Today’s Agenda

1. Introductions
2. Overview of Executive Order
3. Mission and Goals of the Working Group - Discussion
   a. To convene experts
   b. To encourage the development of the automation industry
   c. To consider new regulations and/or legislation, as appropriate
   d. To advise MassDOT on the development of Guidance
   e. Others?
4. Overview of Automation Industry, Technologies, and Regulations - Presentation
5. Overview of Current AV Testing Process in Massachusetts - Presentation
6. Roundtable Discussion
   a. Issues of concern to Working Group members and member organizations
   b. Recommendations of experts to invite to speak to the Working Group
7. Next Steps
   a. Development of Guidance’
   b. Meetings with experts
Introductions
Overview of Executive Order No. 572
Executive Order No. 572

Signed on October 20, 2016 by Governor Baker

1. Created the AV Working Group

2. Established a process to develop Guidance for testing highly automated vehicles and their safe deployment in the Commonwealth
   a. MassDOT, with input from the Working Group and technical experts, will develop a process for companies to obtain approval to test highly automated vehicles (Currently Underway)
   b. Develop an application process for companies (Currently Underway)
Goals of the AV Working Group

1. Convene and consult with experts on motor vehicle safety and vehicle automation

2. Encourage the development of autonomous vehicles and their component parts in Massachusetts

3. Work with the Legislature and executive agencies to consider proposing changes to statutes or regulations that:
   a. Facilitate the widespread deployment of highly automated vehicles in Massachusetts while ensuring the safety of the public
   b. Ensure that vehicles which have completed testing and are in operation are operated safely and in ways that advance the welfare of the residents of the Commonwealth

4. Provide input on Guidance developed by MassDOT to allow for the safe testing of such technologies on designated state highways and on other public roadways in municipalities that desire to permit such testing

5. Follow developments in technology of automated vehicles, federal policy and the laws and policies of other states
Overview of Automation Technologies and Regulations
The automobile was the 20th century’s disruptive technology

Peak Horse – U.S. equine population 1850-2000

Equines (mn)

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<th>Year</th>
<th>1850</th>
<th>1870</th>
<th>1900</th>
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Source: USDA, Kentucky Equine Research

Equines vs vehicles per capita – 1900 - 2000

Per 1000 capita

Source: USDA, Kentucky Equine Research, US DOT
The next disruptive technology could be self-driving or autonomous cars

“One thing is clear. The next five to 10 years are going to be the most disruptive we’ve ever seen in the history of personal transportation.”

Karl Brauer
Senior Analyst, Kelley Blue Book

“We will see more change in the industry in the next five to 10 years than we have in the last 50.”

Mary T. Barra, Chairman and CEO, General Motors Company
How soon could AVs happen?

There are many theories about how quickly AVs could be adopted. Industry is generally more bullish than researchers.

Source: *Driving Towards Driverless*, Lauren Isaac, WSP
Is a future of self-driving cars good, bad or both?

<table>
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<th>Impact</th>
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<th>Driverless Utopia</th>
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<td>Low-Income Mobility</td>
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<td>↑</td>
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</tbody>
</table>

Source: *Driving Towards Driverless*, Lauren Isaac, WSP
Early adopters: Autonomous trucks

In Testing (Not Deployed)
Early adopters: Autonomous Shuttles and Taxis

Most In Testing (Some Deployed)
A Special Case: Tesla

- According to Tesla, starting October 2016, all Tesla cars are built with hardware to allow full self-driving capability at the highest safety level (SAE Level 5).
- The hardware includes eight surround cameras and twelve ultrasonic sensors, in addition to the forward-facing radar with enhanced processing capabilities.
- Tesla’s business model is to sell directly to consumers and update software remotely.
- Tesla owners have been involved in several accidents, including at least 3 fatalities, while operating the vehicle in “auto-pilot” mode.
### SAE Levels of Automation

<table>
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<th>SAE level</th>
<th>Name</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
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<td>3</td>
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<td>System</td>
<td>System</td>
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<tr>
<td>4</td>
<td>High Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
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<tr>
<td>5</td>
<td>Full Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
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</table>

**Human driver monitors the driving environment**

**Levels 1-2**
- Adaptive Cruise Control, Traffic Jam Assist
- Included in existing vehicles for sale

**Levels 3-5**
- Highly Automated Vehicles (HAVs)
- Systems monitor the driving environment instead of the driver
- Level 3 requires human fallback of driving tasks – risk in deployment
Vehicles and Technologies

- **Advanced Driver Assistance Systems (ADAS)**
  - Systems which automate, adapt, and/or enhance vehicle systems for safety purposes. ADAS use cameras, radars, LiDAR, direct short range communications, and more.

- **Automated Vehicles**
  - Vehicles which employ one or more Advanced Driver Assistance Systems and operate at an SAE level between 1-5. A level 1 vehicle can sometimes assist the human driver to conduct some parts of the driving task.

