulations and testing in other states and nations. The recommendations developed by the Working Group provide a clear framework for AV testing for the near future. After the Working Group was created, the Commission on the Future of Transportation began its work, which includes examining the longer-term deployment of autonomous vehicle technologies. The Commission will issue separate policy recommendations which may encompass C/AV deployment in its report in December 2018.

For questions or additional information, please contact: AVs@dot.state.ma.us

7 APPENDIX

7.1 CONNECTED AND AUTONOMOUS VEHICLE TECHNOLOGIES

The following is not intended to be a comprehensive review of the industry, given the highly complex nature of the technologies involved and rapid rate of development within the sector. This introduction represents the best efforts of the Working Group to provide its current understanding of the technologies which comprise connected and automated vehicles.

An autonomous vehicle (AV) is generally described as a vehicle which can conduct all of the dynamic driving tasks for at least some period of time within a designated operating domain (weather, road type, etc.). The dynamic driving task includes steering, acceleration and deceleration, monitoring of the environment, and object and event detection and response. An autonomous vehicle is also commonly described as a "highly automated vehicle" (HAV), or "self-driving" vehicle, though particular definitions can vary.

The distinction between an autonomous and non-autonomous vehicle is primarily based on whether the human operator or AV is responsible for monitoring the driving environment and providing object and event detection and response. An autonomous vehicle should navigate around an unanticipated object in the roadway, or reach a safe and minimal risk operating condition, without human intervention. A vehicle with lower-level automation functions, such as lane-keeping assistance and/or dynamic cruise control (levels 1-2), requires immediate human intervention if an object is encountered.

All autonomous vehicles will, for the foreseeable future, be constrained to a limited operational design domain (ODD), which defines the boundary conditions within which an autonomous vehicle is designed to operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/nighttime, etc.), and other domain constraints. Within its ODD, an AV is expected to be able to detect and respond to other vehicles, pedestrians, cyclists, animals, and objects both in and out of its travel path that could affect safe operation of the AV. Object and event detection and response (OEDR) refers to this detection by a driver or AV system of any circumstance that is relevant to the immediate driving task, as well as the response to such a circumstance. An AV's OEDR should be able to deal with a variety of conditions including emergency vehicles, temporary work zones, and other unusual conditions (e.g., police manually directing traffic, construction worker controlling traffic, emergency response workers) that may impact safe operations of an AV within its operational design domain.

The most commonly accepted terminology is based on the SAE International standard J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. For the purposes of this report, the term "autonomous vehicle" includes those classified by SAE standards as level 3-5. Level 1-2 vehicles are included within the term "automated vehicles", which covers levels 1-5.

- **Level 0 – No Automation**: No automated systems, full human driver operation.
  Example: Traditional cruise control systems.
- **Level 1 – Driver Assistance**: Automated steering *or* acceleration/deceleration, otherwise full human driver operation.
  Example: Dynamic cruise control or lane-keep or lane-centering (used individually, not in combination).
- **Level 2 – Partial Automation:** Automated steering *and* acceleration/deceleration, with the human driver responsible for monitoring the environment and taking full control of steering and acceleration/deceleration instantaneously as needed. A variety of driver-state monitoring systems may be employed to ensure the human driver is monitoring the environment, such as driver-facing cameras and actuators within the steering wheel. Systems are designed to disengage and lock out the autonomous mode if a driver is not actively monitoring the environment.
  Example: Several automakers including Tesla and Cadillac have deployed level 2 systems which combine traffic-aware cruise control and lane centering. Cadillac specifies the road segments on which its level 2 system "Super Cruise" may be used.
- **Level 3 – Conditional Automation**: Steering, acceleration/deceleration, and monitoring of the environment all conducted by autonomous vehicle systems. A human driver must be seated and available for fallback takeover within ~2-10 seconds. If a human driver fails to takeover when necessary, the AV system must enter a minimal risk condition (i.e. safely stop). The requirements for a safe transition from an autonomous system to a human driver are unclear, and are a primary challenge for AV developers and regulators. A level 3 vehicle must still have manual operator controls for when a driver must take over, and for operational design domains the vehicle is not capable of. Some experts do not consider a level 3 vehicle to be an "autonomous vehicle" given the necessity for a human operator.
  Example: None yet in deployment, but several manufacturers claim to release such vehicles in the next year or two in which drivers will not need to actively monitor the environment on specified roadways and in well-defined environmental conditions.
- **Level 4 – High Automation**: No human operator is needed for the vehicle to operate within its defined design domain and driving modes. The system can operate entirely autonomously on some roads, and in some environmental conditions, but not all. A level 4 vehicle may not require a steering wheel or other manual operator controls, but may be rendered inoperable if environmental conditions, such as heavy rain or snow, exceed

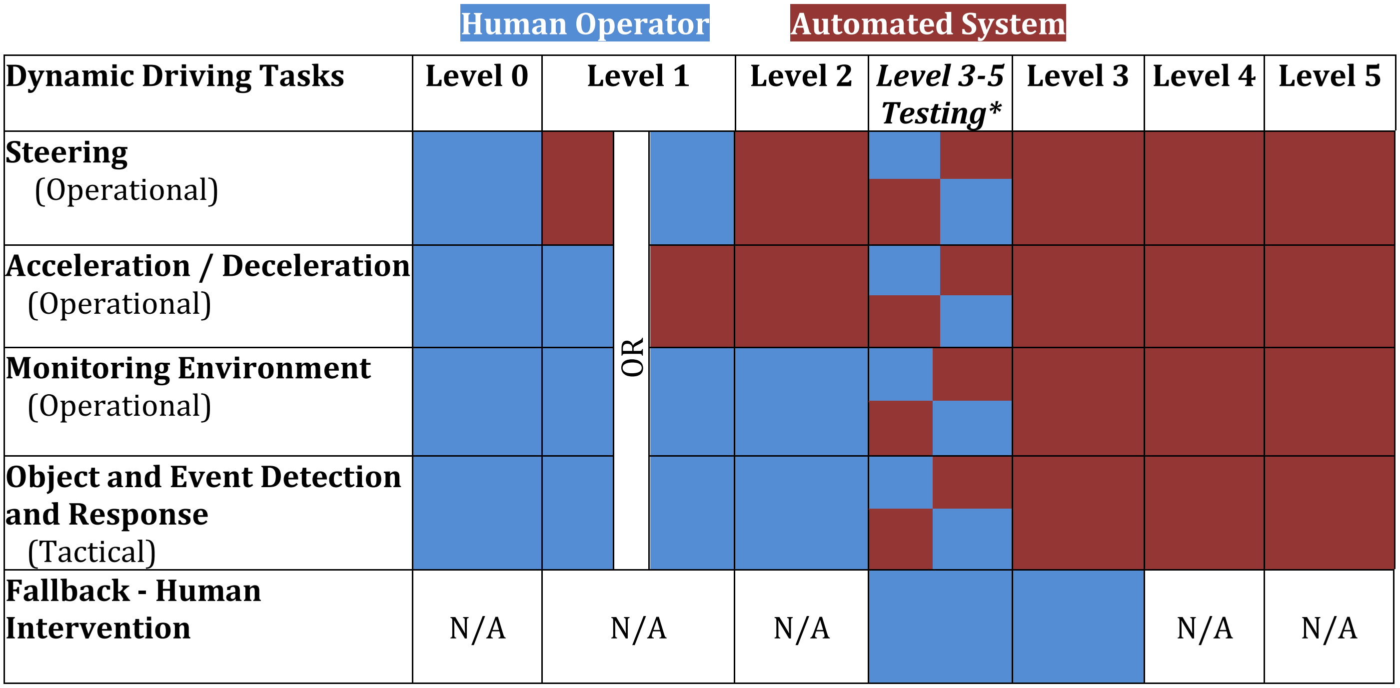
the design limitations of the system.
Example: Autonomous shuttles that operate within closed environments (such as large industrial complexes) or on public low-speed routes and campus environments.

- **Level 5 – Full Automation**: The system can operate entirely autonomously in all conditions and on all roads. Many experts anticipate it will take several decades to fully develop a level 5.

SAE International - J3016: Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems

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

(6)



*When testing a level 3-5 vehicle, the testing entity is responsible for monitoring and evaluating the vehicle's performance, including effective monitoring of the environment and appropriate response to any object and event detection. Testing of a level 3-5 autonomous vehicle with a human backup driver is most similar to how a driver operates a level 2 vehicle: the driver must be actively monitoring the environment and able to take control if needed, and may not be distracted or otherwise disengaged (ie. reading, sleeping, eating, etc.). Testing a level 4-5 AV may entail remote monitoring and tele-operations to actively evaluate the vehicles' performance and intervene as necessary.

Task	SAE Level
Strategic	
Route Planning	0
Operational	
Steering	1+
Acceleration	1+
Deceleration	1+
Monitoring Environment	3+
Tactical	
Object and Event Detection and Response (OEDR)	3+
Fallback	3

7.1.1 Hardware Systems

An autonomous vehicle is equipped with many different hardware systems for localizing the vehicle on the roadway, and perceiving its surrounding environment.

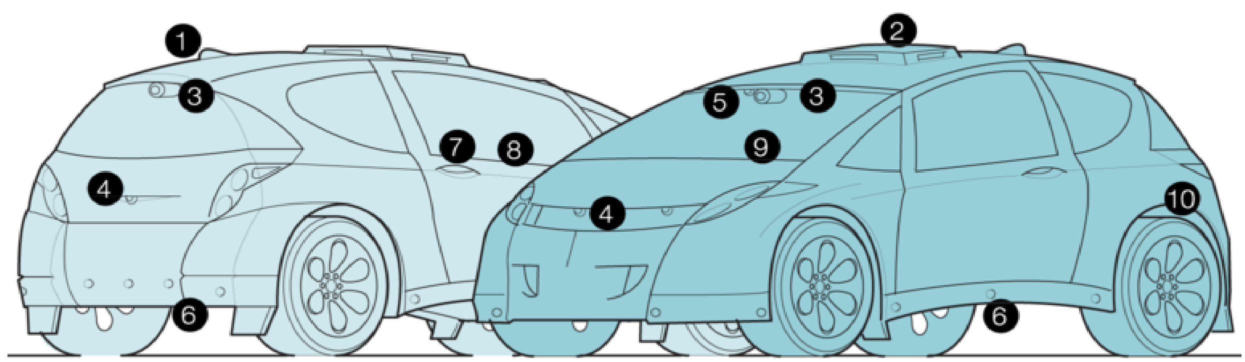
1 Global positioning systems (GPS)
Localize vehicle using satellite triangulation. Accuracy is within several meters.

2 Light detection and ranging (lidar)
Uses light beams to estimate distance between obstacles and sensors with high resolution.

3 Cameras
Use inexpensive hardware that requires complex software suite to interpret collected images.

4 Radio detection and ranging (radar)
Uses electromagnetic waves in certain bands to reflect off of an object and determine its speed and distance.

5 Infrared sensors
Use infrared spectrum to identify and track objects that are hard to detect in low lighting conditions.



6 Ultrasonic sensors
Generally have low resolution and are used for short distances (eg, park assist).

7 Dedicated short-range communication (DSRC)
Used for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) systems to receive and send vehicle and infrastructure (eg, road, traffic light) information.

8 Inertial navigation systems (INS)
Use accelerometers and gyroscopes to estimate vehicle position, orientation, and speed. Typically used in combination with other vehicle-related data (eg, GPS).

9 Prebuilt maps
High-definition maps with detailed information about roads and infra-structure (eg, shoulders, road edges, lanes) are used for precise localization and allow vehicles to better perceive their environment.

10 Odometery sensors
Use wheel speed to estimate how much vehicle travels.

McKinsey&Company

(7)

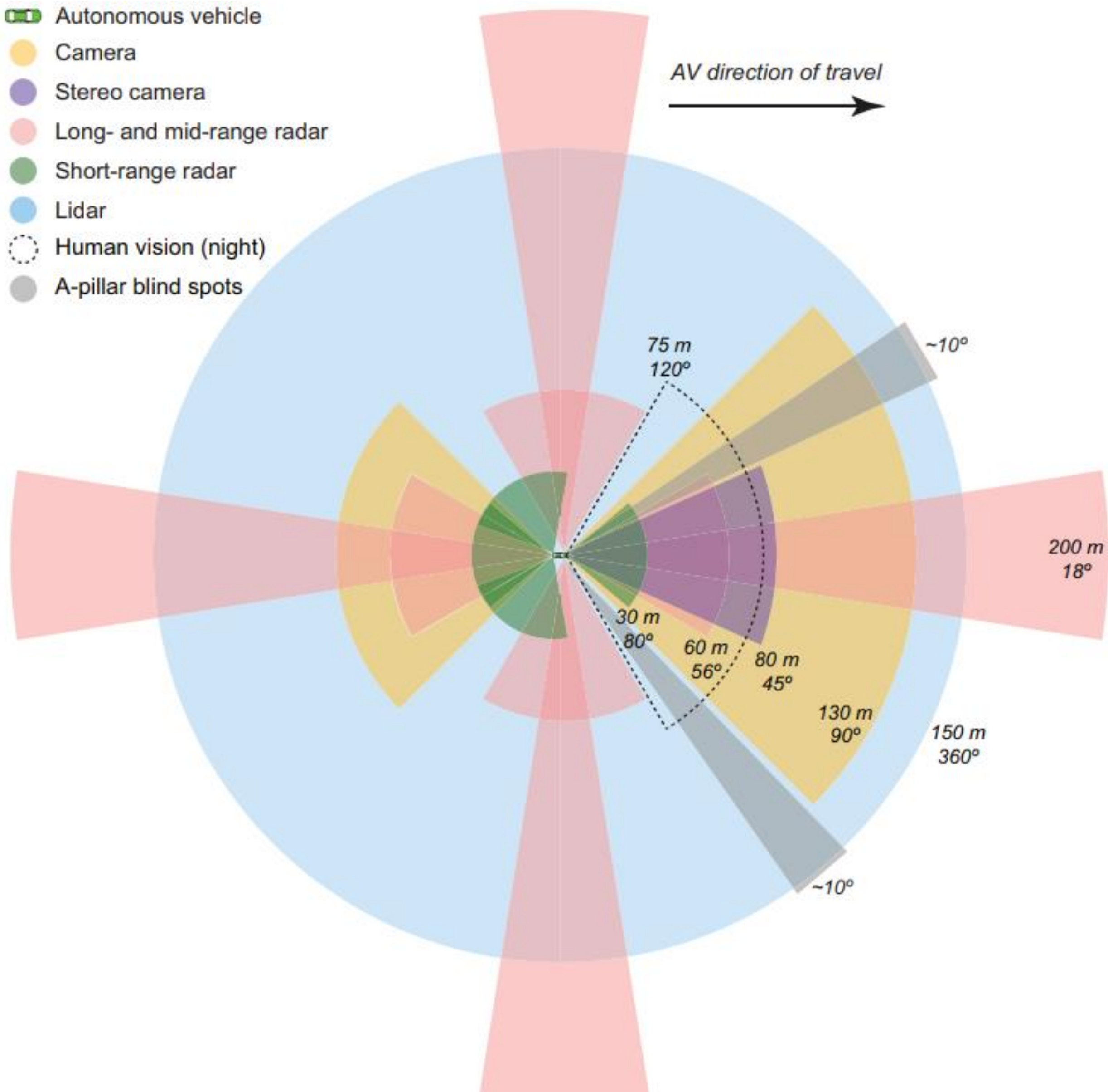
LIDAR, cameras, radar, and ultrasound are considered "perception" sensors, which are synthesized to establish a detailed 3-dimensional electronic map of the surrounding environment. "Localization" sensors include the global positioning system (GPS), inertial navigation systems, and wheel odometery sensors which calculate where the vehicle is on the roadway at any given moment. The range of sensors utilized, the placement locations on the vehicle, and the quality of the instruments all have profound impacts on the vehicle's overall perception and localization capabilities. Each type of sensor, as described below, has strengths and weaknesses which must be accounted for. Autonomous driving is only feasible using a range of sensors which, when used in parallel, can reliably achieve precise localization and detailed perception of the environment.

Table 2
Summary of the key operating characteristics of each sensor as they apply to autonomous vehicles. (AV sensor performance summary adapted, in part, from WCP, 2016.)

Performance aspect	Human	AV			CV	CAV
		Radar	*Lidar*	*Camera*	*DSRC*	*CV+AV*
Object detection	Good	Good	Good	Fair	n/a	Good
Object classification	Good	Poor	Fair	Good	n/a	Good
Distance estimation	Fair	Good	Good	Fair	Good	Good
Edge detection	Good	Poor	Good	Good	n/a	Good
Lane tracking	Good	Poor	Poor	Good	n/a	Good
Visibility range	Good	Good	Fair	Fair	Good	Good
Poor weather performance	Fair	Good	Fair	Poor	Good	Good
Dark or low illumination performance	Poor	Good	Good	Fair	n/a	Good
Ability to communicate with other traffic and infrastructure	Poor	n/a	n/a	n/a	Good	Good

(8)

Brandon Schoettle of the University of Michigan authored a white paper on sensing capabilities of human drivers and highly automated vehicles, including the above table (8). The study found that while no individual sensor completely equals human sensing capabilities alone, some offer capabilities not possible for a human driver. In daytime conditions, the human eye is capable of seeing at least a half of a mile, but this is reduced to only about 250 feet at night under low-beam headlamp conditions. Camera systems can function at about 500 feet or less in daylight, but are similarly subject to performance reductions in low light and poor weather conditions. However, radar and LIDAR systems function about as well at night as during the day, at a range of up to 750-1,000 feet. Rain, snow, and fog conditions can cause LIDAR systems to sense a significant amount of 'white noise'. These effects may be mitigated using machine learning, as Google recently demonstrated (9).



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7.1.1.1 LIDAR

LIDAR stands for Light Detection and Ranging technology, which function similarly to radar systems. LIDAR systems measure the distance to a target by illuminating that target with a pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D-representations of the target. The technology is used to make high-resolution maps and has applications in archaeology, geography, geology, seismology, forestry, atmospheric physics, and more. LIDAR use small wavelength lasers which provide very fine detail resolution, but are susceptible to falling rain and snow, and require unobstructed lines of sight to function effectively (10).

LIDAR systems are generally a core component of AV systems; however some companies - most notably Tesla - have stated intentions to develop level 3-5 AVs without any LIDAR system (11).

