What States Need to Do upon Return to their Home Agencies

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Agenda

- State of Autonomous Vehicle Technology
- DOT Roles for a Successful CAV Deployment
Automated Vehicle Technology Evolution

- First RC vehicles used in 1930s
- FHWA’s Automated Highway System in the 1990s, and demo in 1997.
- DARPA Urban Challenge (on-road automated driving) in 2007.
- Demonstration on the streets of Manhattan, NYC at the 2008 World Congress
- U.S. DoD Investment
- Google’s Demos/Efforts
- Aggressive Marketing Campaigns leading to announcements by OEMs of their plans for production.
NHTSA / SAE Driving Levels

- Partially Automated Driving exists today
- Autonomy limited to specific driving environments
- Requires human fallback
- SAE and NHTSA levels different

<table>
<thead>
<tr>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE narrative definition</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>
<th>BAST level</th>
<th>NHTSA level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
<td>Driver only</td>
<td>0</td>
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<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>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</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Assisted</td>
<td>1</td>
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<tr>
<td>2</td>
<td>Partial Automation</td>
<td>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</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Partially automated</td>
<td>2</td>
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<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Highly automated</td>
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<td>4</td>
<td>High Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
<td>Fully automated</td>
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<td>5</td>
<td>Full Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: SAE
Who is Developing Autonomous Vehicle Capabilities
(list may incomplete because information is not openly shared – some proprietary efforts)

- **US OEMs:**
  - GM
  - Ford
  - Tesla

- **European:**
  - Mercedes
  - BMW
  - Audi
  - Volvo
  - Renault
  - Scania (trucks)
  - Jaguar Landrover
  - Deihl
  - RUAG
  - Rheinmetall Defence

- **Japan:**
  - Nissan
  - Honda
  - Toyota
  - Hino
  - Isuzu
  - Yamaha
  - Yanmar

- **Tier 1 Suppliers:**
  - Bosch
  - Continental
  - Delphi
  - Denso

- **Tech Companies:**
  - Google
  - Apple

- **US non-OEMs:**
  - Lockheed Martin
  - Southwest Research Institute (SwRI)
  - Smaller Defense Contractors:
    - TORC, GDRS, ASI, etc.
  - University Research:
    - CMU, Stanford, VTTI, California PATH, UMTRI/MTC, Princeton, and others

- **Government (non DoD)**
  - US:
    - Human Factors for Vehicle Highway Automation
    - USDOT Automation Program
  - European Union:
    - CitiMobil and CyberCars
    - Safe Road Trains for the Environment (SARTE)
    - Energy ITS Project (Japan)
State of the Practice: Commercial (Google)

- **Pros**
  - Well funded
  - Previously only freeway
  - Advancing arterial capability

- **Cons**
  - Expensive sensor suite
  - Must pre-drive route
  - Requires high precision map database
  - For the U.S. – less than 10,000 km of the 6.4M kms of highway “mapped”
Google’s Change in Direction

- In May 2014 Google revealed a prototype of its latest driverless car:
  - No steering wheel
  - 25 mph
  - No breaks – start/stop button

- Platform developed from scratch

- Google says the car's most important feature is its safety.

- Development timeframe:
  - ~100 prototypes
  - Available for purchase by 2020

Other non-auto companies are developing
State of the Practice: Agriculture (John Deere)

- Constrained environment
- GPS effective in environment
- Limited obstacle avoidance

Source: John Deere
State of the Practice: Mining (Komatsu)

- Fixed route – GPS defined
- Obstacle detection
- Very dirty conditions

Source: Komatsu
State of the Practice: Military (Unmanned Support)

- 2000: Goal 1/3 automation in fleet by 2015
- Reduced exposure to unsafe environments
- Lighten soldier's loads
- Automate re-supply.

Source: Lockheed Martin
State of the Practice: Military (Oshkosh)

TerraMax™
State of the Practice: Military (DSAT)
State of the Practice: Military (Weather)

- Material classification
- Snow and ice environments
- “New” environment to the system

Source: RUAG

Same Field With Snow
Short Summary of AV Technology

• State of Technology:
  o Semi-Autonomous: Available today
  o Full Autonomy: Not yet…

• Connected Autonomy: A likely reality

• Short Term: Adopting connected vehicles (V2V and V2X) is preparing for autonomous vehicles
DOT Roles for a Successful AV Deployment
How will mapping data be handled?

- New Road Construction
  - Almost 14,000 miles of new roads built annually in the US
How will mapping data be handled?

“\textit{It is clear that the industry needs a new kind of intelligent sensor – a "live map" that provides the vehicle with an awareness of the road environment beyond the reach of its other on-board sensors.}” – HERE

Rumor: Google’s reason for advancing AV technology

Roadway Data:
- Delivered in “real-time”
- Centimeter lane level accuracy
- GPS, photo, and point cloud
- Petabytes of data
How will mapping be handled?