- **Highly Automated Vehicles (HAVs)**
  - A vehicle using SAE Level 3 and higher, where the system monitors the driving environment on behalf of the driver, in addition to conducting the dynamic driving tasks.

- **Autonomous Vehicles**
  - Vehicles which are capable of both monitoring the driving environment and executing the dynamic driving tasks, operating at an SAE level between 3-5. A level 3 vehicle requires human fallback of dynamic driving tasks.

- **Connected Vehicles**
  - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications through direct short range communications (DSCR), a two-way short- to- medium-range wireless communications to enable a multitude of new crash-avoidance applications.
Radar
Used for adaptive cruise control. Reflected microwaves can identify location and speed — but not always type — of nearby vehicles.

Ultrasound
Used for assisted parking. Reflected sound waves detect distance to nearby objects. Some cars use short-range radar instead.

LIDAR
Google’s autonomous vehicle project uses a spinning range-finding unit, called lidar, on top of the car. It has 64 lasers and receivers.

The device creates a detailed map of the car’s surroundings as it moves. Software adds information from other sensors and compares the map with existing maps, alerting the system to any differences.

Cameras
Used for lane-keeping and back-up assistance. Image-processing software can detect lane stripes, signs, stop lights, road signs and other objects.

Navigation Aids
Global positioning system unit determines car’s position. Accelerometers and wheel sensors help with navigation when satellite signals are blocked.

Source: New York Times
How do autonomous cars work?

From “How do self-driving cars work?” by Shima Rayej on robohub.org
How do autonomous cars work?

An example of a Google car’s internal map at an intersection.

Google’s Self-Driving Car gathers almost 1 GB of data per second.

From “How do self-driving cars work?” by Shima Rayej on robohub.org
Automated Vehicles Legislation

States with Enacted Autonomous Vehicle Legislation

LEGEND
Enacted
Executive Order

massDOT
Massachusetts Department of Transportation
Federal Guidance

• The National Highway Traffic Safety Administration of the US Department of Transportation published its initial Federal Autonomous Vehicles Policy in September 2016

• The Policy covers the following topics:
  • Levels of Automation
  • Federal vs State Roles
  • Vehicle Safety Assessment
  • Model State Policy
  • NHTSA Regulatory Tools

• While helpful, the Policy leaves many questions unanswered which are important to the Commonwealth
Federal Guidance – Model State Policy

Issues for states to consider and address:

• Administration
• Application
• Jurisdictional Approval
• Testing Procedures
• Vehicles as “Drivers”
• Registration and Titling
• Law Enforcement
• Liability and Insurance
• Next Steps
Important Terms

• Testing
  • The operation of an autonomous vehicle on public roads by employees, contractors, or designees of a manufacturer for the purpose of assessing, demonstrating, and validating the autonomous technology’s capabilities.

• Deployment
  • The operation of an automated vehicle by members of the public for traditional personal or commercial uses, not testing.

• Operational Design Domain
  • A description of the specific operating domain(s) in which an automated function or system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/nighttime, etc.), and other domain constraints.
Overview of Current AV Testing Process in Massachusetts
Executive Order: MassDOT Must Develop Guidance for HAVs

- MassDOT, with input from the Working Group and technical experts, will develop a process for companies to obtain approval from MassDOT to test highly automated vehicles on state highways or other public or publicly accessible state roadways in the Commonwealth. (Underway)
- MassDOT will develop an application process for companies. (Underway)
- MassDOT will develop an MOU which may require a description of testing experience, relevant safety assessment information, vehicle and operator information, a description of operator training, insurance coverage, a maximum vehicle speed, limited operation design domain, data sharing, other conditions as necessary to ensure public safety. (Underway)
- MassDOT seeks to learn from the Working Group members on these topics.
Current Process for Approving AV Testing in the Commonwealth

• MassDOT is following the framework set forth in Executive Order No. 572 and NHTSA’s “Federal Automated Vehicles Guidelines”
• MassDOT is developing a process to facilitate AVs testing on public ways
• Current regulatory framework requires:
  • **Memorandum of Understanding (MOU)** between the company requesting to conduct testing, any municipality or entity whose public roads will be used, and MassDOT
  • **Application** to test highly automated vehicles to be approved by MassDOT

• MassDOT requests the Working Group’s input on this evolving process
Memorandum of Understanding Template

The MOU sets the terms for the company, municipality, and State:

- Operating only for testing
- Application approval by MassDOT required prior to testing
- Driver in seat with human takeover capability, 21 year minimum age and clean record
- Must carry approval letter in test vehicles
- Vehicle complies with federal regulations and has MA inspection
- Conduct a safety check prior to every test
- 24-hour crash reporting
- Video and data sharing
- Signage around test sites
- Police detail if/when needed
- Testing goals of at least X miles and/or X hours
- Marked escort vehicles if/when used
- Limits to the locations and testing dates
Application