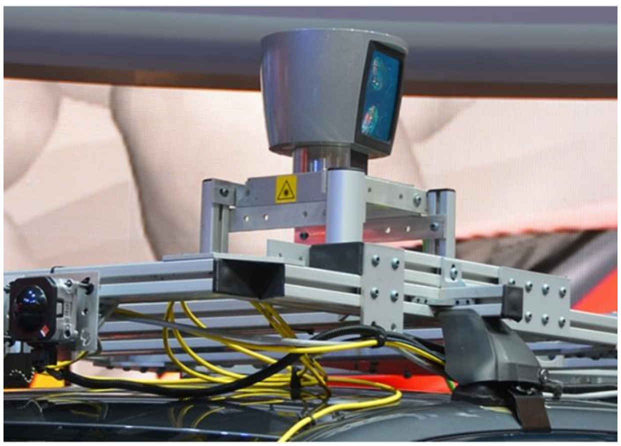
When the LIDAR is active, it emits dozens of laser light pulses, and analyzes the light that bounces back, collecting up to a million individual data points per second. An inertial sensor tracks the pitch, roll, and yaw of the car so that the LIDAR data can be corrected for the position of the car. Depending on the LIDAR design, it may have about a 10 - 30° field of view vertically. Some have limited horizontal fields of view, while others provide a full 360° horizontal perspective. At street level, the margin of error of most LIDAR is at most a few centimeters, and the effective range can vary between about 100 to 500 feet (12).

The “point cloud” developed by a LIDAR can be used to create a detailed 3D map of the surrounding environment in order to view all obstacles in real time. The current cost of a high-end LIDAR system can be upwards of $50,000, however several companies are developing new solid-state LIDAR systems with expectations to significantly reduce the cost of such sensors.

7.1.1.1.1 Solid-State LIDAR Systems

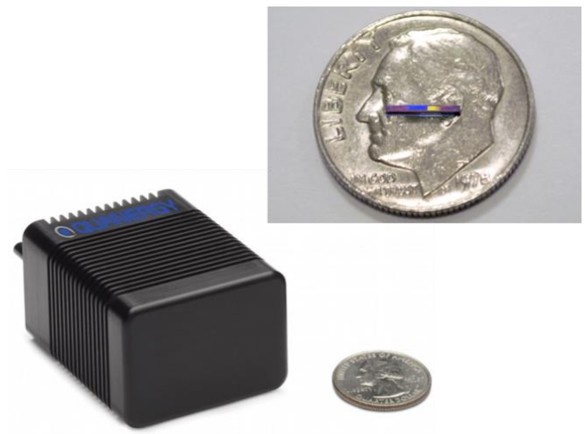
Many companies are pioneering efforts to create a sold-state integrated photonics LIDAR system. Such systems are slated for production by various manufacturers within the next few years, with promises to be smaller, lighter, and several orders of magnitude cheaper at production scale. Sensata is one Massachusetts-based company (Attleboro) which is pioneering solid state LIDAR research and development in partnership with Quanergy, a California-based startup.

Today: Mechanical LIDAR



Revolving Mirrors, Lenses and Motors
Current unit cost from $5,000 - $75,000

The Future: Integrated Photonics LIDAR



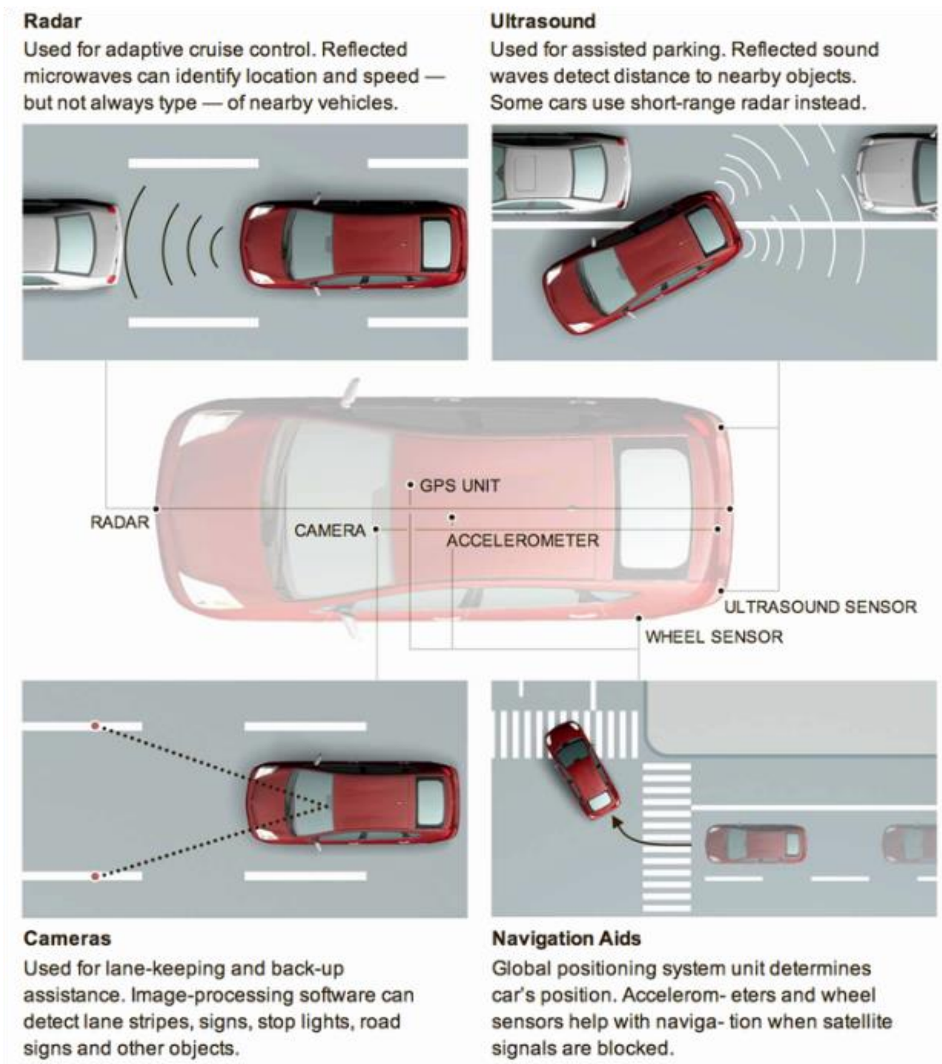
Lighter, Cheaper, Smaller, No Moving Parts
Targeted unit cost under $1,000

7.1.1.2 Radar, Ultrasound, and Cameras

Ultrasound is an object detection system which emits ultrasonic sound waves and detects their return to determine distance to within a centimeter. Ultrasound is useful for short-range detection, with a limit of about 15 feet, and can be used in difficult weather conditions with high accuracy. Ultrasound is used in mostly parking assist functions, though Tesla and other companies employ longer-range ultrasound systems to detect cars in adjacent lanes, up to about 16 feet away (13).

Radars are small and inexpensive, with good range and effectiveness in inclement weather, but relatively poor resolution compared with other sensors. Radar can provide the velocity, range and angle of objects. Short and medium-range radar (up to 250') is used for applications such as cross-traffic alerts, forward and rear collision warnings, adaptive cruise control, and blind spot detection. Long-range radar (250-600') is used in adaptive cruise control systems. Radar systems struggle to detect and measure height.

Cameras and sophisticated object detection algorithms can be used for parking assist, blind-spot detection, lane departure warnings, and some traffic sign recognition. Cameras with image recognition systems have recently become cheaper and smaller, while providing high-resolution. The range and performance of cameras fall in low-light environments and with precipitation, but cameras are the only sensor that can capture texture, color, and contrast information to enable image processing and classification. Cameras are thus effectively necessary for most autonomous vehicles operating in mixed traffic. However, cameras alone are not very effective for depth perception. (14)

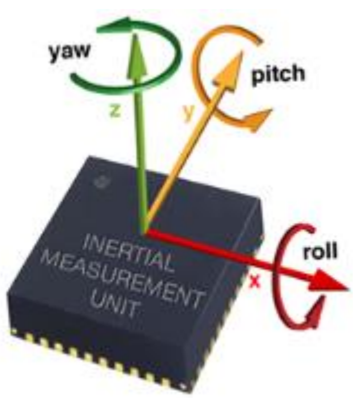


7.1.1.3 Global Positioning Systems

Very precise geolocation information is needed by autonomous vehicles to understand exactly where they are in the physical world. A vehicle can "localize" itself in the surroundings using a highly detailed map and accurate GPS. Current GPS allows only a limited level of accuracy; therefore, it is likely that more precise GPS must be developed and deployed to meet the demands of current and future AV mapping needs. Highly-precise, centimeter-accurate global position system services will be utilized for autonomous vehicles, precision agriculture, unmanned aerial vehicles, robotics, maritime, transportation/logistics, and outdoor industrial applications. Newer GPS systems provide accuracy up to 100 times that of traditional GPS found in a typical phone, to an accuracy of within centimeters (15). In the case that GPS is not available, such as a tunnel or canyon, other systems such as inertial measurement units must be used to localize the vehicle on the roadway.

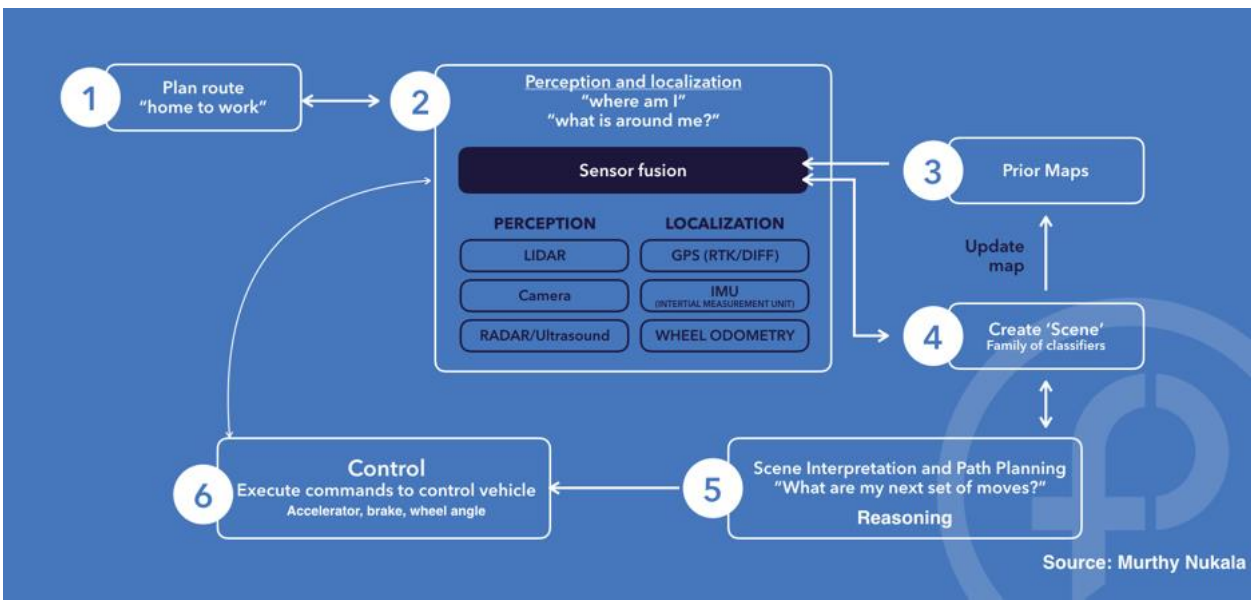
7.1.1.4 Inertial Measurement Units

Inertial Measurement Units (IMUs), also known as inertial navigational systems, include gyroscopes and accelerometers which collect vehicular motion and rotation data. IMUs can supplement GPS when satellite data is unavailable. IMUs cannot alone determine a vehicle's absolute position but can determine the location of a vehicle relative to its starting point. IMUs are small and fairly inexpensive components.



7.1.2 Software

An autonomous vehicle generally relies upon detailed base maps, in addition to the sensors and hardware systems, which enable it to understand precisely where it is (localization), and what is going on in that particular environment (perception). The range of data inputs coming from the vehicle's radar, LIDAR, cameras, and other sensors must be compiled together to develop the vehicle's digital construct of the real-world environment, in a process called 'sensor fusion'. By combining the data from different sensor arrays, the vehicle can significantly improve the accuracy of its understanding of the environment (15). The vehicle continually updates its understanding of the environment and the 'scene' while it drives. As the vehicle interprets the scene, it determines the path planning and actions, which are executed by controls systems. This iterative process generally describes how AVs move through an environment. The decision-making process (i.e. the reasoning layer between the AVs perception and execution) is the subject of highly technical research and development in machine learning far beyond the scope of this Report. Generally speaking, most AV developers employ some combination of machine learning coupled with basic rules-based decision making, to define some basic boundary conditions and conventions, while also allowing vehicles to improve via advanced machine learning techniques.



(15)

Among the most significant challenges in developing reliable level 3-5 vehicles is being able to accurately identify objects. The classification of objects exhibits traits of a 'long tailed' distribution, wherein it becomes exponentially more difficult to correctly classify objects the less frequently they are seen. An object can be easily classified if it is viewed from a traditional frame and perspective, but must still be classified correctly regardless of the angle, lighting, weather conditions, or other variables through which the object is perceived.

AV developers must also subject their hardware and software systems to significant testing in simulations. Real-world tests can be combined with simulations to help reduce the number of miles required for validating performance. There are many different platforms with which developers can simulate driving environments for both hardware and software systems, as well as some emerging efforts to define a testing and validation regime for evaluating AV performance. One example to establish such a regime is the PEGASUS project in Germany. PEGASUS aims to develop generally accepted and standardized procedures for the testing and approval of automated driving functions. While the extent to which regulators may certify or approve such functions is unclear, there is a need for all stakeholders to critically evaluate AV design and performance across vehicle platforms.

7.1.3 Driver Monitoring Systems

Driver monitoring systems (DMS) are used to detect a human operator's level of awareness. DMS are instrumental in level 1-3 vehicles wherein a driver may be required to take control of a vehicle. Driver attention monitoring is also beneficial for reducing crashes generally due to drowsy, distracted, or impaired driving.

The first DMS was introduced to production vehicles by Toyota in 2006; there are currently many different systems and technologies employed by various automakers and AV developers to evaluate drivers' state and attentiveness.

Most DMS rely on biological and/or automotive indicators. Biological signals include face and eye tracking via driver-facing cameras or infrared sensors, and heart rate monitoring. Automotive signals evaluate the driver's engagement with the vehicle, such as the pressure of hands on the steering wheel, amount of torque applied, engagement of gas or brake pedals, and use of the center console. Alcohol detection is a third category of DMS which can continuously measure the blood alcohol concentration of a driver without the use of breathalyzers.

In level 3 vehicles, DMS may be used to evaluate whether a driver is able to take over control of the vehicle any time such takeover becomes necessary. In vehicles with level 1-2 automation, DMS are critical to ensuring that a driver is consistently monitoring the environment and prepared to take over immediately.

Drivers of level 2 vehicles have already begun pushing the limitations of DMS in an effort to exceed the designed limitations of the technology. For example, it was discovered that a tangerine or orange could be wedged into the steering wheel of a Tesla vehicle to trick the pressure sensors into believing that a person's hand was holding the wheel. The Tesla Autopilot Buddy product was developed and sold at a cost of $199 to provide the same effect of over-riding the intended purpose of the driver monitoring system. After the Autopilot Buddy garnered widespread attention, the National Highway Traffic Safety Administration (NHTSA) issued a cease and desist order to the manufacturer, who had advised that the product was intended only for use on a closed-course (16). In prior investigations, NTSB has noted that a driver's inattention due to overreliance on vehicle automation can be a contributing cause of a crash, and that some systems may not effectively ensure driver engagement (17).

7.1.4 Event Data Recorders

Event Data Recorders (EDRs) can capture information such as a vehicle's performance and driver actions immediately preceding and following a crash, and the resultant collision dynamics. Early EDRs developed in the 1990s and early 2000s provided data such as air bag deployment timing, vehicle longitudinal speed and acceleration, driver seat belt status, and other circumstantial conditions of the vehicle sensors. Within the past two decades, additional EDR data has become standard, such as ABS activity, stability and traction control status, steering wheel angle, and more.

NHTSA began working with motor vehicle manufacturers in the 1990s to promulgate an EDR rule as a safety technology useful to safety researchers and common in content across automotive manufacturers and Tier 1 suppliers that applied the technology (18). In June 2004, NHTSA issued a Notice of Proposed Rulemaking recommending that EDRs record a specific set of vehicle-centric parameters. In 2006, NHTSA issued a final rule requiring EDRs in light duty passenger vehicles manufactured after September 2012 (49 CFR Part 563). By model year 2013, 96% of new light duty passenger vehicles were equipped with an EDR (19).

The exact functions and specifications of an "event data recorder" (EDR) equivalent for an autonomous vehicle may be developed by USDOT and NHTSA. NHTSA's Automated Driving Systems 2.0 Guidance outlined a Voluntary Safety Self-Assessment framework, with a recommendation to AV developers that, for crash reconstruction purposes, including during testing, AV data be "…stored, maintained, and readily available for retrieval as is current practice, including applicable privacy protections, for crash event data recorders. Vehicles should record, at a minimum, all available information relevant to the crash, so that the circumstances of the crash can be reconstructed. These data should also contain the status of the [AV] and whether the [AV] or the human driver was in control of the vehicle leading up to, during, and immediately following a crash. Entities should have the technical and legal capability to share with government authorities the relevant recorded information as necessary for crash reconstruction purposes. Meanwhile, for consistency and to build public trust and acceptance, NHTSA will continue working with SAE International to begin the work necessary to establish uniform data elements for [AV] crash reconstruction."

Pennsylvania's voluntary guidance requests that testing entities equip each AV with a means to record operational data before a collision occurs, and that such data should be made available to PennDOT and applicable law enforcement agencies upon request.

California mandates through state regulation that AVs must have a mechanism to "capture and store the autonomous technology sensor data for at least 30 seconds before a collision occurs between the autonomous vehicle and another vehicle, object, or natural person while the vehicle is operating in autonomous mode." (20)

Similar language as that in California's regulation has been incorporated into the template agreements for testing of autonomous vehicles in Massachusetts to help ensure that such data exists in the event of an autonomous vehicle crash. MassDOT also currently requires that any testing entity provide in its application a copy of the Voluntary Safety Self-Assessment, or similar documentation, including descriptions of the data recording functions and specifications.

