Development of California Regulations to Govern the Testing and Operation of Automated Driving Systems (ADS)

June 3, 2015

Christopher Nowakowski

California PATH Program
Institute of Transportation Studies
University of California, Berkeley
Automation blurs the traditional regulatory boundaries
  - NHTSA is responsible for new vehicle equipment & safety
  - States are responsible for vehicle operation (driver licensing)
  - State laws regarding ADS are preceding federal regulations

Need to balance:
  - Public Safety while unproven systems are being tested & deployed
  - Encouraging Technological Innovation promising improved safety
  - Handle the wide range of different ADS concepts being proposed

Lack of technical standards to provide baseline references for performance, safety, testing protocols, or validation/verification methods

Cultural differences between different regulatory agencies, the automotive industry, and the IT industry

Differing models, concepts, and definitions of certification across government agencies, industries, and countries
<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Dynamic Driving Steering/Speed</th>
<th>Roadway Monitoring</th>
<th>Fallback Steering/Speed</th>
<th>System Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Human Driver Monitors the Driving Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>Driver + System</td>
<td>Driver</td>
<td>Driver</td>
<td>Limitations</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>System</td>
<td>Driver</td>
<td>Driver</td>
<td>Limitations</td>
</tr>
<tr>
<td></td>
<td>ADS Monitors the Driving Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>System</td>
<td>System</td>
<td>Driver</td>
<td>Limitations</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Limitations</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Everywhere</td>
</tr>
</tbody>
</table>

http://www.sae.org/misc/pdfs/automated_driving.pdf
## Driving Automation System Examples

<table>
<thead>
<tr>
<th>Level</th>
<th>System Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human Driver Monitors the Driving Environment</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| 1 | **Driver Assistance**  
  • ACC OR Lane Centering | Honda, Audi, Chrysler, Ford, GM, Hyundai, Mercedes, Nissan, Tesla, Toyota, Volvo |
| 2 | **Partial Automation**  
  • ACC AND Lane Centering  
  • Traffic Jam Assist (Low Speed)  
  • Highway Autopilot / Super Cruise | Acura, Audi, Hyundai, Infiniti, Mercedes  
Tesla (2015), Audi (2016?), Cadillac (2017?) |
| **Automated Driving System (ADS) Monitors the Driving Environment** | | |
| 3 | **Conditional Automation**  
  • All Test Vehicles / Pilot Deployments  
  • Other Applications Unclear | Volvo 100-Car Gothenburg Tests (2017?) |
| 4 | **High Automation**  
  • Driving Pilot (w. Limitations)  
  • Driverless Taxi (w. Limitations)  
  • Closed Campus Driverless Shuttle  
  • Driverless Valet Garage Parking | Long-Term Target for Most Manufacturers  
Geographic, weather, road type, etc.  
Google NEV  
CityMobil2 (Low Speed / Segregated Routes)  
Most Manufacturers Have Shown Prototypes |
| 5 | **Full Automation**  
  • Automated Driverless Taxi | Anywhere, Anytime |
SAE Level 2
Driving Automation Systems

- Not currently covered by CA legislation
- Level 2 systems can be severely limited by factors not necessarily apparent to drivers
  - Lane marking quality, curve radius, deceleration rates, objects, etc.
  - Can’t anticipate trouble (e.g., work zones)
- Drivers feel they can look away from the road
  - How long is too long?
  - Can drivers interact with a phone?
- Misuse (Unknowing)
  - Will the public understand that difference between SAE Level 2 vs. Level 4 System?
- Abuse (Intentional)
  - Leaving the driver’s seat
  - Taping a soda can to the steering wheel
Guiding Principles For Public Roads Testing Regulations

• Recognize that testing is iterative, changes are frequent, and faults/failures are to be expected
  – Not a linear progression from test track to public roads to deployment
  – Minimum testing miles not an indication of readiness

• Safety is achieved through the combination of design, testing policies & procedures, and the test driver training
  – Test driver qualifications ➞ Minimum equivalent to CDL
  – Demonstrate test driver training process (concept dependent)
  – Demonstrate safety management process (continual risk assessment)
  – Prohibiting testing locations or vehicle types is counterproductive

• Allow / support different testing stages & goals
  – Engineering / prototype testing
  – Validation testing
  – Naïve driver testing (usability, user experience)
  – Field operational testing (limited deployments)
Should You Require AV Test Vehicles Markings?

- Static: Decal or License Plate
- Dynamic: Light when AV System is Active

Pros & Cons

- Warns other in case test vehicle does something unexpected…
- The test driver is responsible for preventing bad behavior
- Some cars already easily identifiable…others are not
- Other road users may treat AV differently (decreasing validity of testing)
- Marking makes the vehicle a target for fraud or hackers
- CHP – Not needed because test driver is ultimately responsible
How do you evaluate a test permit program’s safety?