**Challenges**

- Real-time updates to:
  - Changes in roadway infrastructure
  - Road closures
  - Conditions
  - Construction lane changes
- Distributing large data set on a national scale in real-time

**HERE financially backed by Audi, BMW, and Daimler**
How will mapping be handled?

❖ Your Data Will Have Value
  ▪ Traffic data for public: “Nice to have”
  ▪ Roadway map data for AVs: “Must have”
  ▪ New roadways require pre-mapping
  ▪ Capturing and real-time distribution of map data:
    • Complex and expensive
    • Commercial sector moving
  ▪ Conclusion: Commercial sector managed

❖ Actions to Consider:
  ▪ Short-term: Build relationships and partnerships
  ▪ Short-term: Commoditize or find a value proposition
  ▪ Medium-term: Plan to allow mapping providers advanced access to new roadways
Negative Obstacle Avoidance

- Challenging for AV’s to detect
- Low-probability, high-impact problem
- Technical need for a high fidelity observed world model that is dynamically updated in real-time.
How will Traffic Operations Change?

- Systems need to be capable of adapting to dynamic traffic patterns, construction/work zones, accidents, weather, etc.
How will traffic operations change?

- **Proposed HERE real-time environment data:**
  - Construction
  - Traffic congestion
  - Lane closures
  - Accidents
  - Weather-related changes
  - Variable traffic regulations

- **Who is the best source of this kind of data?**
  - You are! (DOTs)
    - Monitor for events
    - Verify events
    - Know when events clear
How will traffic operations change?

- **Autonomy Sensors dual-purposed**
  - Detect accidents
  - Report traffic conditions
  - Find potholes

- **Traffic operations information sources**
  - Current: DOT managed
    - 911, DOT sensor networks
  - Future: Vehicles as probes
    - Auto OEMs, Google (Waze), etc
    - CV Infrastructure (V2X)

- **Actions to Consider (All short-term):**
  - Be ready for more trends like Waze
  - A consortium of many states might get an auto OEM’s attention (hint)
  - Research ways to communicate construction
  - Use analytics to parse big data
What changes need to be made to the roadway infrastructure?

- **Building our way out of congestion: Does this problem go away?**
  - Obtain 3,000, 4,000, or more vehicles/hour/lane?
    - Some say even more and some say no…
  - Can we narrow lanes?
  - Reduced accidents translates to less capacity to handle non-recurring congestion
  - Transition period: mixed autonomy and human driven vehicles
    - Efficiencies will be hard to gain
    - “Technology Lanes” – Next evolution to HOV and express-lanes

- **Actions to Consider:**
  - Medium-term: Planning to facilitate technology lanes
  - Long-term: Planning requires a full understanding of autonomous vehicle throughput / density
    - Research of autonomous vehicle throughput / density needs further funding
What changes need to be made to the roadway infrastructure?

What about roadway signage?

- Expensive
- Delivery mechanism not verifiable
  - Perception in poor conditions (weather)
  - Visually occluded
  - Knocked over

“Connected autonomy” realistic

Actions to Consider:

- Short-term:
  - Dynamic content: Adopt Connected Vehicles travel advisory messages (TAMs)
  - Static content: Likely handled by mapping firms. Will DOT deploy “virtual signs”?  
- Long-term: maybe no physical signs
What changes need to be made to the roadway infrastructure?

Does lane stripping, centerline markers, and other road markings matter?

- Now: Yes!
- Future: Probably not…

Actions:

- Short-term: Road markings are important.
- Long-term: a future of no markings (or barriers?)
What are the security implications?

❖ **Automobile Security**
  - 200+ electronic control units
  - 100M lines of code
  - Multiple suppliers
  - Cars are complex…

❖ **Attack Surfaces of AV/CV Environment**
  - Vehicle
  - Wireless communication
  - DOT infrastructure

❖ **Actions to Consider:**
  - Short-term: Build a culture of cyber-security into your agencies.
    • Treat it like Safety.
  - Short-term: Take steps to secure your ITS infrastructure

June 22, 2016
How do I handle the policy and legal issues?

- Abusing autopilot functions
  - Cannonball Run with a Tesla S
    - October 2015
    - L.A. to NY under 58 hours (including charging)
    - 96% autonomous mode
    - Speeds up to 90 mph
  - A matter of time…

- Actions to Consider:
  - November 7, 2000
  - For the Long-Term: Stay the course
    - begin with the end in mind.
How soon is full automation?

- Perception and behavior: 98% easy – last 2% is hard
How soon is full automation?

- “Deer in the headlights” (need 80 meters visibility)
- “Realistic” (aggressive) driving
  - June 2014 in DC
  - Taxi “strike”
  - How to “nose” into traffic (30 min)
- 50/50 odds my 2 year old could get an autonomous ride home from high school soccer practice
To prepare for a future of autonomy, embrace connected-vehicles

Thank you!

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