The Driver Privacy Act of 2015 (codified at 49 U.S.C. § 30101) places restrictions on retrieval of data contained in an EDR following a crash. Under the law and NHTSA policies, such data belongs to the owner of the vehicle in which the recorder is installed, and cannot be accessed by anyone else, law enforcement or otherwise, without one of the following:

- Judicial authorization
- Owner's consent
- Investigation by the U.S. Department of Transportation pursuant to 49 U.S.C. § 30166
- Necessity for facilitating emergency medical response
- Traffic safety research, provided the owner's personally identifiable information and vehicle identification number are not disclosed

Seventeen states have passed legislation restricting access to event data recorders; Massachusetts is not one of them. (21)

7.1.5 CONNECTED VEHICLES

Connected vehicles employ vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) technologies that allow vehicles to send and receive critical safety information about their surroundings. V2I technologies can support environmental and safety goals by providing traffic signal phase information, red light violation warnings, reduced speed/work zone warnings, and pedestrian in crosswalk warnings. V2V technologies can share information such as a vehicle's speed and bearing to provide warnings or intervention in the case of an impending collision. V2I and V2V communications can detect developing threat situations up to a few hundred yards away and in situations in which the driver and on-board sensors alone may not be able to.

Vehicles with V2V devices transmit can data such as location, direction and speed, to nearby vehicles. That data is updated and broadcast to nearby vehicles several times per second. Other vehicles equipped with V2V technology can then identify issues and provide warnings to drivers to help prevent crashes. V2V applications enable crash prevention benefits by providing collision warnings, left turn assistance, blind spot warnings, and more. Vehicles with advanced driver assistance systems such as automatic emergency braking or adaptive cruise control can also benefit from the use of V2V technologies to better understand the surrounding environment.

V2I technologies can support environmental and safety goals by providing traffic signal phase information, red light violation warnings, reduced speed/work zone warnings, and pedestrian in crosswalk warnings. V2V and V2I technologies can provide the vehicle and driver with an improved awareness of potential crash situations. In those situations, V2V communications can detect developing threat situations up to a few hundred yards away, and often in situations in which the driver and on-board sensors alone may not be able to detect the threat.

An autonomous vehicle does not need be "connected" in order to operate in an autonomous mode (as defined by SAE levels 3-5), however it is beneficial to understand how connected vehicles can be an integral supplement for both human operators and autonomous systems. There are several benefits to connected vehicle technologies, most notably that they offer a long effective range, can communicate a wide range of information from multiple sources, and do not require unobstructed line of sight as AV sensors generally do. Combining connected and autonomous vehicle technologies can potentially offer great potential for improving awareness of roadway conditions and other road users (8).

Connected vehicles can employ two main types of communications platforms: Direct Short-Range Communications (DSRC) and cellular-based 5G. There are distinct benefits and costs associated with DSRC and 5G, and there is some disagreement within the industry as to which platform is most effective and scalable overall.

DSRC is a two-way short- to- medium-range wireless communications capability (802.11p-based) that permits very high data transmission, which is critical in communications-based active safety applications. It is a proactive technology for crash prevention. DSRC uses radio frequencies in the 5.9 GHz spectrum which offer low latency, or minimal "lag" between transmission and receival of messages. DSRC was designed to operate in this spectrum in a mobile environment to achieve both low latency and high reliability. It has very short time delays and high assurance of message delivery, so that it works in a fast-moving and mobile environment. The communication paths used for safety applications need to be available continuously so that critical information can get through in the split-seconds needed to avoid collisions, and so that as many vehicles as possible can communicate together. DSRC applications can function up to a distance of 1,000 feet, and are not impacted by inclement weather. DSRC between vehicles (V2V) simply requires the vehicles to both have a transmitter and receiver. To connect with infrastructure (V2I), DSRC requires installation of roadside units at traffic signals, intersections, and other areas where the technology could be used to improve safety or traffic flow. Among the noted benefits of connected vehicle technologies is the ability to transmit information over significantly greater distances than current AV perception systems (LIDAR, radar, and camera) are capable of capable of sensing. DSRC can transmit safety-critical messages up to a quarter of a mile depending on the environment, more than twice as far as current radar and LIDAR systems.

There is currently a debate about the best medium for V2V and V2I communications; some stakeholders anticipate that cellular-based connected technologies will support autonomous vehicles better than DSRC. Cellular connected vehicles would operate on 5G, the next generation of cellular technology, which could provide peak speeds of up to 20 gigabits per second. 5G operates at much higher frequencies (30GHz-300GHz) than the current 4G networks, enabling greater data transmissions and connections to more devices in a given area. Higher frequency waves can be more easily blocked by obstacles, and so more transmitters may be required than for the current cellular system which could slow the roll-out of such technologies, particularly in rural areas.

The speed, security, and reliability of the basic safety messages are critical to the safety technology. Connected vehicles can transmit position, direction, and speed (e.g., whether you were turning or putting on your brakes), as well as other information, to vehicles (V2V) and any infrastructure that is able to receive and broadcast such signals (V2I) (22).

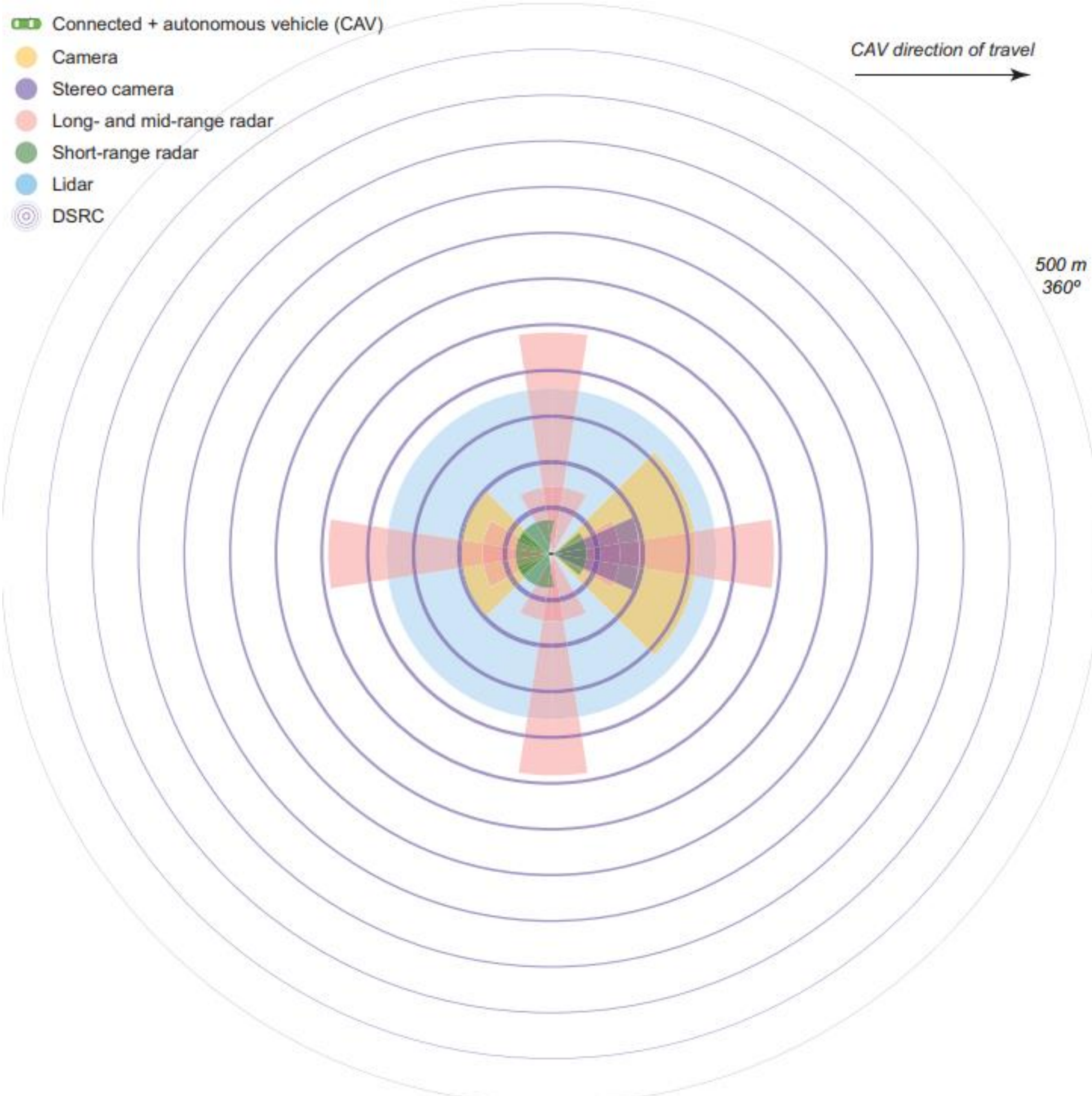
The U.S. Department of Transportation (USDOT) has been researching and testing this system of vehicle-based communications since the early 2000's.

In December 2016, NHTSA issued a notice of proposed rulemaking for connected V2V technologies (23) (23). The first phase of the NHTSA proposed rulemaking would require the technology only for new light-duty vehicles. The proposal foresees a phased implementation with a final ruling in 2019, a phased in period beginning in 2021, and all light-duty vehicles subject to the rule in 2023 (24). The notice is still currently pending.

The Federal Highway Administration issued guidance in late January 2017 on V2I deployments to assist planners, transportation engineers, and policy makers on technologies which allow vehicles to communicate with transportation infrastructure such as traffic lights, stop signs, and works zones to reduce congestion and improve safety (25) (26).

Privacy is also a key concern for V2V and V2I safety protocols. Connected vehicle technologies do not generally involve the exchange of personally identifiable information, however the proposed rulemaking by NHTSA would mandate certain privacy and security controls in V2V devices.

Connected vehicles are relevant to autonomous vehicles insofar as they may offer supplemental safety benefits through data provided from other vehicles or physical infrastructure, such as traffic lights. An autonomous vehicle does not need be a “connected” vehicle in order to operate in autonomous mode; however connected vehicle technologies can be an integral supplement for both human operators and autonomous systems. There are several benefits to connected vehicle technologies, most notably that they offer a longer effective range than current AV sensors, can communicate a wide range of information from multiple sources, and do not require an unobstructed line of sight (as AV sensors generally do). Combining connected and autonomous vehicle technologies could offer great potential for improving vehicles’ awareness of roadway conditions and other road users (3).


Connected + autonomous vehicle (CAV)
Camera
Stereo camera
Long- and mid-range radar
Short-range radar
Lidar
DSRC
CAV direction of travel
500 m
360º

7.2 AV Testing Process in the Commonwealth

As defined in Executive Order 572, the State's AV testing process requires that companies submit an Application to MassDOT, in addition to executing a memorandum of agreement (MOA) with MassDOT and any municipalities or other State agencies whose road facilities will be utilized.

MassDOT developed an initial Application document in November of 2016, and signed the first memorandum and Letter of Approval in December. Since that time, MassDOT has worked in collaboration with other state agencies and municipalities to draft a revised Application and template MOA. The Working Group provided its feedback and considerations to MassDOT on the initial and revised documents. A general summary of these documents is included below, and more information can be found on the mass.gov website under "How to test autonomous vehicles in Massachusetts"[1].

Only approval issued by MassDOT shall authorize operation of autonomous test vehicles on public ways. Applicants shall complete the Application in full, execute the MOA, and submit the documents to MassDOT for review. MassDOT will review an Application with other state agencies or municipal participants, and provide approval, rejection, or a request for additional information within 30 business days. If MassDOT or any participant requires additional information to assess the Application, the Applicant should submit such information or provide to the satisfaction of MassDOT an explanation of any omission(s) from the Application within 15 business days of the request. Prior to issuing approval to test, MassDOT may request a meeting with the Applicant and any interested participants to discuss the application. MassDOT may issue a letter of approval upon the successful completion of the application process, which should be carried in the test vehicles at all times. If MassDOT does not approve of an application, a letter of denial may be issued along with instructions on how the Applicant may revise and resubmit an application for a subsequent review.

Companies may operate vehicles autonomously only on the defined and agreed-upon roads and in the approved Operational Design Domains (roadway types and environmental conditions) as described in each company's respective Application. Testing is conducted in a phased approach, with organizations beginning on the least-complex roadways and environments. After meeting the milestone for a testing phase, organizations may request approval to advance testing to the next testing phase, which may, depending on the particular phase, expand the ODD to include nighttime or inclement weather testing, and/or

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[1] https://www.mass.gov/how-to/how-to-test-autonomous-vehicles-in-massachusetts

new roadways and jurisdictions. It is up to each participating jurisdiction to determine which roadways may be used for testing during each progressive testing phase. As municipalities and state agencies designate specific routes within their jurisdictions for testing, these routes are provided to applicants in the Testing Phase Schedule, an appendix to the Application document. Participants may elect to opt-out of approval of an Application at any time.

7.2.1 APPLICATION

The draft AV Application includes many critical reporting and documentation requirements as a prerequisite for approval to test on public ways.

The Application contains a section for general contact and office location information, followed by nine detailed response sections. The general components of each detail include:

- Detail # 1: Experience with Autonomous Vehicles
  - A brief history of the applicant's business as it regards autonomous vehicles
  - A summary of the applicant's experience operating autonomous vehicles on private facilities (closed to the public)
  - A summary of the applicant's experience operating autonomous vehicles on public ways while the road was open to other road users
  - A description and summary of any crashes (regardless of the degree of seriousness) that resulted during testing of autonomous vehicles on public ways by the applicant

- Detail # 2: Applicant's Voluntary Safety Self-Assessment
  - A copy of the voluntary safety self-assessment in accordance with NHTSA's Automated Driving Systems 2.0 guidance, or similar documentation which addresses the safety issues contained therein

- Detail # 3: Testing Plan
  - A description of the roads and/or areas from the provided options (Testing Phase Schedule) which will be used for testing
  - If applicable, a request for a waiver for any phases of the Testing Phase Schedule which the Applicant can prove have been sufficiently completed through recent testing in other jurisdictions and documented in Detail #1. MassDOT will review and permit any waiver requests in consultation with the municipal and state participants.

    - The Applicant may submit to MassDOT and any municipal or state participant a proposal for a new testing phase, or changes to an existing phase(s), to be considered by MassDOT and any participant(s).

- Detail # 4: First Responders Interaction Plan
    - Information that will be made available to the law enforcement agencies and other first responders (including fire department and emergency medical personnel) to instruct those agencies on how to interact with the vehicle in emergency and traffic enforcement situations
    - Reviewed on a regular basis by the Applicant and revised and resubmitted at least annually, or as changes are needed

- Detail # 5: Summary of Training and Operations Protocol
    - A summary of the type(s) of training required of employees, contractors and/or other persons designated by the Applicant as Test Drivers, and related operational protocols for testing on public ways
    - A general description of the training and instruction provided on private facilities and public ways, including how a test driver is made aware of the limitations of the vehicle's autonomous technology
    - General steps or checklist items which must be completed prior to a new test driver beginning on-road testing
    - A description of the test driver's role and responsibilities when operating in autonomous mode
    - A description of the Applicant's processes, protocols, and/or physical systems for ensuring the human test driver effectively monitors the environment and is able to take over immediately as necessary during testing

- Detail # 6: Motor Vehicles in Testing Program
    - A copy of the certificate of registration for each Autonomous Test Vehicle.
    - Any exemptions issued by USDOT, EPA, or any other

- Detail # 7: Drivers in Testing Program
    - A copy of the current driver's license of each human operator who will be designated as a test driver, and a certified copy of the driving record for any drivers with an out-of-state license

- Detail # 8: Insurance Requirement
    - Insurance Certificates including statements evidencing all requirements listed in the Memorandum of Agreement

- Detail # 9: Additional Questions
    - Why the organization is applying to test autonomous vehicles in Massachusetts
    - If the organizations' efforts create temporary or permanent employment in the Commonwealth
    - The organization's long-term vision of autonomous mobility

At least every six months, MassDOT will review the technological advancements, federal policy progress, and developments in the autonomous vehicle industry and adjust or modify the Application and associated requirements as appropriate.

7.2.2 MEMORANDUM OF AGREEMENT (MOA)

In addition to the Application, the draft regional AV MOA details several fundamental conditions and best practices for organizations to abide by during public roads testing. A selection of these requirements has been summarized below.

When AVs are operated autonomously, a test driver who is trained and experienced in the operation and control of AVs must be in the driver's seat, or other location in the vehicle, and able to take immediate control if necessary. Each test driver must be at least 21 years of age, possess a valid driver's license, and have a driving record free of any pending cases or convictions for serious motor vehicle violations including but not limited to operation of a motor vehicle while under the influence of alcohol or drugs, operating to endanger the safety of the public, leaving the scene after personal injury or property damage, and motor vehicle homicide. MassDOT may deny approval for any test driver at its sole discretion. The Applicant must also enroll in the Commonwealth's Driver Verification System to track any changes to test drivers' license status. Test drivers are not permitted to use a mobile telephone, hands-free mobile telephone or mobile electronic device while an autonomous test vehicle is operating in autonomous mode on any public way. A test driver shall not conduct testing activities for more than 8 hours in any consecutive 24-hour period.

AVs must be built from passenger vehicles that comply with federal regulations except for those parts, components, or vehicle systems that have been made inactive or modified in order to enable such passenger vehicles to be autonomous. Each vehicle used for testing should follow the Voluntary Safety Self-Assessment set forth by NHTSA in September 2017, and meet applicable Federal Motor Vehicle Safety Standards, or provide a waiver or exemption from NHTSA, unless otherwise approved by MassDOT. The MassDOT Letter of

Approval must be carried in the approved test vehicle(s) at all times. All vehicles used for public road tests must display a current inspection sticker, current registration plates, and signage on the sides and rear of the vehicle to identify the vehicle as an "Autonomous Test Vehicle". Organizations are also required to carry at least the minimum insurance requirements described in the MOA.

In designated phases of the Testing Phase Schedule, members of the public may ride in an autonomous test vehicle, provided there are no fees charged to the passenger. The Applicant should make all reasonable efforts to accommodate passengers including senior citizens and people with mobility impairments, vision impairments, or other sensory impairments. The Applicant shall disclose to any passenger in the vehicle that is not a test driver, employee, contractor, or designee of the Applicant what personal information, if any, may be collected about the passenger and how it may be used. The Applicant must consult with MassDOT and Participants to explore potential use cases.