- **Crashes**
  - ADSs & ADS testing programs will not be crashless
  - Looking for patterns of bad system *or* test driver behavior
  - Report all crashes (not just AV active or at fault)
  - Need to account for exposure & crash severity

- **EDR Data**
  - Each vehicle will have different sensors & data definitions
  - Focus on defining a MFG. crash report using EDR data
  - Timeline of speed, braking, lead vehicle, test driver intervention
  - Was vehicle and test driver behavior reasonable?

- **Surrogate Safety Metrics (Near Crashes)**
  - Most SSMs based on hard accelerations (braking, lateral)
  - No clear metrics in literature w/o video analysis (false alarms)
  - Many near misses never get captured (can’t record what you didn’t see)
  - Metrics must be related to safety (e.g., AV disengagements may not be)
• Goal: Ensuring Safety Prior to Deployment
  1. Behavioral Competency
  2. Functional Safety
  3. Models Certification

• Additional Deployment Issues Worth Considering
  – ADS Registration
  – External Marking
  – Driver Training & Licensing
  – ADS Driverless Operation Issues

• Other Industry Activities
• **Behavioral Competency** describes how well the automation behaves when dealing with *external hazards* in the driving environment.

• Is **Behavioral Competency** just a *Driving Performance Exam*?
  – DPE looks at benign traffic conditions (sometimes only urban)
    • Basic vehicle control in benign conditions is easy
    • Safety is more related to behavior in abnormal conditions
  – DPE infers potential driving performance potential based on where the driver is looking, sequences of maneuvers, etc.
    • AV sensors always looking everywhere
    • How do you infer what the system does with that data?
  – Multiple AV concepts with different operating scenarios
    • Not all tests will apply to all ADS concepts
    • ADS can add transitions to driver control
1. Define ADS Operating Scenarios (from various mfg. concepts)
   - Freeway Pilot
   - Rural Highway Pilot
   - City Street Pilot

2. Define High-Level Minimum Competencies (Critical Maneuvers)
   - Could be defined by DMV, NHTSA, SAE, ISO, MFG
   - Minimum competency varies by operating scenario & ADS level
   - Minimum competency may simply be driver takeover
   - Generally assuming 3-5 s for driver takeover

3. Define Test Conditions & Pass/Fail for Each Competency
   - Could be defined by DMV, NHTSA, SAE, ISO, MFG, 3rd Party
   - NHTSA NCAP FCW Confirmation Test (34 Pages)

3. Conduct Tests
   - Could be DMV, NHTSA, MFG, 3rd Party
<table>
<thead>
<tr>
<th>Minimum Competencies / Critical Driving Maneuvers</th>
<th>Freeway</th>
<th>Rural Highway</th>
<th>City Streets</th>
<th>Valet Parking</th>
<th>Low-Speed Shuttles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect Operating Envelope &amp; System Malfunctions</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Speed Limit Changes (Including Advisories)</td>
<td>✓+</td>
<td>✓+</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect Passing and No Passing Zones / Perform Passing Maneuver</td>
<td>opt</td>
<td>opt</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Detect &amp; Respond Work Zones, Temporary Lanes, and Safety Officials</td>
<td>✓+</td>
<td>✓+</td>
<td>✓+</td>
<td>*</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Traffic Control Devices</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Access Restrictions (One-Way, No Turn,...)</td>
<td>*</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Perform High Speed Merge (e.g., Freeway)</td>
<td>opt</td>
<td>opt</td>
<td></td>
<td></td>
<td>*</td>
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<tr>
<td>Perform a Lane Change or Lower Speed Merge</td>
<td>*</td>
<td>*</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Park on the Shoulder (e.g., Minimal Risk State)</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Navigate Intersections &amp; Perform Turns</td>
<td>*</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Navigate a Parking Lot &amp; Locate Open Spaces</td>
<td></td>
<td></td>
<td>opt</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Perform Car Following (Including Stop &amp; Go)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Stopped Vehicles</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Intended Lane Changes / Cut-Ins</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>opt</td>
</tr>
<tr>
<td>Detect &amp; Respond to Encroaching Oncoming Vehicles</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Static Obstacles in Roadway</td>
<td>✓+</td>
<td>✓+</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Bikes, Peds, Animals, or Moving Objects</td>
<td>*</td>
<td>✓+</td>
<td>✓+</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect &amp; Respond to Emergency Vehicles</td>
<td>✓+</td>
<td>✓+</td>
<td>✓+</td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>
## Detect & Respond to Work Zones & Temporary Lane Shifts

- Illustrates potentially different requirements by ADS Level
- Illustrates potentially different requirements by ADS Functionality
- Note: defined minimums for SAE Level 3 ADS, but should we allow it?