The Application details a company’s qualifications for testing, including:

• Applicant Info (Address, Organization Type, Certification)
• Supplemental Information
  • Experience with AVs
  • Safety Assessment Documentation
  • Initial Driving Plan
  • Vehicles in Testing
  • Drivers in Testing
  • Summary of Training
  • Proof of Insurance
nuTonomy

- Developer of state-of-the-art software for self-driving vehicles
- Founded by Dr. Karl Iagnemma and Dr. Emilio Frazzoli of MIT
- One of four agencies which are permitted by the Land Transport Authority (LTA) to conduct trials of driverless vehicles
- Signed a Memorandum of Understanding (MOU) with the City of Boston and the MassDOT
- Have submitted an Application to Test with MassDOT
Testing Site – Devens

- Public and private roads
- 4,400 acres mixed-use
- 79 years as the U.S. Army’s New England headquarters
- Closed in 1996
- MassDevelopment purchased and is implementing a comprehensive re-use plan designed by citizens and public officials.
- Currently supports closed-track testing
Potential Testing Site – Union Point

- Public and private roads
- 1,453 acres mixed-use
- Developing 4,000 residential units, recreation complex, retail center and 8 mill. sq. ft. of commercial space
- 1st significant commercial tenant is an electronics and robotics design and manufacturing firm
- Facilities include:
  - A secured area for testing with back movie sets – one urban and one suburban
  - Six miles of existing roads open to the public and
  - Four miles of roadways that we will construct next year.
- Interested in connected and automated vehicles testing and deployment, in addition to development and manufacturing
Roundtable Discussion
Discussion

• Issues of concern to Working Group members and member organizations

• Recommendations of experts to invite to speak to the Working Group
Next Steps

• Development of Guidance
• Scheduling Next Meeting
• Collecting Resources and Information
Appendix
Advanced Driver Assistance Systems

• **Lidar**
  • A surveying method that measures distance to a target by illuminating that target with a laser light. Lidar uses ultraviolet, visible, or near infrared light to image objects. Lidar has limited use in inclement weather, though research and development initiatives are in progress to address this.

• **Ultrasound**
  • Used mainly for assistive parking. Reflected sound waves detect the distance to a nearby object. Some vehicles use short-range radar to accomplish the same tasks as ultrasound. Ultrasound will work in rain or some inclement weather.

• **Cameras**
  • Cameras are used primarily for lane-keeping and back-up assist technologies. Image-processing can allow cameras to see lane stripes, signs, stop lights, and other objects and events. Cameras can have limited use in nighttime and inclement weather.

• **Short/Medium and Long Range Radar**
  • Long range radar is used for adaptive cruise control. Short/Medium Range Radar is used for cross-traffic and blind spot monitoring. Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects and can work through precipitation and some inclement weather.
Connected Vehicles: Direct Short Range Communications

- Two-way short- to- medium-range wireless communications capability that allows very high data transmission.
- Supports both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.
- DSRC works in high vehicle speed mobility conditions and delivers performance immune to extreme weather conditions (e.g., rain, fog, snow).
Connected Automated Vehicle

- Utilizes DSRC radio transmissions in combination with Advanced Driver Assistance Systems (ADAS) such as lidar, radar and/or cameras.

Source: Texas Instruments Advanced Driver Assistance (ADAS) Solutions Guide and Volpe Transportation Research Center
Automated Vehicles (SAE 1-5)

**Partial Automation (SAE 1-2)**
- Execution of Steering and Acceleration: Adaptive Cruise Control, Traffic Jam Assist

**Highly Automated Vehicles or HAVs (SAE 3-5)**
- Monitoring of Environment and Emergency Fallback: Autonomous

**Connected HAVs**

**Connected Vehicles (DSRC)**
- Vehicle to Infrastructure (V2I)
- Vehicle to Vehicle (V2V)
- Vehicle to Device (V2D)

Advanced Driver Assistance Systems (ADAS)
Execution, Monitoring, and Fallback

• **Execution**
  • Action which results in changes to the lateral movement of the vehicle and/or acceleration.

• **Monitoring**
  • Awareness of and ability to respond to the driving environment. Human operator is responsible in SAE levels 1-2, and the System is for SAE levels 3-5.

• **Fallback**
  • Ability to take over the dynamic driving tasks upon disengagement of automated systems.

• **Dynamic Driving**
  • Includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task.
## Automated Vehicles Legislation

A partial list of regulations and legislation promulgated for autonomous vehicles in the United States

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<th>State</th>
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X = Existing Statute or Regulation  
P = Pending Bill or Reg.  
L = Limited  
? = Unclear