In the event of a crash, companies must comply with the laws of the Commonwealth in regard to notifying police, if necessary, assisting at the crash scene if it can be done safely, and exchanging vehicle ownership and insurance information with other vehicle and property owners that may be involved. Companies are required to notify MassDOT and the jurisdiction in which the crash occurred of a crash as soon as possible after it occurs, or within at most 12 hours.

Regardless of the severity of the crash, an RMV "Crash Report" form must be filed with the RMV pursuant to Chapter 90, Section 26 within 5 days of the crash, providing specific details of the crash. The Crash Report contains a description of the crash, and any available information as to the possible cause or causes. If a crash occurs, further testing may be temporarily suspended by MassDOT and/or a participating jurisdiction(s) depending on the cause and severity of the crash, as described in the crash protocol section of the MOA. MassDOT may also require testing organizations to complete a Crash Response Form, when and as described in the MOA. The Crash Response Form provides information to MassDOT and participants about any changes which the organization may implement to the vehicle's hardware or software systems, or to the organizations application materials and training/operations protocol, in response to the crash.

Autonomous test vehicles must be equipped with a data recorder which captures and stores autonomous technology sensor data for all vehicle functions that are controlled by the autonomous technology for at least 30 seconds before a collision with another vehicle, person, or other object while the test vehicle is operating in autonomous mode.

7.3 Autonomous Vehicles Industry in Massachusetts

7.3.1 AV Developers

The **Toyota-CSAIL Joint Research Center** is part of a combined $50 million that Toyota has committed to dual centers at MIT and Stanford University to advance the state of autonomous systems. The center focuses on developing advanced decision-making algorithms and systems that allow vehicles to perceive and safely navigate their surroundings without human assistance. Toyota Research Institute is headquartered in Palo Alto, California, with additional teams in Ann Arbor, Michigan, and Cambridge, Massachusetts.

nuTonomy is a leading developer of state-of-the-art software for self-driving vehicles founded by two world-renowned experts in robotics and intelligent vehicle technology, Drs. Karl Iagnemma and Emilio Frazzoli of MIT. nuTonomy is developing level 4 autonomous vehicle technologies. The company's vehicles have been tested in the U.S., Singapore, and Europe.

In December 2016, nuTonomy signed a Memorandum of Understanding (MOU) with the City of Boston and the Massachusetts Department of Transportation which authorized nuTonomy to begin testing its growing fleet of self-driving cars on specific public streets in a designated area of Boston. nuTonomy currently has 5 vehicles permitted for operation in Massachusetts.

nuTonomy is one of a handful of agencies which are permitted by the Land Transport Authority (LTA) of Singapore to conduct trials of driverless vehicles. nuTonomy targets to have a limited commercial service by 2018 with up to 75 vehicles available in certain areas, with services rolled out island-wide by 2020, according to reports.

Figure 1 - A nuTonomy vehicle

nuTonomy conducted a passenger pilot in late 2017. In the passenger pilot, the company provided rides in their AVs to invited guests. In a partnership with Lyft pilot, nuTonomy demonstrated how a basic autonomous ridehailing service could function. Passengers hailed a ride through the Lyft app, and were taken to their destination in a nuTonomy vehicle. In the nuTonomy pilot, they carried passengers in AVs along a fixed route in the Seaport. At the end of each trip, the user research team conducted detailed interviews with each passenger about their experience riding in the AV. The passengers included six seniors and one person with visual impairment. The passengers gave nuTonomy feedback on how to adapt the technology for a diverse user base. In the nuTonomy-Lyft pilot, the company provided rides to passengers along multiple user-selected routes. The passengers hailed the nuTonomy ride from the Lyft app. While in the vehicle, passengers were able to view an electronic display that showed the vehicle's planned trajectory and key obstacles around the vehicle. After each ride, passengers completed a questionnaire on the ride-hailing app and in-car display.

Optimus Ride is a MIT spinoff self-driving vehicle technology company developing systems for geo-fenced environments. The founders built self-driving technology while at MIT and entered into the DARPA Urban Challenge in 2007, one of the six teams that finished the race. Since then, they have built fully autonomous cars, trucks, forklifts and other ground vehicles. The team also has experience in designing and building shared-electric vehicles as well as managing shared fleets. Optimus Ride was founded as a Delaware corporation in August 2015. Their goal is to develop self-driving vehicles that enable safe, sustainable, and equitable mobility access. They design fully autonomous (level 4) systems for electric vehicle fleets.

Optimus Ride has been testing continuously since 2015. They have been conducting off-road testing in collaboration with the City of Boston and the Perkins School for the Blind. The company tests on closed facilities up to 40 hours per week in vehicles manufactured by Textron and Polaris. Optimus Ride has been testing SAE level 4 technologies.

Figure 2 - An Optimus Ride vehicle

NextDroid is a "stealth mode" startup company that is on advanced driving assistance systems in Boston and Pittsburgh. Founded by alumni of MIT and CMU, the company states only that they are working in partnership with a top five automaker and an offshore market leader.

7.3.2 HARDWARE AND SOFTWARE DEVELOPERS

Analog Devices, Inc., also known as ADI or Analog, is an American multinational semiconductor company that specializes in data conversion and signal processing technology. The company is headquartered in Norwood, MA and serves roughly 100,000 customers, with roughly $5.2B in sales in FY2017. There are about 10,000 current employees worldwide, and three locations in Massachusetts (Norwood, Wilmington, and Chelmsford). ADI manufactures analog, mixed-signal and digital signal processing integrated circuits used in electronic equipment. These technologies are used to convert, condition, and process real-world environmental conditions, such as light, sound, temperature, motion, and pressure into electrical signals. In July 2018, ADI began collaborating with Baidu on Project Apollo to Advance Autonomous Driving. The collaboration will focus on providing comprehensive, systematic and reliable solutions to address autonomous driving and intelligent connectivity critical to the future of smart traffic. ADI and Baidu will share resources and technologies to further develop the sensing and navigation application for Project Apollo including radar, LIDAR, Inertial Measurement Units, and digital signal processing products.

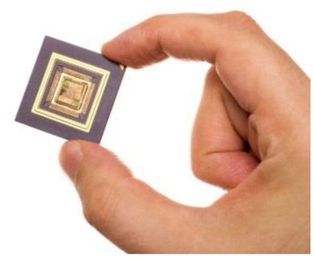


Figure 3 - Chip-Scale LIDAR

Analog Photonics is a fast-growing startup, based in Boston, developing the next generation miniaturized LIDAR sensors for autonomous applications. The company is developing the next generation chip-scale LIDAR sensor solutions using proprietary and patented silicon photonics and optical phased array technology. Using a combination of silicon and silicon nitride as core waveguide layers, the silicon photonics platform is low loss and can handle high optical power in the visible and near-infrared region of the electromagnetic spectrum. Having the capability to achieve high, medium and low index contrast is at the basis of their state-of-the-art photonic components, while maintaining a low footprint.

Aptiv designs and manufactures vehicle components, and provides electrical and electronic and active safety technology solutions to the global automotive and commercial vehicle markets. Formerly known as Delphi Automotive, Aptiv emerged from the completion of Delphi's spin-off of its powertrain segment in late 2017. A core function of Aptiv is software and vehicle architecture expertise that enables the advanced safety, automated driving, user experience, and connected services that are making the future of mobility work.

Aptiv acquired nuTonomy in October of 2017, and two months later announced plans to open a new technology center in Boston's Seaport District. Aptiv has two additional technology centers in Pittsburgh, PA and Mountain View, CA focused on automated mobility-on-demand and data management development. Aptiv selected Boston's Seaport district as the location of its new technical center due to the City's technically proficient work force, world-class universities, and local government's track record of supporting technology and growth. Aptiv has about 147,000 employees and operates 14 technical centers, as well as manufacturing sites and customer support centers, in 45 countries.

Autoliv is a Fortune 500 company headquartered in Stockholm, Sweden and incorporated in Delaware. It is one of the world's largest automotive safety suppliers, with sales to all the leading car manufacturers in the world. Autoliv has about 80 facilities worldwide, more than 70,000 employees, and 19 closed-course test tracks, with revenues exceeding $10B in 2016. Autoliv's mission is to be the leading supplier of safety systems for the future autonomous car.

Autoliv develops, manufactures, and markets protective systems such as airbags, seatbelts, steering wheels, as well as passive and active safety systems including brake control systems, radar, night vision and camera vision systems. The company occupies a market share of approximately 39% of the global passive safety market. A main focus area of Autoliv's business ventures is in active safety systems, such as radar, night vision, driver monitoring systems.

In June of 2018, Autoliv spun off its electronics business segment, creating a new, independent publicly traded company called Veoneer, Inc. The electronics segment includes the active safety market, comprising automotive radars, cameras with driver assist systems, night vision systems, and positioning systems.

Autoliv came to Lowell in 2008 when it acquired a piece of M/A-Com Inc., purchasing the whole company in 2015. Autoliv spokesman Henrik Kaar stated that the Lowell engineering facility is "a key corporate technology center to design radar systems for the automotive market." Applications of this work include night vision and sensors that can detect traffic when backing out of a parking space. Autoliv's Lowell workforce also includes quality testing, radar-range testing, engineering, human relations and other operations.

Neurala is a software and services company that helps bring artificial intelligence (AI) to drones, robots, cars, and consumer electronics. Founded in 2006, Neurala has been building the "intelligence" to enable autonomous machines to be able to function without a human, from toys to self-driving cars.

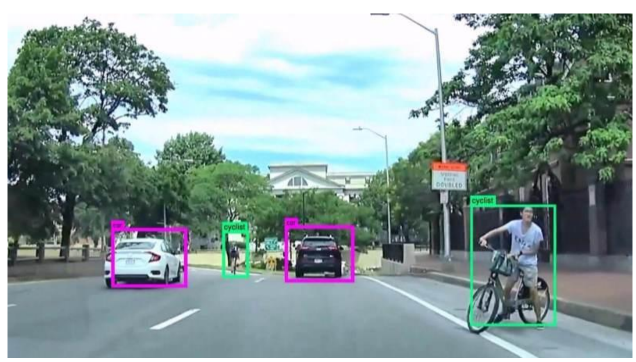


Figure 4 - A Neurala camera on Massachusetts Avenue in Cambridge, Massachusetts, automatically identifies pedestrians, cars, cyclists and trucks in the scene

There are currently between 11-50 employees.

The Boston-based startup offers what it calls the Neurala Brains for Bots software development kit (SDK), which developers can request access to. In a nutshell, the SDK gives developers access to out-of-the-box knowledge to integrate into their products, built on a deep learning neural network that is designed to emulate the human brain, and with computer vision capabilities too. All the functions of the SDK can work offline, meaning internet or server access isn't required.

Sensata Technologies is one of the world's leading suppliers of sensing, electrical protection, control and power management solutions, with operations and business centers in fifteen countries. In 2016, there were 20,300 employees across the globe; 1,000 of which were centered in Attleboro at the company's global headquarters. Sensata's products improve safety, efficiency and comfort for millions of people every day in automotive, appliance, aircraft, industrial, military, heavy vehicle, heating, air-conditioning, data, telecommunications, recreational vehicle and marine applications (27).

Sensata entered into a strategic partnership and investment agreements with Quanergy Systems to advance the ongoing development and commercialization of Quanergy's LIDAR technology. Quanergy Systems, Inc. is a leading provider of solid state LIDAR sensors and smart sensing solutions. Sensata and Quanergy will be exclusive partners for component level solid state LIDAR sensors in the transportation market.

"A production line being set up in Attleboro, Massachusetts, is intended to make those crucial components compact enough to fit inside the outlines of a conventional vehicle. It will start producing fist-sized LIDARs early 2017 that should also see farther and more clearly than [existing mechanical systems]." (28)

7.3.3 History of Vehicle Development in Massachusetts

Since the early 1900's Massachusetts has played a role in the development of motor vehicles and their component parts, beginning in earnest with the 1913 opening of Ford's Cambridge Assembly plant along the Charles River in Cambridge. The building was subsequently reused by Polaroid, and is now owned by MIT.

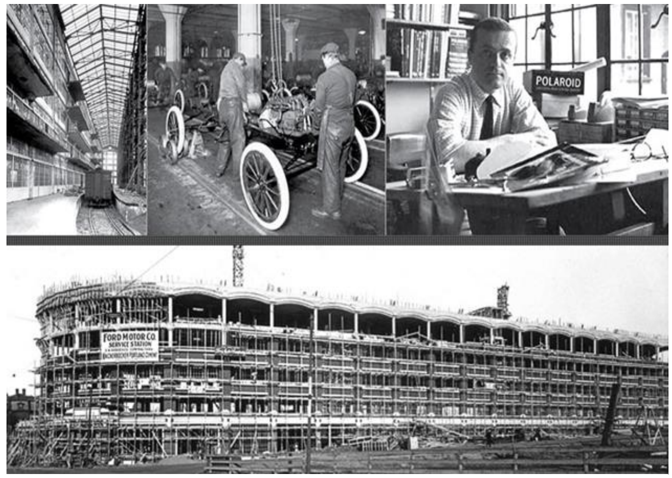


Figure 5 - Cambridge Assembly Ford Motor Company (1913) (4)

After the construction of the McGrath Highway in 1925, full industrial development, albeit short-lived, took hold in Somerville. The Ford Motor Company moved their Cambridge Assembly to a plant in Somerville in 1926, which would, over time, lend Assembly Square its name. Additionally, the Boston and Maine Railroad also owned large tracts of land in the district and the land was crisscrossed by spur tracks. With both road and rail connections, the strong transportation infrastructure was a major draw, and other industries soon followed, including First National Stores, a retail supermarket chain, which opened a grocery manufacturing and distribution center in the area. Within the next 30 years, Assembly Square remained one of the largest employment centers in the region, and paid the city over $1 million in annual taxes (29).

Figure 6 - Assembly Row Ford Motor Company (1926) (6)

In 1958, as a result of the failure of the Edsel Division of the Ford Motor Company and the change of Ford's manufacturing plans, the Assembly Plant was closed, leaving a vast complex of empty manufacturing buildings. First National moved into the Assembly Plant site shortly after Ford's departure. By the late 1950s and early 1960s, industries were already making the choice to move to suburban locations along newly constructed highways, where land costs were lower. The construction of the elevated Northern Expressway portion of Interstate 93 in the 1970s segregated the uses on both sides of the highway and significantly reduced its access and visibility from the surrounding areas. In 1976, First National closed its operations, marking the end of Assembly Square as a major industrial employment center.

While Massachusetts may no longer be a location for the manufacturing and assembly of vehicles, a range of companies and institutions within the State continue to play an essential role within the industry.

7.4 AV Initiatives in the United States

The following sections are not intended to provide a comprehensive review of the autonomous and connected vehicle efforts in respective states, but to highlight important or noteworthy regulations and initiatives.

The below chart provides an example of some leading states' positions on key AV issues.

	Testing with Seated Backup Driver	**Testing without Seated Backup Driver**	**Passengers Allowed in Tests**	**Low-Speed AV Shuttles**	**AV Trucks and Platoons**	**Driverless Deployment**
California (Legislation, Regulations)	✓ By Permit	✓ By Permit	✓	✓ By Permit		✓ By Permit
Michigan (Legislation, Regulations)	✓	✓	✓	✓	✓ ✓ Platoons	Allowed with Limitations
Nevada (Legislation, Regulations)	✓ By Permit	✓ By Permit	✓	✓	✓ ✓ Platoons	Allowed with License Endorsement
Florida (Legislation, Regulations)	✓	✓	✓	✓	Platoons Pilot Study	✓
Arizona (Exec Order)	✓	✓	✓	✓	✓	
Pennsylvania (None)	✓		✓	✓	✓	
Massachusetts (Exec Order)	✓ By Permit		✓			

7.4.1 California

CA passed legislation in 2012 requiring the Department of Motor Vehicles (DMV) to promulgate regulations for operating AVs in CA. California's first AV testing regulations were adopted in May 2014 and became effective in September of that year, when the DMV began permitting autonomous vehicles to test with a driver inside. The regulations (Article 3.7) established an Autonomous Vehicles Tester Program administered by the Occupational Licensing Branch of the DMV.

In 2016, AB 1592, a more localized bill exempting state AV rules for testing and piloting self-driving vehicles at the GoMentum Station under the guidance of the Contra Costa Transportation Authority (CCTA) passed. CCTA has partnerships with private companies, including Honda, EasyMile and Uber's Otto. GoMentum station was also selected as one of 10 designated proving grounds for autonomous vehicle research by the U.S. Department of Transportation. California has also conducted research and pilot deployments of connected vehicle and infrastructure technologies.

As of June 2018, the DMV had issued permits to 55 entities to conduct testing with a seated driver, an increase from 30 in April of 2017 and 18 in October 2016.

The current application for testing with a seated driver includes a checklist of "acknowledgements" including adherence to Federal Motor Vehicle Safety Standards or appropriate waivers, operator takeover requirements, and more. California requires an annual report of disengagements occurring within the previous year. Testing entities must submit annual "disengagements" report which includes: evidence of insurance, outline of the driver training program, vehicle registration information, cause of disengagement, and the total annual number of disengagements per vehicle. Disengagement is defined as an instance where the autonomous system fails or stops unexpectedly. Additionally, manufacturers are required to provide the DMV with a Report of Traffic Collision Involving an Autonomous Vehicle within 10 business days of the incident (regardless of amount of damage done). The report must include information about damage and injury, what happened, road conditions, etc.

Updated regulations were published in March 2017 and are currently in effect. The updated regulations include:

- Revised definitions and terms
- A permitting process for driverless AV testing (with advanced notice of testing given to municipalities but no local approval required, and at no cost to riders)
- A permitting process for deployment of vehicles with and without a driver
- Expansion of the current self-certification process for adherence to FMVSS

- Requirement of a NHTSA Safety Assessment Letter for testing without a driver and deployment with or without a driver

California began accepting permit applications for driverless testing from qualifying companies starting in April 2018. Waymo (Google) and a Chinese/American company called JingChi.ai were the first to submit applications to date, the status of which is still pending as of August 2018. These vehicles must have a remote operator able to assume control. Driverless shuttle are being tested at Contra Costa's closed-course facility.