<table>
<thead>
<tr>
<th>SAE Level &amp; ADS Functionality</th>
<th>Detection</th>
<th>ADS Response</th>
<th>Fallback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3</td>
<td>Req’d</td>
<td>Alert Driver (~5 s)</td>
<td>Driver (by definition)</td>
</tr>
</tbody>
</table>
| Level 4+ w. Driver           | Req’d     | Alert Driver  
  **Optional Functionality:**
  - *Navigate temp. lanes*
  - *Respond to temp. TCDs*
  - *Lane changes if needed*
  - *Respond to safety officials* | ADS Safe Stop |
| Level 4+ w/o Driver          | Req’d     | *Navigate temp. lanes*  
  *Respond to temp. TCDs*  
  *Lane changes if needed*  
  *Respond to safety officials* | ADS Safe Stop?  
  Alert Remote Operator? |
• **Functional Safety** refers to the ability of the automated driving system to accommodate *internal hazards & failures*, which could be electrical, mechanical, or software.
  – Cannot be evaluated through comprehensive testing
  – Achieved during the design and development using methodologies such as those described in ISO 26262

• ISO 26262 currently relies on the driver as a backup
  – Driver intervention not required in Levels 4+ ADS
  – Also not entirely considered are interactions between the ADS and driver: *Errors, Misuse, and Abuse*
  – Efforts to modify ISO 26262 for ADS will take time

• Few avenues to define sensible functional safety regulations, especially in the short term
Ensuring Safety: Certification Models

• **Self-Certification** used in the US for compliance with FMVSS
  – NHTSA spends about $11 M / year on compliance testing
  – NHTSA ➔ Broad investigation, recall, & punitive powers
  – NHTSA can investigate/recall any safety defect
  – Manufacturers still responsible for thorough internal testing

• **Type Approvals** used outside the US for ADAS & in US by EPA
  – Requires testable standards (e.g., ISO)
  – Requires an approval body with approval authority

• **Third-Party Testing** NHTSA NCAP (5-Star Crash Rating) & IIHS
  – NHTSA: $17.4 M / yr in testing and $16.6 M / yr in development
  – More appropriate for behavioral competency than functional safety

• **Third-Party Safety Concept Certification** used by EU manufacturers
  – Safety management process during prototype development & testing

• **Third-Party Functional Safety Certification** gaining popularity in EU
  – Manufacturer correctly following ISO 26262 methodology
Certification Model Questions

- **What is being certified?**
  - Behavioral Competency
  - Functional Safety

- **Who is doing the certification?**
  - MFG. Self-Certification, Approval Agency, Independent 3rd Party

- **What is the depth of the certification?**
  - Benign Driving Conditions DPE
  - Review of MFG. Tests & Data
  - Behavioral Competency Testing (Hazards, Abnormal Conditions)
  - MFG. Functional Safety Process Review (Following ISO 26262)
  - Functional Safety “Hazard Analysis” by Behavioral Competency
  - Embedded 3rd Party Documentation (Aviation/Rail)
  - Full Code Review (Aviation)
AV Registration and External Marking

- Key Registration Issue: Understanding ADS capabilities (resale, CHP)
- External Marking: Currently more cons than benefits
- May need to distinguish L2 from L3+ or driverless operation capability

Driver Training and Licensing

- License endorsements proposed in NV, NJ, others
  - Is the ADS driver training universal or vehicle-specific?
  - What special knowledge (written test) must be demonstrated?
  - What special skills (driving test) must be demonstrated?
  - Not recommended
- How do drivers get trained?
  - Manufacturers / Dealers / In-Vehicle Tutorials
  - Current ADAS owners often unaware of vehicle features
  - New Vehicles vs. Used Vehicles vs. Borrowed/Rented Vehicles
  - PSA Campaigns?
- General license testing should exclude ADS usage
Driverless operation is a feature of SAE Level 4+ ADS
- Valet Parking, Low Speed Shuttles, NEV Taxi, Automated Taxi
- Some may or may not allow manual driving
- Different behavioral competency requirements

Clear marking such as a special license plate?
- CA CHP wanted some way to quickly identify an unmanned or driverless ADS vs. runaway vehicle

Emergency stop (request) for occupants?

Communication to owner/operator for passengers, maintenance, failures, crashes, stuck vehicle, etc.

Owner/operator information exchange post-incident

Restrictions on who can activate or use (children)
What’s Next?

• Industry standards development proceeding slowly
  – ISO revisiting 26262 for ADS
  – SAE ORAV (J3016, J3018, V&V TF), S&HF ADS Task Force
  – NHTSA/NCHRP have funded a variety of research projects
  – European Commission funded project on ADS standards & certifications needs prior to deployment

• Long-term adapting or re-interpreting existing codes
  – Responding to police, crash monitoring, insurance exchange
  – Penalties for bad driving behavior
  – Restrictions on driver/passenger behaviors (DUI, open alcohol, cell phones, texting, distraction, recklessness…)
  – Protection of unattended children

• Harmonizing diversity of state approaches ➔ AAMVA