In 2018, CA 145 passed which repealed a requirement that the Department of Motor Vehicles notify the Legislature of receipt of an application seeking approval to operate an autonomous vehicle capable of operating without the presence of a driver inside the vehicle on public roads.

7.4.1.1 I-10 Corridor Coalition

The I-10 Coalition is a four-state joint effort between the Arizona, California, New Mexico, and Texas state departments of transportation. The vision is to achieve a connected corridor throughout the four states, and the coalition leverages collective expertise, resources, and economies of scale, applying regional best practices to ensure safe and efficient corridor operations. The coalition members are developing technology, standards of practice, and protocols to enable better freight and passenger movement along the corridor, utilizing CV/AV applications such as truck platooning and V2V/V2I communications. The coalition is currently working on producing a Concept of Operations that identifies and implements operations and technology improvements that will lead to a "connected corridor".

7.4.2 Michigan

Michigan passed new AV legislation in December of 2016 (S995, 996, 997, and 998), which establish regulations for the testing, use, and eventual sale of autonomous vehicle technology and are meant to more clearly define how self-driving vehicles can be legally used on public roadways. The law specifies the conditions under which driverless vehicles can be tested and used on public roads. Going far beyond current developments in driverless technology, the regulations also covers the testing of fully autonomous vehicles with no steering wheels, pedals, or any provision for human control.

The new legislation allows both traditional automakers and tech companies to operate driverless ridesharing services. Also, once self-driving technologies have been tested and certified for use, the regulations allow the sale of driverless cars for public use. The legislation reverses a 2013 law that required autonomous vehicles to have a backup driver aboard.

The legislation is imperfect, such as the inconsistent in the use of terms like "operation," "operator," and "driver", and the language is likely to be revised over the coming years. For example, one piece of legislation makes the manufacturer liable for "incidents in which the automated driving system is at fault," but only when it's operating the vehicle as part of an on-demand network.

The final bill updates the language to clarify that technology companies can definitely take to the roads in Michigan, but all but requires "automobile manufacturers" to be part of the efforts. A company like Google would either have to link up with a vehicle manufacturer, purchase manufacturers' federal government-approved vehicles, or build its own cars that meet federal safety standards to really get in on the action.

Michigan is also piloting several connected vehicle and infrastructure projects, including projects for red light violation warnings, work zone/reduced lane warnings, truck platooning, and truck parking information and management systems. The Michigan Department of Transportation and 3M are installing vehicle-to-infrastructure technology in a three-mile stretch of I-75 in Oakland County to become one of the country's first connected highways. This project will help pave the way for the advancement and safety of connected and autonomous vehicles. The I-75 Modernization project will allow it to serve as a test bed for emerging transportation technologies. Roadside dedicated short-range communication devices will deliver valuable information to connected

Figure 7 - Mcity

vehicles. Advanced all-weather lane markings and retroreflective smart signs are not only easier for human drivers to see, but it allows for greater visibility for sensors on cars (machine vision), increasing safety of robot and human drivers alike.

University of Michigan opened Mcity in 2015, a $10 million 32-acre closed-course testing track in Ann Arbor that simulates urban and suburban streets.

Michigan has also established the American Center for Mobility, ACM, which includes real-world vehicle testing and is one of the 10 USDOT Designated Proving Grounds for AVs. The site is a uniquely purpose-built facility focused on testing, verification and self-certification of connected and automated vehicles and other mobility technologies at the 335-acre historic Willow Run site in Ypsilanti Township in Southeast Michigan.

The first phase of construction was approved in May 2017, and included a 2.5-mile highway loop with on- and off-ramps and a 700' curved tunnel, a customer garage, and an operations center. The first phase was completed and opened in December 2017.

Construction began following announcements of a second round of $30 million in funding. More than half of the $110 million needed to fund the advanced test bed has been secured, and additional private investment announcements are expected.

Figure 8 - Design Plans for the ATC at Willow Run

7.4.2.1 Smart Belt Coalition

In May 2017, the Pennsylvania Department of Transportation (PennDOT) and Pennsylvania Turnpike Commission (PTC) signed a letter of understanding to form the Smart Belt Coalition with transportation agencies in Ohio and Michigan to focus on automated and connected vehicle initiatives.

The coalition, which includes transportation and academic partners, brings together leaders on these technologies to support research, testing, policy, funding pursuits and deployment, as well as share data and provide unique opportunities for private-sector testers. The goals of the coalitions are to support research, testing, policy, funding pursuits and deployment, as well as share data and provide unique opportunities for private-sector testers. The coalition believes that in order to create a uniform code that will allow driverless cars and connected vehicles to seamlessly cross state borders, a collaborative effort beyond one state and one jurisdiction is needed. It is also working toward the creation of a “smart corridor” that will eventually stretch from the East Coast to Detroit and Chicago.

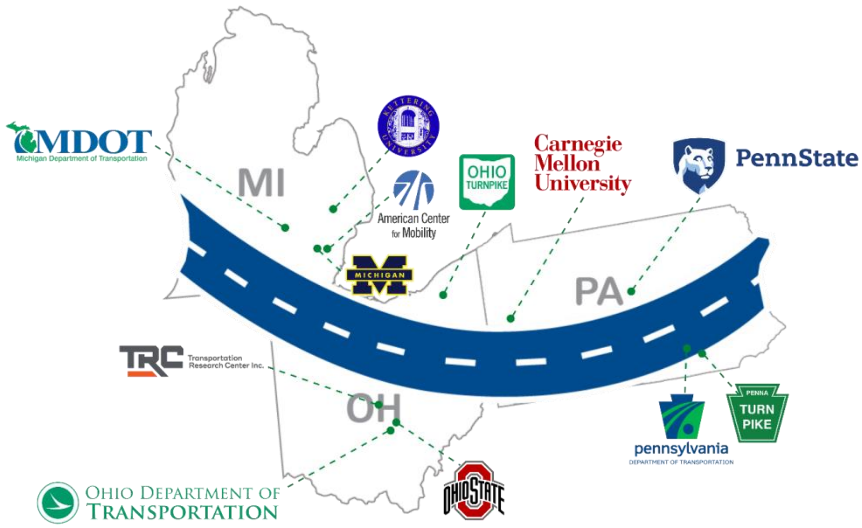
While coalition membership may expand in the future, participating agencies, organizations, and universities include:

- Pennsylvania: PennDOT, Pennsylvania Turnpike Commission, Pennsylvania State University, and Carnegie Mellon University;
- Michigan: Michigan Department of Transportation, University of Michigan, Kettering University, and The American Center for Mobility; and
- Ohio: Ohio Department of Transportation, Ohio Turnpike and Infrastructure Commission, The Ohio State University, and Transportation Research Center.

With similar climates, commercial truck traffic and active work on these technologies in the participating states, the coalition will be a resource for transportation stakeholders and the private sector alike. The coalition is developing its strategic plan which initially focuses on:

- Connected and automated applications in work zones, including uniform work-zone scenarios offering consistency for testers as well as technologies offering better information to motorists.
- Commercial freight opportunities in testing, including platooning (connecting more than one vehicle) and potential coordination on interstates.
- Incident management applications providing better information to and infrastructure for emergency responders and other agencies.

The coalition is the latest example of Pennsylvania's commitment to safe and innovative development of these technologies and complements the Autonomous Vehicle Policy Task Force, which is chaired by PennDOT (Learn more about the task force, which includes government, academic and private-sector members, at www.penndot.gov under "Projects & Programs" and then "Research and Testing.").



7.4.3 PENNSYLVANIA

The only state law which applies to AVs in Pennsylvania is the requirement of a seated and licensed driver able to assume control if necessary (unmanned and/or remote testing on public ways is prohibited). There are no current laws or regulations which require AV Testers to report testing activities to PennDOT. Following workshops and meetings with the state's Autonomous Vehicle Policy Task Force and automated vehicle technology companies, PennDOT issued voluntary guidance to enhance safety oversight of Highly Automated Vehicles in Pennsylvania (31).

The guidance, effective August 1, 2018, requests that AV testing entities submit a Notice of Testing to PennDOT, including information on the testing organization and drivers, vehicles, counties where testing will occur, and a safety and risk mitigation plan (or voluntary safety self-assessment letter as defined by NHTSA). PennDOT has prescribed that testing above 25 mph should be conducted with a secondary 'safety associate' present in the vehicle, or a plan for enhanced performance driver training should be provided. PennDOT shall provide an approval letter within ten business days of receipt of the Notice, or an explanation as to why the application was declined and opportunity to meet prior to resubmittal. The guidance also defines conditions which may necessitate suspension or revocation of testing authorization, and cases for temporarily restricting testing (due to emergencies, special events, or safety concerns). A local municipality, city, or operating agency may request a temporary prohibition or restriction on the testing of a HAV for emergencies, special events or safety concerns by contacting the Department. PennDOT will review the request and determine if the prohibition or restriction is necessary and justified to address a safety concern.

With respect to data and crash reporting, the guidance requests semi-annual submission of a simple "Data Collection Form", including the approximate number of miles traveled in autonomous mode in PA, the type(s) of roadways tested on, the counties tested in, the approximate number of employees in the state, the approximate number of new jobs created as a function of the testing, and new facilities constructed, purchased, or rented as a function of the testing. Pennsylvania also requests that the vehicle record operational data before a collision occurs.   Such data should be made available to PennDOT and applicable law enforcement agencies upon request.

Two bills are pending in Pennsylvania's General Assembly; SB 427/HB1637 would define autonomous vehicles and maintain the PennDOT and PTC's oversight of AVs, and HB 1958 would allow platooning of up to three vehicles and would allow a highly autonomous working zone vehicle to drive with no operator in working zones. According to current state law, reporting is only required for crashes that result in the death or injury of a person or damage a vehicle to the point it cannot be driven. Additionally, reports do not require the identification of cars as AVs.

Proposed PennSTART test track visualization.

In May 2018, PennDOT announced the Pennsylvania Turnpike Commission announced its partnership with Pennsylvania State University to create the Pennsylvania Safety, Transportation and Research Track, PennSTART. The goal of the track is to provide a testing ground to benefit emergency responders, transportation companies, and research institutions by allowing them to test a number of other transportation technologies including traffic incident management systems tolling and intelligent transportation systems CVs and AVs. PennSTART defines one of its goals as providing "controlled environments to test various connected and automated vehicle technologies for infrastructure equipment, fleets, and other applications." The test track is expected to be operational beginning 2020.

Several companies are headquartered or have significant AV research and development in Pennsylvania and Pittsburgh in particular. Argo AI, Aurora Innovation, Aptiv, GM, and other companies are testing AVs in the state. Uber introduced a fleet of autonomous test vehicles in Pittsburgh in late 2016, drawn by the engineering talent at Carnegie Mellon University (CMU). Google and Uber have opened research centers and hired many CMU faculty and students. Pittsburgh was selected in January 2017 by USDOT as one of the nation's current ten proving ground pilot sites to encourage testing and information sharing around automated vehicle technologies.

7.4.4 Ohio

Governor John Kasich signed an Executive Order in May of 2018 to allow companies to test cars on any public road in the state, including without anyone behind the wheel (32). A licensed driver will have to monitor the car remotely and have the ability to avoid crashes in the event the car's system fails, according to the order. Following the fatal Uber crash in Arizona, said he wants to make Ohio the "wild, wild west" of autonomous vehicle testing, while acknowledging that the crash was a terrible incident. "You'll always have to take risks," Kasich said Wednesday while announcing the order. "If you don't take risks, you die." (33) Governor Kasich noted that he believes Ohio should rank among the top five states for development of the technology, alongside California, Arizona, Florida and Michigan. In July 2018, ground was broken to build a $45 million center to test AVs.

In the Governor's Executive Order, a process for companies to register is described. Companies must register with DriveOhio, and provide the following information:

- General contact information
- Vehicle identification such as make, model, and license plate numbers
- Names of designated operators
- Proof of insurance
- Municipalities or other areas of the state where the company plans to test
- The conditions under which the vehicle can operate in autonomous mode, and restrictions under which he vehicle cannot operate
- Compliance with state traffic and safety laws, and FMVSS or FMCSA regulations except where exempted

For driverless testing of level 4-5 vehicles, the Executive Order requires additional information and assurances are provided to DriveOhio, including that the autonomous vehicle(s) will:

- Achieve a minimum risk condition if there is a malfunction in the hardware or software
- Have a designated driver (not required to be inside the vehicle, but) able to ensure compliance with traffic laws, actively monitor the autonomous systems, detect whether the vehicle is not operating safely and intervene to bring the vehicle to a minimum risk condition
- Be capable of complying with Ohio motor vehicle laws
- Cooperate with any appropriate law enforcement agency request for information about an incident, including sharing of any non-proprietary data, in the event of a violation of the law or regulations of the state, or in the event of a collision

Companies must inform DriveOhio of plans to test an AV without a human operator, including the routes or areas where testing will occur, and the designated operators. The company and DriveOhio will also coordinate on providing notification to relevant municipalities where testing will occur.

Municipalities and companies may participate in the AV Pilot Program by entering into agreements with DriveOhio, which will work with the municipality to create an inventory of unique testing attributes for consideration by company partners. However, Kasich said he would not allow communities to block the operation of public cars in their area during his term in office.

The Order also notes that the Governor may pause testing of any autonomous vehicle if there is clear evidence that the technology is not safe.

7.4.5 ARIZONA

An Executive Order permits the testing with safety drivers, and driverless testing on university campuses through partnerships. In 2015, Governor Doug Ducey signed an executive order directing several state agencies to undertake "any necessary steps to support the testing and operation of self-driving vehicles on public roads." The order also set up a Self-Driving Vehicle Oversight Committee within the governor's office.

Companies need only to carry minimum liability insurance policies to operate. Companies are not required to track crashes or disengagements or to report any information to the state. Vehicles may be operated only by an employee, contractor, or other person designated or otherwise authorized by the entity developing the self-driving technology. Vehicles must be monitored and an operator should have the ability to direct the vehicle's movement if assistance is required. The individuals operating vehicles must be licensed to operate a motor vehicle in the United States. In addition, the vehicle owner must submit proof of financial responsibility, in an amount and on a form established by the Director of the Arizona Department of Transportation.

After a crash in early 2018 in which an Uber autonomous vehicle killed a pedestrian in Tempe, Arizona, Arizona's governor suspended the company from testing in the state. In May 2018, two months after the crash, Uber shut down its AV program in Arizona.

Waymo (Google) has been offering rides around Phoenix for a few hundred citizens in its "early rider" program, using their growing fleet of Chrysler minivans. The state had approximately 600 autonomous vehicles that were operating on its roads as of mid-2018. In March of 2018, the state issued an update to the governor's previous executive order allowing the operation of "robotaxi" services beyond testing purposes. Since that time, several companies have announced or begun tests of delivery services and commercial activities using autonomous vehicles in Arizona (34).

7.4.6 VIRGINIA

In Virginia, no applications or permits are required for AV testing, or reporting requirements. There are no laws regarding autonomous vehicles in the state; rather, the state's autonomous vehicle rules are based on pre-existing state laws that define an "operator" as a person in "actual physical control" of a vehicle. Additionally, the state does not require a bond for automation testing.

The state has also invested heavily to create, in conjunction with the Virginia Tech Transportation Institute, the Virginia Automated Corridors. The state has done high-definition mapping of the 78 miles worth of express lanes comprising the Automated Corridors as well as installing equipment that can communicate with CVs and AVs. Virginia is also allowing testing on certain highways during light traffic conditions to test autonomous/traditional vehicle interactions. The corridors also include two test-track environments - the Virginia Smart Road, located on-site at the Virginia Tech Transportation Institute, and the Virginia International Raceway. The state has appropriated $25 million a year for roadway technology including those that assist AVs and CVs.

7.4.7 NEVADA

The Nevada Legislature and the DMV enacted legislation and regulations to enable the testing and operation (deployment) of autonomous vehicles.

In 2011, Nevada became the first state to issue legislation on AVs with AB 511. The bill allowed for AV operation after obtaining a special license issued by the state DMV. The legislation also directed the DMV to adopt rules for license endorsement and for operation, including insurance, safety standards and testing. In 2013, SB 313 required that any autonomous vehicle being tested on a highway meet certain conditions relating to a human operator. The legislation also prohibited autonomous vehicles from being registered in the state, unless they meet certain conditions, authorized the use of driver-assistive platooning technology, and authorized the use of an autonomous vehicle to transport persons or property in certain circumstances. AB 69 also laid some of the groundwork for potential autonomous ride-sharing fleets, creating a permitting requirement and addressing accessibility issues.

Currently, the DMV is accepting applications for testing only. Autonomous vehicles are not available to the general public.

Companies applying to test must submit an application to the Department along with proof of at least 10,000 miles driving experience, a complete description of the autonomous technology, a detailed safety plan, and plan for hiring and training test drivers. Additionally, companies must provide evidence of an insurance policy, or self-insurance, worth $5,000,000 (compared to the $25,000/$50,000/$20,000 for a human driven car).

Governance in Nevada requires that no later than 7 months after a company is issued a permit, it must provide reports of the number of motor vehicles that occurred in the first 6 months and the highest, lowest, and average amount paid for bodily harm occurred in crashes, and the same information for property damage. Furthermore, governance requires that "any person responsible for the testing of an autonomous vehicle shall report to the Department, within 10 business days after a motor vehicle crash, any motor vehicle crash involving the testing of the autonomous vehicle which results in personal injury or property damage estimated to exceed $750."

As of August 8, 2016, the Department made a policy decision to remove the formal drive demonstration requirement prior to issuing an autonomous test license. The Department has made changes to the application packet (OBL 326) to ensure the company provides a sufficient overview of the technology's capabilities and limitations.

When autonomous vehicles are eventually made available for public use, motorists will be required to obtain a special driver license endorsement and the DMV will issue green license plates for the vehicles.

The autonomous, fully electric shuttle, which can transport a dozen passengers, is shown above in downtown Las Vegas at CES 2017. The Nevada Automotive Test Center is the primary place where AV testing is occurring within the state.

7.4.8 FLORIDA

Florida Statutes Section 316.85 allows for the operation (testing and deployment) of AVs on public roads without an “operator” physically in the vehicle. Florida had previously allowed AVs only for testing, but removed that limitation in 2016, along with the requirement that the vehicle “operator” be present in the vehicle.

The vehicles must still have a means to engage and disengage the autonomous mode, and alert the operator of a failure. An AV can arguably be deployed so long as a remote operator is available to receive alerts about system failures, and onboard vehicle software is capable of safely bringing the vehicle to a stop if it or the operator is unable to effectively navigate the vehicle.

Florida is developing Suntrax, a large-scale, cutting-edge facility dedicated to the research, development and testing of emerging transportation technologies in controlled environments. The 475-acre site will include a 2.25-mile long oval track, which will provide an opportunity for high-speed testing, along with a 200-acre infield that will allow for the testing of a multitude of different technologies. Many of the designed functions are related to tolling, ITS, and automated and connected vehicles. Additionally, the entire site will be a connected environment for the testing of Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communications.

Several cities within Florida have begun testing and pilot service initiatives. The city of Gainesville is piloting an autonomous EasyMile shuttle on city streets, free of charge. The pilot is part of a three-year study for up to $2.7 million, funded by Florida DOT. Babcock

Ranch, a small town in southern Florida, also has an EasyMile (Transdev) shuttle in pilot service (35). The Tampa-Hillsborough Expressway Authority (THEA) hosted three demo days to give the public the opportunity to experience self-driving vehicle demonstrations on the Selmon Expressway's Reversible Express Lanes, which was closed to traffic from 10 a.m. to 4 p.m. on the days of testing. Public participants were also able to test out a virtual reality system, and were surveyed about their experiences. Ford has begun testing AVs in Miami, and is conducting driverless delivery pilots (36).

Florida is also piloting several connected vehicle projects to offer new safety functions on public roadways. In one such project, the Selmon Expressway is being utilized for connected vehicle testing as part of Tampa's Connected Vehicle Pilot. THEA is equipping approximately 10 buses, 10 streetcars, and 1,600 privately-owned automobiles with this connected vehicle technology as part of the Tampa Connected Vehicle Pilot program. As an incentive, participating drivers will receive a 30% toll rebate on the Express Lanes, up to a maximum of $550 (37). Additionally, Central Florida Automated Vehicle Partners is one of ten official proving sites identified by the USDOT. The Tampa CV pilot, aimed at transforming the experience of automobile drivers, transit riders, and pedestrians by increasing safety and efficiency of the transportation network, deployed 13 CV applications, including end of ramp deceleration warning, wrong-way entry warning, and probe data enabled traffic monitoring.

7.4.9 MINNESOTA

In March of 2018, Governor Mark Dayton signed Executive Order 18-04 which established the Governor's Advisory Council on Connected and Automated Vehicles. The Order recognizes that the state should prepare for the transportation, safety, business and equity transformations and opportunities. The Order establishes an advisory council comprising 15 members appointed by the Governor and ex-officio members from state agencies and the legislature. Information on council members, meeting notices, and advisory council background can be found online here[2]. The advisory council is charged with consulting with stakeholders, and preparing a report to the Governor and legislature by the end of 2018 to recommend changes in statues, rules, and policies around several key topic areas including transportation infrastructure, vehicle registration, driver training and licensure, cybersecurity, and more.

Minnesota has conducted several pilot tests and research initiatives for connected and automated vehicle technologies, including several winter-weather technology tests.

[2] http://www.dot.state.mn.us/automated/advisory.html

MnDOT conducted an Autonomous Bus Pilot project in 2017-18, the purpose of which was to help prepare for the operations of an automated shuttle bus in mixed general traffic and in Minnesota cold weather climate conditions. MnDOT tested an automated shuttle bus supplied by EasyMile at the MnROAD facility in December 2017 and January 2018.

The testing and demonstrations were useful in identifying challenges of operating AVs in snow and ice conditions, identifying challenges of having third parties conduct testing activities, defining infrastructure gaps and solutions for the safe operation of AVs, and providing opportunities for engagement with various stakeholders and public outreach/education.

Some findings of the final report, issued in June 2018, are included below (38).

- The automated shuttle bus operated well under dry pavement conditions with no precipitation. The vehicle kept a safe operating distance from other vehicles, pedestrians, bicycles and other roadway obstructions on the track, performing slowdowns and stops as needed. Daytime and nighttime light conditions did not impact the shuttle performance.
- Falling snow, blowing snow, or loose snow on the track was often detected as obstructions by vehicle sensors, causing the vehicle to slow down or stop to avoid a collision.
- Snow banks alongside the vehicle routes caused issues with pre-programmed paths. Snow banks had to be removed at the Minnesota Capitol demonstration and the Hennepin County demonstration was delayed a week from plan to allow the snow banks to melt.
- At times, compacted snow and patches of ice or slush on the track caused the wheels to slip, which in turn created issues with the bus not responding to its exact location on the track.
- Salt spray from treated sections of roadway that collected on the vehicle sensors did not appear to significantly degrade performance. While some minor anomalies were observed, the reason could not be confirmed. Cleaning dirt accumulation from the sensors due to normal operations appeared to improve the automated shuttle bus performance.
- Due to the rural nature of the MnROAD site, the vehicle required installation of localization infrastructure. Signs posts were installed approximately every 100 feet around the test loop to help the vehicle with localization.
- As the core temperature of the battery dropped, automated shuttle bus operations were negatively impacted. Charging times during colder temperatures increased compared to charging times during warmer temperatures.

Figure 9 - MnDOT Shuttle Testing in a Snow Cloud

7.4.10 WASHINGTON DC

The District of Columbia law presently allows AVs to be operated on the road in autonomous mode and is not limited to testing. However, under D.C. Code section 50-2352, a human driver must be present in the "control seat of the vehicle" at all times, and must be able to assume control of the car. The only data sharing requirements are that initial applicants are required to undergo training certification in AV operation from a self-driving car dealership or manufacturer.

7.4.11 NEW YORK

In 2017, New York Governance passed SB 2005 bill that gave authority to the commissioner of motor vehicles to approve AV testing within the state. The bill codified reporting and insurance requirements. In 2018, the finalized transportation and economic development bill extended AV testing in NY for up to one year and provides the State Police with more direct approval over the tests.

New York law requires that all autonomous vehicle tests and demonstrations must be done under supervision of New York State Police. The commissioner of motor vehicles with the superintendent of state police must then submit a report that includes "a description of the parameters and purpose of such demonstrations and tests, the location or locations where demonstrations and tests were conducted, the demonstrations' and tests' impacts on safety, traffic control, traffic enforcement, emergency services, and such other areas as may be identified by such commissioner."

New York City is installing CV devices at 400 intersections in Manhattan and Brooklyn as part of a USDOT initiative that will communicate with up to 8,000 vehicles. In September 2016, New York announced the project had reached phase II and III of testing which are installing the device in the roadways, traffic lights, and vehicles and then an 18-month deployment period where the effectiveness of the deployed technology is tested. The New York City pilot, aimed at improving safety for travelers and pedestrians in the city, deployed 15 connected vehicle applications, including: red light violation warning, curve speed compliance, reduced speed/work zone warning and pedestrian in signalized crosswalk warning.

7.4.12 Connecticut

Connecticut established, through legislation (SB 260/Public Act 17-69), a pilot AV testing program for up to four municipalities, which shall apply to participate in the pilot through the Secretary of the Office of Policy Management. There must be at least one municipality with a population of at least 120,000, but not more 124,000, and one municipality with a population of at least 100,000. No testing on limited access highways is permitted.

The chief elected official or chief executive officer of a municipality selected by the secretary shall select and enter into a written agreement with an autonomous vehicle tester or autonomous vehicle testers to test fully autonomous vehicles on the highways of the municipality. Such agreement shall, at a minimum: (1) Specify the locations and routes where such fully autonomous vehicles may operate; (2) Prohibit the operation of such fully autonomous vehicles outside such locations and routes except in the case of an emergency; (3) Identify each fully autonomous vehicle to be tested by vehicle identification number, make, year and model; and (4) Specify the hours of operation of such fully autonomous vehicles. The municipality is then required to apply to the state.

Testing companies must have a driver in the driver's seat who is monitoring the environment and capable of taking immediate control. Each vehicle must be registered, and have insurance coverage of at least $5M.

Testing companies must provide non-confidential information to the secretary and the task force that the secretary and task force deem to be appropriate for measuring the performance of the pilot program.

The legislation also creates a Task Force to evaluate NHTSA standards, evaluate national laws, regulations, and legislation, recommend how Connecticut should regulate AVs with respect to laws and regulations, and evaluate the pilot program tests. The Task Force should report its findings in interim reports in January 2018 and July 2018, and a final report by January 2019.

7.4.13 MARYLAND

In 2015, Pete Rahn, Maryland's Transportation Secretary established the Connected and Automated Vehicles (CAV) Working Group. In December of 2017, the group released its "Connected and Automated Vehicles Strategic Action Plan" in which it laid out its plan to make the state more welcoming to AV testing. Included in this plan is an initiative to create specialized highway corridors with upgraded signals to support future CV tests and CCTV cameras to monitor incidents and traffic. This is being done in the US 1 Innovative Technology Deployment Corridor. Additionally, the state is upgrading infrastructure surrounding designated AV and CV testing zones.

Starting in February of 2018, Maryland began offering autonomous vehicle testing permits to private companies wishing to test on public roads in the state. The companies must first submit an expression of interest and then will be given a dedicated Point of Contact to begin a dialogue to create "the flexibility necessary to accommodate many different testing scenarios" for each respective company. Maryland has also launched a site dedicated to providing information about the available testing locations, all of which currently are parking lots, and is promising to add more sites soon. STEER, a Maryland-based autonomous parking technology company, is the first to have received a Maryland highly automated vehicle permit for testing. More than 10 companies have expressed interest in such testing.

MDOT developed "Maryland Locations to Enable Testing Sites (LETS) for CAV" system. Through this online database, MDOT welcomes all public and private sector partners to submit potential test sites, to be included on the webpage.

The state also published two outreach materials earlier this year: "Fast Facts on CAV Technology", and "Maryland Open for Business – CAV Technology".

7.4.14 TEXAS

On June 15, 2017, Texas Governor Greg Abbott signed a bill that will allow AVs to operate on the state's roads.

There was nothing in existing law that banned autonomous vehicles from Texas roads, yet because state statutes did not address the emerging technology at all, some manufacturers told state officials they were wary about testing vehicles alongside street and highway traffic in Texas. Google has been testing AVs since 2015 in Austin, and Arlington is rolling them out. In addition, several Texas sites were chosen by the U.S. Department of Transportation to test the technology in closed-course settings.

In 2017, HB 1791 passed which connected braking systems to allow for the platooning of vehicles. Senate Bill 2205 defines several terms related to autonomous vehicles and requires that driverless vehicles used on highways be capable of complying with all traffic laws, be equipped with video recording devices and be insured just like other cars. It also makes the manufacturer responsible for any broken traffic laws or car wrecks, as long as the automated driving system has not been modified by anyone else.

7.4.15 WYOMING

There is no current legislation or requirements for data sharing in Wyoming. However, the Wyoming Department of Transportation has begun testing CV applications as part of a $4.4 million pilot project with USDOT. The pilot is testing the transmission of warning messages to drivers along I-80 via DSRC. During the winter, bad weather contributes to crashes on the state's main east-west highway, so officials want to see how DSRC can improve driver awareness. The pilot program will test warnings advising travelers of crashes ahead, and advice about weather, speed restrictions, work zones and other matters. The state will use existing weather stations collect data and relay it to WYDOT's Transportation Management Center, which can in turn send out the information to vehicles using the 75 DSRC radios it has mounted along the roadway. This is an important means of communication in a region with limited to no cell service.

Additionally, the state is in the process of recruiting 300 truck drivers to receive DSRC radios and mounted tablets in the cabin. Some companies, including UPS, have signed on. The onboard DSRC system will record information about the conditions the truck experienced in the past roadway section and upload it to the highway-based receivers, as well as be able to tell a truck driver to stop if he's about to hit another DSRC-equipped vehicle.

7.4.16 TENNESSEE

In 2015, Tennessee joined a few other states in passing legislation to prohibit municipal governments from banning AVs at the local level. AVs are exempted from traditional licensing requirements, and the autonomous system is considered the operator of the vehicle for the purpose of determining liability in the event of a collision or violation of traffic laws. The state can legislate that autonomous vehicles be equipped with an integrated electronic display visible to the operator while the motor vehicle's autonomous technology is engaged. (T.C.A. Title 55 Ch. 8 § 55-8-202; 55-30-105; SB 151).

SB 1561 which passed in 2016 cleared up some ambiguity around the definitions of autonomous technology, driving mode and dynamic driving task. The following year, a bill passed to clear the way for vehicle platooning research on streets and highways as long as companies disclose programs to the Department of Transportation and Department of Safety. In 2017, the "Automated Vehicles Act," was passed which established the requirements for autonomous vehicles to operate on public roads and highways. The most recent governance modified requirements for operator licensing, seatbelts, liability issues and crash reporting. The law requires the vehicles owner or a person on behalf of the owner to promptly contact a law enforcement officer or agency to report the crash and the ADS-operated vehicle to remain on the scene of the crash.

7.4.17 NEBRASKA

In April 2018, the Governor signed an act to revise provisions related to AV testing and provide requirements and restrictions. The legislation prohibited municipal regulation, bans, or taxes on AVs. Governance in Nebraska requires that in the event of a crash, the AV must stay on the scene and the owner (or someone appointed by the owner) must notify the police. There is no minimum damage requirement to warrant reporting.

7.5 INTERNATIONAL AV INITIATIVES

7.5.1 SINGAPORE

Autonomous vehicle trials first began in Singapore in July 2015. Under the Road Traffic Act, Singapore's Land Transport Authority (LTA) is empowered to regulate AV trials.

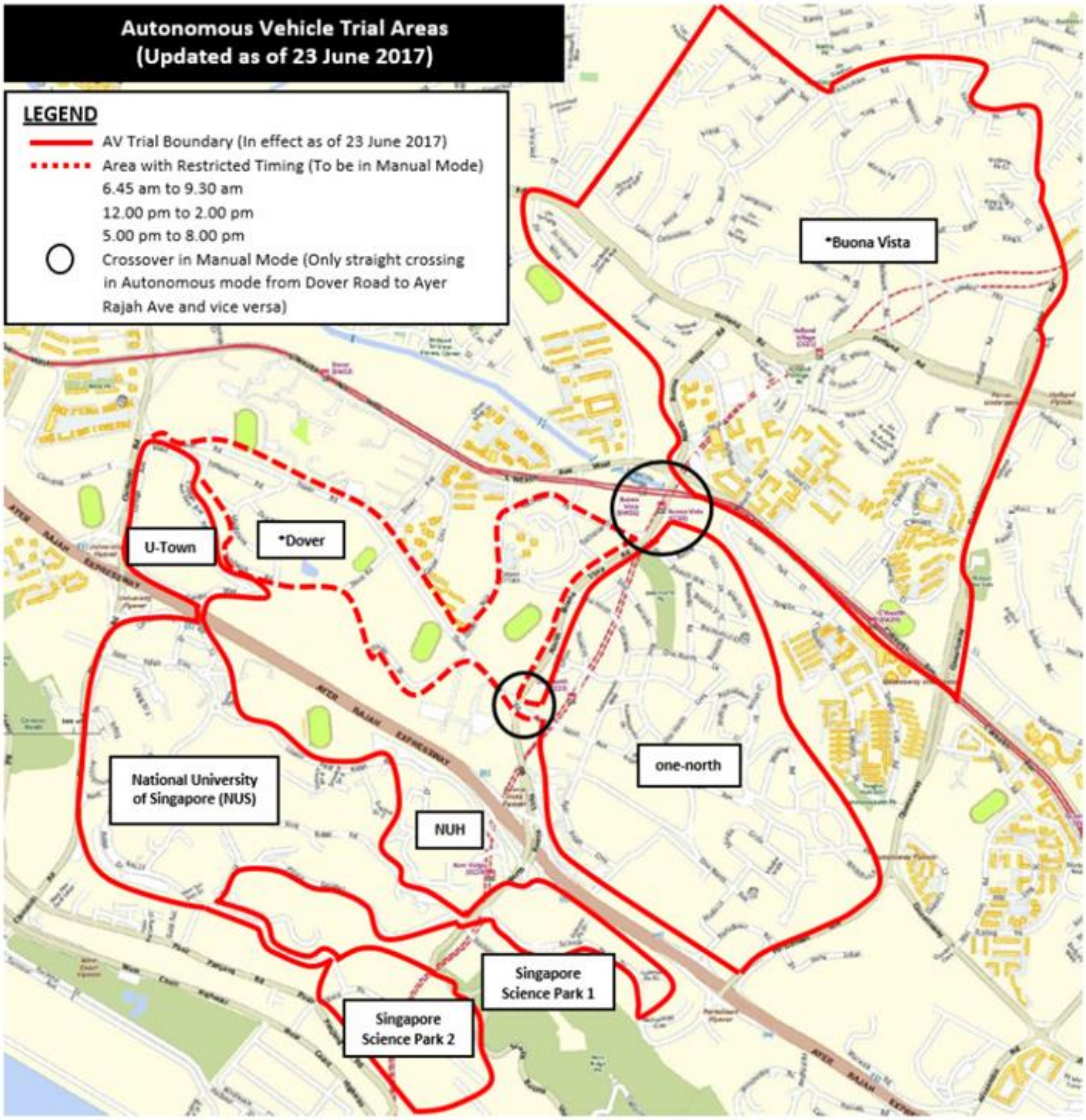
In 2017, traffic law was amended to include some Av guidelines. The Road Traffic Act now includes rules regarding trials of AVs on the city-state's roads. One amendment was that motor vehicles no longer need to have a human driver to take over command. AVs and their operators will also be exempt from current regulations which require a human driver to always be responsible for a motor vehicles safety on the road. However, the vehicle must have adequate liability insurance,

The government plans to provide autonomous vehicle legislation by the second half of 2018 to be proactive and systematic in deploying regulations.

Companies are required to pass certain tests and requirements on a closed course (state-owned) prior to being permitted to conduct some testing in defined geographic area, under specific conditions (weather, time, etc).

In September 2016, LTA doubled the length of the public roads test routes within one-north from 6km to 12km. LTA expanded the AV test bed in one-north again in June of 2017 to neighboring areas, adding 55km to the existing AV trial routes (see map).

To conduct trials in the mixed-use, residential neighborhood areas*, trial participants must demonstrate to LTA and traffic police readiness to handle more dynamic traffic environments. Test vehicles are required to have a qualified safety driver ready to take over control of the vehicle; until the entity demonstrate that their technology is ready for driverless testing. Testing entities are required to have third-party insurance for their vehicles, and to share data from with LTA to facilitate the evaluation of trials.


Autonomous Vehicle Trial Areas
(Updated as of 23 June 2017)
LEGEND
AV Trial Boundary (In effect as of 23 June 2017)
Area with Restricted Timing (To be in Manual Mode)
6.45 am to 9.30 am
12.00 pm to 2.00 pm
5.00 pm to 8.00 pm
Crossover in Manual Mode (Only straight crossing in Autonomous mode from Dover Road to Ayer Rajah Ave and vice versa)
*Buona Vista
U-Town
*Dover
one-north
National University of Singapore (NUS)
NUH
Singapore Science Park 1
Singapore Science Park 2
AYER RAJAH EXPRESSWAY

7.5.2 GERMANY

In 2017, Germany passed the Road Traffic Act which required a driver to be sitting behind the wheel at all times ready to take back control if prompted to do so by the AV. The act only covers the law governing driver behavior - it does not affect regulation for the approval of new vehicles with automated driving systems. This regulation is predominately governed by EU and international law (UN/ECE).

Key governance aspects:

- Defines liability for the driver. The driver is not obliged to monitor the driving system constantly; however, he must exert sufficient attention and perceptiveness so as to be able to take back control of the vehicle instantly the moment the system prompts him to do so.
- If the driver fails to meet any of these obligations, he may find himself liable in the event of a crash. However, if the crash is caused by a failure of the system at a time when the driver was properly relying on it, the driver will be able to exclude his liability. This is done by help of a black box integrated into the system. The manufacturer may then face liability for the system's malfunction.

The law is set to be revised in two years' time in the light of technological developments in order to address data protection and the use of the data collected during rides. A strategy for Automated and Connected Driving has been released by the Federal Government including the following aspects: Infrastructure (Digital infrastructure and standards), legislation, driver training, type approval/technical monitoring, cybersecurity, social dialogue and more.

With regards to data sharing the law requires recorded data to be kept for 6 months and in case of crash for 3 years. There are no specific requirements which have led to 4 major concerns from policy leaders:

- Who is responsible for recording and deleting the data
- The details on the technical design and the location of the data storage device
- The methods of recording the data
- The measures required to protect the recorded data against unauthorized access in the event the vehicle is sold

The legislation requires that a black box records the journey and logs whether the human driver or the car's self-piloting system was in charge at all moments of the ride. This is required to help allocate fault and liability in the event of an crash. The box also records where and when these events happen via the vehicle's GPS data on position and time. The driver will bear responsibility for crashes that take place under his or her watch, under the legislation, but if the self-driving system is in charge and a system failure is to blame, the manufacturer will be responsible.

Driverless parking systems are only allowed on private grounds outside of public roadways. The vehicles must be operating at a low speed. There are several testing fields, and in spring 2018 a new field became operational in the state of Baden- Württemberg including all different types of roads.

The PEGASUS project, promoted by the Federal Ministry for Economic Affairs and Energy, is developing a standardized procedure for the testing and experimenting of automated vehicle systems in simulation, on test stands and in real environments.

7.5.3 SWEDEN

In 2017, Sweden piloted about 100 AVs on a specific highway route around the City. This route was chosen as it has a low rate of crashes, separated travel direction, shoulder for emergency pullover, and other safety features (such as no signals). Some additional preparation has been done for this testing; including, a detailed mapping of the route. AVs will be fully autonomous in this route, and then when the car leaves the route it will transfer control to the driver through a "handshake", which is also used to initiate the autonomous mode. The government is still determining what types of data to collect from the vehicles and how.

7.5.4 FRANCE

The French government has announced that it will allow car companies to test self-driving cars on public French roads. The change in policy is an element of the New Industrial France initiative, which aims to energize the country's industrial and manufacturing sectors. France already allows some self-driving cars on its roads. The PSA Group, a French carmaker, has tested autonomous vehicles on public roadways. These new regulations will allow foreign manufacturers to begin testing their autonomous cars in France as well, providing a new site to gather data and further develop the programming behind self-driving technology, much like Toyota hopes to achieve in Japan.

The New France for Industry plan provides a legal framework for AV experimentation, 10,000 km of road facilities, and several active experiments, working groups, in addition to technical, research, and test bed projects.

7.5.5 FINLAND

Finland's current road traffic legislation already permits automated vehicle trials – no amendments will be required. Trafi, the Finnish Transport Safety Agency, aims to make the testing and use of automated vehicles possible in Finland. Parties interested in or planning trials of automated vehicles are invited to contact Trafi in this regard. In practice, Trafi will facilitate the implementation of trials through means such as proposing solutions for driver specification and helping with the technical approval and registration of the vehicle. Testing of all automated vehicles (1-5) is possible on public roads in Finland using a test plate certificate. Vehicles under testing must have a driver either inside or outside the vehicle. The test plate certificate holder, who is running the tests, must submit a report to the Finnish Transport Safety Agency. The report should describe how the trial was implemented, what kind of deviations were encountered, etc.

National activities include extreme weather testing in Northern Finland Aurora public test section for AVs on highway E8, urban testing facilities in Tampere and Tuusula, SOHJOA automated electric buses in Helsinki, Espoo, Tampere, and automated last-mile solutions. 3 companies have applied for a test plate as of December 2016. Reports will be posted online here: https://www.trafi.fi/en/road/automated_vehicle_trials

7.5.6 UNITED KINGDOM

The UK government created in 2015 the Centre for Connected and Autonomous Vehicles (CCAV), and a 2015 Code of Practice sets out that testers must obey all relevant traffic laws and that test vehicles must be roadworthy, a trained driver or operator must be ready, willing and able to take control (but not necessarily in the vehicle), and appropriate insurance must be held.

A competition in 2015-16 was launched and funded projects will run in the 2016-19 timeframe. £20m was allocated for 21 collaborative R&D projects and feasibility studies to stimulate developments in AVs.

7.5.7 CHINA

China has set a goal for 10 to 20 percent of vehicles to be highly autonomous by 2025, and for 10 percent of cars to be fully self-driving in 2030.

Baidu, a Chinese technology firm, wants to provide the technology to get those vehicles on the roads in China and abroad. The firm unveiled its 50+ partners in an open source development program, revised its timeline for introducing autonomous driving capabilities on open city roads, described the Project Apollo consortium and its goals, and declared Apollo to be the 'Android of the autonomous driving industry.' It will start driving testing in restricted environments immediately before gradually introducing fully autonomous driving capabilities on highways and open city roads by 2020. The program is making its autonomous car software open source in the same way that Google released its Android operating system for smartphones. By encouraging companies to build upon the system and share their results, it hopes to overtake rivals such as Google/Waymo, Tencent, Alibaba and others researching self-driving technology.

The Apollo platform consists of a core software stack, a number of cloud services, and self-driving vehicle hardware such as GPS, cameras, LIDAR, and radar. The software currently available to outside developers is relatively simple: it can record the behavior of a car being driven by a person and then play that back in autonomous mode. This November, the company plans to release perception capabilities that will allow Apollo cars to identify objects in their vicinity. This will be followed by planning and localization capabilities and a driver interface.

The cloud services being developed by Baidu include mapping services, a simulation platform, a security framework, and Baidu's DuerOS voice-interface technology.

7.6 RELATED AV RESEARCH AND GUIDANCE

1. **Strategic Planning for Connected and Automated Vehicles in Massachusetts**
   MassDOT, University of Massachusetts at Lowell

   This study was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program with the University of Massachusetts Transportation Center. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies. The purpose of this study is to provide baseline information pertaining to strategic planning for CAV technologies in Massachusetts.

2. **Quick Response: New England Connected Automated Vehicles**
   New England Transportation Consortium, AECOM

   The purpose of this research, funded by the New England Transportation Consortium (NETC), is to determine considerations for cross-border and collaborative challenges, and to develop a roadmap of actions for the states to conduct to facilitate the operation of CVs and AVs in the region. The roadmap is based on examining current status, reviewing best practices and current research, a stakeholder workshop, and discussions with relevant personnel and industry experts.

3. **Jurisdictional Guidelines for the Safe Testing and Deployment of Highly Automated Vehicles**
   American Association of Motor Vehicle Administrators (AAMVA)

   AAMVA is a non-profit organization developing model programs in motor vehicle administration, law enforcement, and highway safety. In May of 2018, AAMVA released its first guidance for testing and deployment of AVs, with recommendations for manufacturers, state transportation and motor vehicle agencies, and other stakeholders.

4. **How Autonomous Vehicles with Drive our Budgets**
   Conservation law Foundation (CLF)

   In July 2018, CLF released this report to help the Commonwealth realize the potential benefits of this new technology, while minimizing its potential downsides and costs. CLF analyzed the economic and fiscal impacts of self-driving cars on the Commonwealth of Massachusetts, and provided policy recommendations. They concluded that self-driving vehicles may have a significant impact on state and local budgets, as well as the economic outlook in the Commonwealth. Self-driving cars may affect the considerable state and local revenues related to motor vehicles, including motor fuels taxes, excise taxes, and parking fees. In addition, the shift to self-driving vehicles may lead to economic impacts, including congestion and air pollution costs, if not properly addressed. To maximize the benefits of the transition to AVs, CLF proposes that Massachusetts enacts policies such as an emphasis on electric and ride-pooling vehicles, and investments in public transit.

5. **Preparing for Automated Vehicles**
   Governors Highway Safety Association (GHSA)

   The report outlines traffic safety issues and discusses how law enforcement and State Highway Safety Offices (SHSOs) should prepare for them. The report offers recommendations to states. The report provides references to research, survey findings, position papers, government documents, news media, and other resources on automated vehicles that have appeared in the last four years. It includes information obtained by GHSA from a survey of State Highway Safety Offices. It does not attempt to be a complete review of the extensive and rapidly-changing information available on automated vehicles.

6. **Impacts of Connected Vehicles and Automated Vehicles on State and Local Transportation Agencies (Project 20-102)**
   National Cooperative Highway Research Program (NCHRP)

   NCHRP is funded by the state Departments of Transportation and managed by the Transportation Research Board, a part of the National Academies of Sciences, Engineering and Medicine. The objectives of NCHRP Project 20-102 are to (1) identify critical issues associated with connected vehicles and automated vehicles that state and local transportation agencies and AASHTO will face, (2) conduct research to address those issues, and (3) conduct related technology transfer and information exchange activities.

Several tasks have already been completed, with several ongoing tasks planned for finalization in Q3 and Q4 of 2018. Some tasks include:

- Advancing Automated and Connected Vehicles: Policy and Planning Actions for State and Local Transportation Agencies (NCHRP Project 20-102[1])
  The 2017 report and accompanying briefing document present potential societal outcomes of these technologies along with 18 policy and planning strategies that agency and legislative decision-makers could apply to align AV and CV technologies with public policy interests more effectively.

- Impacts of Laws and Regulations on CV and AV Technology Introduction in Transit Operations (NCHRP Project 20-102[2])
  The report presents a roadmap of activities by industry, legislatures, federal government, and others to facilitate automated transit deployment and accelerate the societal benefits. These activities address technology, safety, workforce, operating policies, laws and regulations, and implementation.

- Challenges to CV and AV Application in Truck Freight Operations (NCHRP Project 20-102[3])
  The report describes freight environments and challenges for connected and highly automated technologies, identifies public and private sector barriers to implementation, and proposes next steps for addressing the challenges for deployment and adoption.

- Road Markings for Machine Vision (NCHRP Project 20-102[6])
  This project task report will provide information on the performance characteristics of longitudinal pavement markings (e.g., center lines, lane lines, edge lines) that affect the ability of machine vision systems to recognize them. This information will be used by the AASHTO/SAE Working Group as they develop guidelines and criteria. The results of this study (report not yet published) suggest that the contrast ratio of the longitudinal pavement markings relative to the pavement should be around three, meaning that a marking luminance factor or coefficient of retro-reflected luminance should be three times higher on the pavement marking than on the adjacent pavement surface. The full report is expected in Q3 2018.

- Implications of Automation for Motor Vehicle Codes (NCHRP Project 20-102[7])
  This project task provides state DOTs and motor vehicle departments with guidance to assist with the legal changes that will result from the roll out of connected and automated vehicles. The project was coordinated with AAMVA.

- Dedicating Lanes for Priority or Exclusive Use by CVs and AVs (NCHRP Project 20-102[8])
  The task identified conditions amenable to dedicated CV/AV lanes and obstacles to implementing them. The project also evaluated how to measure benefits and possible consequences, and documented specific laws and regulations that might impact dedicating lanes to specific user categories.

- Providing Support to the Introduction of CV/AV Impacts into Regional Transportation Planning and Modeling Tools (NCHRP Project 20-102[9])
  The purpose of this task is to provide a conceptual framework and applicable guidelines to support state DOTs and regional MPOs as they begin to incorporate CVs and AVs into their planning, modeling, and forecasting tools. The final report is expected in Q4 2018.

- Cybersecurity of Traffic Management Systems (NCHRP 03-127 and NCHRP 20-102[10])
  The objective of the research is to develop guidance for state and local transportation agencies on mitigating the risks from cyber-attacks on the field side of traffic management systems (including traffic signal systems, intelligent transportation systems, vehicle-to-infrastructure systems (V2I), and closed-circuit television systems) and, secondarily, on informing the agency's response to an attack. The report should be completed in the fall of 2019.

- Impacts of Connected and Automated Vehicle Technologies on the Highway Infrastructure (NCHRP 20-102[15])
  The objective of this research is to produce guidance for state and local transportation agencies in evaluating and, if necessary, adapting standards and practices for roadway and intelligent transportation system designs (including traffic control devices) and related maintenance and operations to reflect the deployment of connected and automated vehicle technologies. The guidance will consider trends and timelines in the development and deployment of various connected and automated driving technologies (primarily SAE Levels 2 and 3, with some consideration of Level 4), including sensor systems and the increasing role of digital infrastructure and connectivity (e.g., dynamic high-definition

maps, real-time data and information, and geo-referencing). The estimated completion date is February 2020.

- Preparing Traffic Incident Management (TIM) Responders for CVs and AVs (NCHRP 20-102[16])
  The objective of this project is to investigate how traffic incidents might change in a more connected transportation system and what the needs of traffic incident responders would be. A secondary objective is to describe how traffic incident responders should be included in the CV/AV research agenda moving forward. This task has not yet started as of August 2018.

- Minimum Safety Data Needed for Automated Vehicle Operations and Crash Analysis (NCHRP 20-102[18])
  This project aims to identify and define the minimum set of safety data associated with AVs that should be available to conduct crash and safety analyses. This data should include on-road and validation and testing data for crashes and near-crashes and include relevant information on the conditions associated with the incident. It is expected that a key part of the research will be convening safety and AV specialists and data scientists to explore, among other issues, uses of the data, relevant data collected by AVs, privacy restrictions, reliance on other data sources, data sharing arrangements, and liability. This task has not yet started as of August 2018.

- Update AASHTO's Connected Vehicle/Automated Vehicle Research Roadmap (NCHRP 20-102[19])
  The objective of this project is to update and maintain the research roadmap to reflect the current landscape. The research team will be expected to bring knowledge gained from many sources to the roadmap, including the literature, relevant AASHTO events, and relevant research underway or planned by other research institutions, the annual Automated Vehicle Symposium sponsored by TRB and AUVSI, and the newly formed TRB Forum on Preparing for Automated Vehicles and Shared Mobility. The estimated completion date is March 2020.

7. **Connected Vehicle Pooled Fund Study**
   Virginia DOT, Federal Highway Administration

   The Connected Vehicle Pooled Fund Study (CV PFS) was created by a group of state, local, and international transportation agencies and the Federal Highway

Administration in order to provide a means to conduct the work necessary for infrastructure providers to play a leading role in advancing the Connected Vehicle systems. There are 19 state departments of transportation as of August 2018.

The CV PFS research efforts facilitate pilot demonstrations and deployments of connected vehicle infrastructure applications, working with OEMS on documenting best practices and guidance for CV deployments. The CV PFS was initiated as a phased program beginning 2009, with research, field testing, and continued development of pilot initiatives and related research.

The CV PFS is currently sponsoring three projects:

a. Connected Traffic Control System (CTCS): Research Planning and Concept Development
    - Review existing studies and developments, engage stakeholders to identify need, map potential benefits of CTCS
    - Engage with stakeholders to avoid duplication when possible and enhance research outcomes
    - Develop the CTCS research plan and Concept of Operations that comprehends the entire roadway system
b. Multi-Modal Intelligent Traffic Signal System – Phase III: Deployment Readiness Enhancements
    - The readiness enhancements are focused on created enhanced and “cleaned up” code that is transferable regardless of hardware vendors
    - Improve the MMITSS software manuals, including the requirements on platforms, download/build instructions, and the API
    - Make the source code hardware agnostic (can be run on any hardware)
    - Carry out additional testing for fine tuning
c. Basic Infrastructure Message Development and Standards Support
    - Goal is to develop a Basic Infrastructure Message (BIM) and a means to collaborate with relevant standards development organizations
    - Better understand and define what message infrastructure will send to vehicles
    - Will help public transportation agencies know what kind of information to broadcast for Road Side Equipment

8. **Analysis, Modeling, and Simulation (AMS) Tools for Connected and Automated Vehicle (C/AV) Applications (FHWA-HRT 18-026)**

    FHWA initiated an effort to develop AMS tools for C/AV applications and to conduct realistic case studies with these tools to help inform implementation and estimation of benefits. Current traffic analysis and planning tools are not well suited for evaluating C/AV applications because of their inability to incorporate vehicle connectivity and automated features. It is necessary to adapt and re-engineer the existing set of tools available to agencies, validate these models and tools, and provide a mechanism to share these models and tools with public agencies.

9. **Analysis of Low-Speed Automated Vehicle (LSAV): Pilots and Deployments (TCRP J-11/Task 27)**

    The objective of this research is to develop guidance for transit agencies and communities on the development and deployment of LSAV pilots. The guidance should provide lessons learned from the initial pilots that are underway and soon to be launched. The research should conduct analyses of possible use cases for LSAVs and develop guidance.

7.7 FEDERAL AV LEGISLATION

There are not currently any federal laws specific to autonomous vehicles. The 115th Congress introduced several bills concerning AV technologies.

In July of 2017, the Self Drive Act (HR3388) was introduced in the House by Representative Robert Latta. The bill passed in the House with overwhelming support in September (39). The bill defines the federal role in ensuring the safety of HAVs by encouraging the testing and deployment of such vehicles. Under the Self Drive Act, the Department of Transportation (DOT) would require safety assessment certifications from manufacturers of an automated driving system. Manufacturers would also be required to develop written cybersecurity and privacy plans for such vehicles prior to offering them for sale. Additionally, the bill would require NHTSA to begin updating vehicle safety standards to consider newly-developing technology. The bill would preempt states from enacting laws regarding the design, construction, or performance of highly automated vehicles or automated driving systems, unless such laws enact standards identical to federal standards, and would also allow for additional FMVSS exemptions for companies seeking to manufacture AVs (39). Finally, the bill would establish an advisory council to provide recommendations to DOT. (40)

The Senate's most prominent effort is the AV Start Act (S1885), sponsored by Senator John Thune and introduced in September 2017. It was referred to the Committee on Commerce, Science, and Transportation and approved by a unanimous voice vote on October of 2017, but is currently stalled (41).

The AV START Act would establish regulations for the development of AV technologies for vehicles with a gross weight of 10,000 pounds or less, including provisions to address cyber security, safety standards, FMVSS exemptions, and consumer education (42). The bill would prohibit state and local governments from regulating the design, construction, or performance standards but otherwise maintains the jurisdiction of the NHTSA. The Act would initiate a process to update the FMVSS to apply to vehicles driven by autonomous technology instead of a human, and also establish an advisory technical committee consisting of 15 members to make recommendations to DOT.

Manufacturers are currently prohibited from rendering inoperable any federally mandated vehicle safety controls (e.g., steering wheel and pedals). The AV START Act would provide for the possibility of exemptions from these requirements. US DOT would also be permitted to increase the number of vehicles per manufacturer which are exempt from FMVSS from 2,500 today to 50,000 in the first year, and then 100,000 by the fifth year. Manufacturers would be required to submit a public safety evaluation report (SER) no later than 90 days before the manufacturer introduces an AV system or component into commerce. The SER would be updated each year and include assessment, testing, and validation processes for nine subject areas including system safety, data recording, cybersecurity, human-machine interface, crashworthiness, post-crash behavior, and more. While the reports would be required, the manufacture and sale of AVs would not be conditional on the content of the reports.

The Act includes several consumer education initiatives, including research of educational strategies, cybersecurity, and traffic safety effects of mixed fleets. The bill would also require US DOT to establish a Technical Committee comprised of industry experts to make recommendations to US DOT related to rulemaking, policy, guidance, performance, and safety of AVs.

The AV Start Act is stalled in the Senate due to 3 main concerns: the preemption language, data sharing, and safety issues.

The bill would preempt state and local laws that affect the “design, construction or performance” of an automated vehicle. As “performance” is not defined in the bill or federal legislation, it is unclear which state or local laws may be considered to affect the “performance” of the vehicle and therefore subject to this preemption. This framework could preempt any current or future law or regulation related to any of the nine subject areas in the SER.

Many stakeholders have expressed a need for increased data sharing between manufacturers and states. The Act could limit the amount and range of data types that states and cities could require of autonomous vehicles. The proposed HAV Data Access Advisory Committee would also only address ownership and access issues, and not the type (collisions, near-misses, disengagements, etc), amount, or frequency of data to be collected and shared.

Public interest groups and states have expressed concerned about exposing motorists and pedestrians to unreasonable risks by limiting safety regulations and testing oversight (43). Some stakeholders have suggested that level 2 autonomous vehicles should adhere to all of the same safety regulations as level 3-5 systems (44).

7.8 Federal AV Guidance – Detailed Review

7.8.1 Voluntary Guidance (For ADS Developers)

The Voluntary Guidance takes the form of a "Safety Self-Assessment" which includes 12 "Safety Elements", as compared with 15 in the prior Safety Assessment Letter (see below sections). The Voluntary Guidance applies to the design aspects of motor vehicles and equipment under NHTSA's jurisdiction, including low-speed and heavy-duty vehicles.

The purpose of the Voluntary Guidance is to help ADS developers and manufacturers analyze, identify, and resolve safety considerations prior to deployment. It outlines 12 safety elements that are generally considered to be the most significant design aspects to consider and address when developing, testing, and deploying ADSs on public roadways. Within each of the 12 safety design elements, entities are encouraged to consider and document their use of industry standards, best practices, company policies, or other methods they have employed to provide for increased system safety in real-world conditions. The 12 safety design elements apply to both ADS original equipment and to replacement equipment or updates (including software updates/upgrades) to ADSs.

Entities engaged in ADS testing and deployment may demonstrate how they address the safety elements contained in the Voluntary Guidance by publishing a Voluntary Safety Self-Assessment. Entities are not required to submit a Voluntary Safety Self-Assessment, nor is there any mechanism to compel entities to do so. While these assessments are encouraged prior to testing and deployment, NHTSA does not require that entities provide submissions nor are they required to delay testing or deployment. Assessments are not subject to Federal approval.

ADS 2.0 Voluntary Safety Self-Assessment

- System Safety
- Operational Design Domain
- Object/Event Detection and Response
- Fallback (Minimal Risk Condition)
- Validation Methods
- Human Machine Interface
- Vehicle Cybersecurity
- Crashworthiness
- Post-Crash ADS Behavior
- Data Recording
- Consumer Education and Training
- Federal, State, and Local Laws

Original Policy – Safety Assessment Letter

- *System Safety*
- *Operational Design Domain*
- *Object/Event Detection and Response*
- *Fall Back (Minimal Risk Condition)*
- *Validation Methods*
- *Human Machine Interface*
- *Vehicle Cybersecurity*
- *Crashworthiness*
- *Post-Crash Behavior*
- *Data Recording and Sharing*
- *Consumer Education and Training*
- *Federal, State and Local Laws*
- ~~*Privacy*~~
- ~~*Registration and Certification*~~
- ~~*Ethical Consideration*~~

7.8.2 Technical Assistance to States

The updated ADS 2.0 document includes a section on "Technical Assistance to States" which provides useful guidance for testing and deployment at the state level.

NHTSA again urges states to not codify the Voluntary Safety Self-Assessment into law or regulation as a legal requirement for any phases of development, testing, or deployment in order to leave safety design and performance aspects of ADS within the purview of USDOT/NHTSA.

It reiterates that **NHTSA's responsibilities include**: setting FMVSS for new vehicles and equipment, enforcing compliance with FMVSS, investigating and managing recalls of noncompliance and defects, and communicating with and educating the public about motor vehicle safety.

The **states' responsibilities include:** licensing of *human* drivers, registering vehicles, enacting and enforcing traffic laws and regulations, conducting safety inspections, and regulating motor vehicle insurance and liability.

7.8.2.1 Best Practices for Legislatures

The Guidance suggest best practices for state Legislatures which include: providing a tech-neutral environment, providing licensing and registration procedures for vehicles with ADS, providing reporting and communications methods for public safety officials, and reviewing traffic laws and regulations which may impede ADS operation.

7.8.2.2 Best Practices for State Highway Safety Officials

The policy framework provides **administrative** recommendations to states, including to:

- Establish a lead state agency
- Create an inter-agency committee and communication plan
- Use or establish statutory authority to implement a framework for policies and regulations
- Examine existing laws and regulations to remove operational barriers
- Consider an application to test in the state
- Consider issuing ADS test vehicle permits

Within an **application to test on public roadways**, the policy recommends:

- The application for testing should remain at the state level
- States could have an ADS testing application process, and should consider applications in which multiple entities are involved in the testing
- States could request information such as physical and mailing addresses, VIN numbers of vehicles, and test operator ID information
- Including the Safety Self-Assessment could provide additional assurance to the state
- Proof of insurance, a surety bond, or proof of self-insurance
- Inclusion of a summary of training provided to operators

With respect to **granting permission to test on public roadways:**

- It is recommended that permission to test remain at the state level; however, state and local governments should coordinate. If a state chooses to request applications at a local level, these considerations would carry to those jurisdictions.
- The lead state agency should involve law enforcement in responding to applications to test
- Testing permissions should be suspended for failure to comply with insurance or driver requirements
- It would be appropriate to request additional information or require an entity to modify its application before granting approval
- State should provide a notice of permission to test, and may require that permission be carried in the vehicles

Some of the **additional considerations** presented in the policy include:

- For vehicles at SAE levels 3 and lower, a licensed driver has responsibility to operate the vehicle, monitor the operation, or be immediately available to perform the driving task when requested or the lower level automated system disengages
- Fully automated vehicles are driven entirely by the vehicle itself and require no licensed human driver
- Consider identifying ADS on titles and registrations
- Consider requiring notification of ADS upgrades if the vehicle has been significantly upgraded post-sale. Applicable state forms could be adjusted to reflect the upgrade
- States could consider training public safety officials in conjunction with ADS deployments in to improve understanding of ADS operation and potential interactions

- Coordination among states would be beneficial for developing policies on human operator behaviors, as to monitor behavior changes—if any—in the presence of ADSs when the vehicle is in control
- Initial considerations for state relegation of liability during an incident and insurance of the driver, entity, and/or ADS. How to allocate liability among ADS owners, operators, passengers, manufacturers, and other entities when a crash occurs
- For insurance purposes, who (owner, operator, passenger, manufacturer, other entity, etc.) must carry motor vehicle insurance
- Consider rules and laws allocating tort liability

7.9 FEDERAL MOTOR VEHICLE SAFETY STANDARDS (FMVSS)

In order to sell a motor vehicle in the U.S. market, a vehicle manufacturer must certify that the vehicle meets performance requirements specified in the Federal Motor Vehicle Safety Standards, or FMVSS. The FMVSS are codified in 49 C.F.R. 571, and encompass 73 separate standards that address crash avoidance, crashworthiness, and post-crash survivability. The FMVSS includes safety standards which apply specifically to different vehicle types, including low-speed vehicles, passenger cars, vans and sport-utility vehicles, trucks, trailers, and buses.

The FMVSS were first established through the National Traffic and Motor Vehicle Safety Act of 1966. The standards were developed with the general assumption that vehicles would be driven by a human operator. Automated vehicle technologies present a need to consider how to revise the FMVSS to contemplate vehicles which may be partially or fully capable of managing the dynamic driving tasks.

Considering that automated vehicles of some form are likely to be production-ready in the near future, USDOT Volpe Center, in support of the Intelligent Transportation Systems (ITS) Joint Program Office's (JPO) Automated Vehicle Program and in coordination with NHTSA, recently completed a review of the FMVSS to understand how the existing standards might create certification challenges for manufacturers producing highly automated vehicle technologies. (45) The review highlighted situations in which automated technology characteristics could conflict with or introduce ambiguity into the interpretation of existing standards.

USDOT Volpe conducted two reviews of the FMVSS, for drivers and for automated vehicle technologies. The driver reference review identified standards which include explicit or implicit reference to a human driver. The driver reference scan identified several standards for drivers (defined in §571.3 as "…the occupant of the motor vehicle seated immediately behind the steering control system"), a driver's seating position, or controls and displays that must be visible to or operable by a driver, or actuated by a driver's hands or feet. The scan for automated vehicle concepts identified standards which could pose an issue for a range of automated vehicle capabilities and concepts. In order to conduct this scan, Volpe developed 13 different automated vehicle concepts, ranging from lower levels of automation (and near-term applications) to highly automated or completely driverless concepts with innovative vehicle designs.

The review revealed a limited number of barriers for lower level automated vehicles to comply with FMVSS, provided the vehicle does not significantly diverge from conventional vehicle designs. Two standards – theft protection and rollaway prevention (§571.114), and light vehicle brake systems (§571.135) – were identified as having potential conflicts for automated vehicles with conventional designs.

Automated vehicles that begin diverge from conventional design (for example, those with alternative interior layouts and/or lack of manual controls) are constrained by the current FMVSS. Many of the current standards are based on conventional vehicle designs and the presence of a human operator, and thus pose challenges for some fully automated concepts wherein the human occupants have no way of driving the vehicle (i.e. §571.101, controls and displays, §571.111, rear visibility, §571.208, occupant crash protection).

7.10 FEDERALLY DESIGNATED PROVING GROUNDS

In January 2017, USDOT designated 10 'proving ground pilot sites' to encourage testing and information sharing around automated vehicle technologies. "The designated proving grounds will collectively form a Community of Practice around safe testing and deployment. The group will openly share best practices for the safe conduct of testing and operations as they are developed, enabling the participants and the general public to learn at a faster rate and accelerating the pace of safe deployment" stated prior USDOT Secretary Anthony Foxx. The proving grounds sites are:

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

Many large and well-established companies and AV developers have private closed-course facilities. A recent article by The Atlantic highlights the closed-course test facility that Waymo developed in California to supplement virtual testing activities (46). The University of Michigan established M-City in 2014, a 32-acre facility of a simulated city center and four-lane highway.

A few MA-based autonomous and connected vehicle companies have stated that they could use a testing facility available for use – particularly for anchor research institutions such as universities, who are likely to conduct research for many years to come.

Both highway-style roadways and urban core environments are needed for testing a full range of autonomous vehicle systems on closed courses, and such facilities provide overlapping opportunities for public safety training (fire, police, etc).

A physical testing facility can provide tremendous opportunity for AV manufacturers and component developers, but companies must spend significant time and resources in virtual testing and simulation. Huei Peng, Director of Mcity, the University of Michigan's autonomous- and connected vehicle lab, noted that any system that works for self-driving cars will be “a combination of more than 99 percent simulation plus some carefully designed structured testing plus some on-road testing.”

Closed-course and public roads test facilities does fulfill a critical need for autonomous and connected vehicle developers. Both indoor and outdoor closed-course facilities are used to validate software and hardware developments, to calibrate systems, and to conduct a bevy of tests on systems and operators. Along with a variety of road types that are closed to the public, such facilities generally also provide some garage or workshop space. Testing can include activities such as the calibration of sensors, for which the infrastructure requirements are specific and sensitive – calibration targets must be placed in precise locations, and developers must be able to run repeatable tests over months and years to duplicate the conditions of both the vehicles and calibration targets. Public roads testing is necessary for developers to gather extensive amounts of data and test systems performance within real-world conditions.

7.11 REVIEW OF AV WORKING GROUP MEETINGS

The Autonomous Vehicles Working Group convened 11 meetings between October 2016 and END DATE, with around 50 to 75 attendees on average, including companies and representatives, academic institutions, regional planning organizations, and news organizations.

In the Working Group's first meeting on December 15, 2016, MassDOT provided a general overview of autonomous vehicle technologies, federal AV guidance, and the varied approaches which other states have developed to regulate AV testing and deployment. MassDOT provided an overview of the AV industry and testing process in Massachusetts, where efforts began in conjunction with the City of Boston and incorporated considerations of NHTSA's original Federal AV Policy guidance. MassDOT shared the Application and MOU, along with news of the first applicant to the process.

In its second meeting in February 2017, the AV Working Group discussed the Group's goals and activities pursuant to EO 572. The Group received a presentation by WSP USA on Scenarios and Approaches to AVs, and an update from the City of Boston and nuTonomy on testing activities. The meeting concluded with a discussion about upcoming dates, topics, and deliverables for the Group.

For the third meeting on March 30th, the Working Group discussed existing laws and regulations that may be relevant in the testing and deployment of autonomous vehicles. MassDOT staff reviewed sections of the Massachusetts General Laws and the Code of Massachusetts Regulations for consideration in future legislative or regulatory updates. In this meeting, MassDOT provided a draft regulation for consideration which addressed enforcement of the AV testing program requirements. Finally, staff also provided an overview of California's draft regulations for AV testing and deployment.

In May 2017, nuTonomy provided a regular update on their testing activities. The Working Group reviewed draft Testing Guidance developed by MassDOT which summarized the MOU and Application process and contents. The Group was also provided an introductory presentation to cybersecurity considerations for autonomous vehicles and policy and regulatory implications.

The July 13th meeting was convened at the Massachusetts State House to hear from State legislators about bills filed pertaining to autonomous vehicles. Senator Jason Lewis (S1945), Representative Tricia Farley-Bouvier (H1829), Representative Michael Day (H3417), Representative Peter Durant (H1822), Representative Aaron Michlewitz (H2742), and Representative Ann-Margaret Ferrante (H3422) either spoke at the event or provided written comments on the respective legislation they had filed.

On September 19th, the AV Working Group heard from nearly 20 stakeholders in an open forum event. Stakeholders ranged from AV companies and component suppliers to academic research institutions and transportation advocacy organizations. The Group received a wealth of feedback and testimony through this condensed forum.

In November 2017, the Group was provided an update on testing activities, and discussed insurance and liability considerations in depth with representatives of the Massachusetts Insurance Federation and the National Association of Mutual Insurance Companies. The meeting concluded with a discussion of lessons learned, additional considerations and areas of interest, and next steps towards developing a report and guidance.

After a planned March meeting was postponed due to weather, the Group met again for the eighth time on May 3rd, 2018 to discuss the draft report of the AV Working Group, including considerations for areas of policy and operation to continue monitoring and discussing. In addition, the Group received an update from MassDOT and Metropolitan Area Planning Council (MAPC) staff about efforts to establish a regional testing framework to streamline the application process across multiple municipalities. The meeting also included a brief update of two active research projects; one by the University of Massachusetts Transportation Center to develop strategic plan considerations for the Commonwealth's connected and autonomous vehicle efforts, and a second effort through the New England Transportation Consortium about inter-state AV testing opportunities and challenges.

The ninth meeting of the Working Group was held on June 27th and included updates on current AV testing and the development of the regional AV testing process in collaboration with MAPC. The City of Boston & Harvard Kennedy School provided a review of a "Policy Scrum" event which aimed to develop recommendations for the deployment of AVs. The Chairs of the Autonomous and Connected Vehicles sub-group of the Governor's Commission on the Future of Transportation shared an update on the Commission's listening sessions and activities, and discussed continued engagement and collaboration between the two efforts. The meeting concluded with a review and discussion on the draft report, followed by public comment.

[Add additional meeting narratives – Sept 12, Oct…]

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