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

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Overview

- Automated Vehicles Levels (Continuum)
- Fundamental Regulatory Challenges
- Regulatory Issues Considered for Public Roads Testing
- Regulatory Issues Considered for Deployment
- What’s Next?
# SAE J3016 Levels of Automation

<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>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>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>

Human Driver Monitors the Driving Environment

System Monitors the Driving Environment

[http://www.sae.org/misc/pdfs/automated_driving.pdf](http://www.sae.org/misc/pdfs/automated_driving.pdf)
# Driver Takeover!

<table>
<thead>
<tr>
<th>Event</th>
<th>Mean PRT</th>
<th>85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRT to Tail Lights (1978)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distracted BRT to FCW (2000)</td>
<td></td>
<td>1.18 s</td>
</tr>
<tr>
<td>BRT to Vehicle Pull-Out / Objects (2000)</td>
<td>1.28 - 2.3 s</td>
<td>1.3 - 1.9 s</td>
</tr>
<tr>
<td>PRT to Freeway Lane Drop Sign (1990)</td>
<td>3.7 - 6.6 s</td>
<td></td>
</tr>
</tbody>
</table>

- **BMW (2013)** – Distracted Driver, Stopped Car Ahead, Takeover
  - 7 Second Notice → 100% Lane Change
  - 5 Second Notice → 20% Stopped, Then Lane Change
- **Leeds, UK (2014)** – Distracted, Unexpected Takeover
  - Steering took up to 45 s to really stabilize
- **NHTSA L2/L3 Studies (2015)**
- Even with short mean PRTs, populations exhibit long tails
# SAE J3016 Examples

<table>
<thead>
<tr>
<th>Level</th>
<th>System Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Driver Assistance</strong></td>
<td>Acura/Honda, Audi, Cadillac/GM, Chrysler, Ford/Lincoln, Hyundai, Infiniti, Lexus/Toyota, Mercedes, Volvo</td>
</tr>
<tr>
<td></td>
<td>• Adaptive Cruise Control OR Lane Keeping Assistance</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td><strong>Partial Automation</strong></td>
<td>ACC+LC (LKA/LC may not handle all marking/curves)</td>
</tr>
<tr>
<td></td>
<td>• Adaptive Cruise Control AND Lane Centering</td>
<td>Acura, Audi, Hyundai, Infiniti, Mercedes</td>
</tr>
<tr>
<td></td>
<td>• Traffic Jam Assist (Low Speed)</td>
<td>GM’s Super Cruise (High Speed / Freeway)</td>
</tr>
<tr>
<td></td>
<td>• Parking Assist</td>
<td>Cadillac (2017?)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic Jam Assist (Low Speed / Freeway)</td>
</tr>
<tr>
<td>3</td>
<td><strong>Conditional Automation</strong></td>
<td>Google Lexus Test Cars (2010-Current)</td>
</tr>
<tr>
<td></td>
<td>• Test Vehicles</td>
<td>Volvo 100-Car Gothenburg Tests (2017?)</td>
</tr>
<tr>
<td></td>
<td>• Other Applications Unclear</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td><strong>High Automation</strong></td>
<td>Long-Term Target for Most Manufacturers</td>
</tr>
<tr>
<td></td>
<td>• Driving Pilot (w. Limitations)</td>
<td>Google’s Target for 2-Seat NEV Test Vehicle</td>
</tr>
<tr>
<td></td>
<td>• Closed Campus Driverless Shuttle</td>
<td>CityMobil2 (Low Speed / Segregated Routes)</td>
</tr>
<tr>
<td></td>
<td>• Driverless Valet Garage Parking</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><strong>Full Automation</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Automated Taxi (Even for Children)</td>
<td></td>
</tr>
</tbody>
</table>
Fundamental Regulatory Challenges

- Automation blurs the traditional regulatory boundaries
  - NHTSA is responsible for new vehicle equipment & safety
  - States are responsible for vehicle operation (driver licensing)

- Need to balance:
  - Public Safety while unproven systems are being tested
  - Encouraging technological innovation promising improved safety

- Lack of technical standards to provide baseline references for performance, safety, or testing protocols or procedures

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

- Differing concepts of certification across government agencies, industries, and countries:
  - Self-Certification vs. Third-Party Certification
SAE Level 2 Automation Systems: Issues to Consider

- Level 1-2 systems are severely limited by factors not necessarily apparent to drivers
  - lane marking type, curve radius, etc.
- Level 1-2 system can’t spot trouble
- Drivers can safely 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
AV Public Roads Testing Regulations

• **Understanding Testing Characteristics & Goals**
  – Manufacturer interviews

• **Administrative Regulations Considered**
  – Ensuring safety management in the development process
  – Prohibition against testing certain vehicles or locations
  – Test driver qualifications and training
  – Identification or marking of test vehicles
  – Crash reporting thresholds
  – EDR data specifications & privacy issues
  – EDR data usage and program evaluation metrics
Testing Characteristics & Goals

• 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
  – Minimum testing miles not an indication of readiness
• Safety is achieved through the combination of design, testing policies, and the test driver
  – Test Driver Qualifications & Training
  – Safety Management Process
  – Different levels of system maturity (confidence)
• Prohibiting certain testing locations or vehicle types is counterproductive
• Different testing stages, goals, and protocols
  – Engineering Testing
  – Naïve Driver Testing (Usability, User Experience)
  – Field Operational Testing
Manufacturer Testing Permit Issues: Demonstrating Safety Management

• **Questions We Initially Considered**
  – How many test drivers should be in the vehicle?
  – When is the system ready for more challenging tests and when does the system need to go back to test track testing?
  – What testing protocols are needed to maintain safety?

• **Safety Management Process**
  – No one-size fits all answer to many safety policy questions
  – Continual risk assessment in decision making
  – Safety Culture - policies and protocols must be followed
  – Potential for 3\textsuperscript{rd} Party Safety Concept Certification (Bosch received this type of certification from TÜV Süd, 2013)

• **Test Drivers**
  – Qualifications $\rightarrow$ minimum equivalent to commercial drivers
  – Training $\rightarrow$ dependent on system, graduated programs
Test Vehicle Marking

• Should You Require AV Test Vehicles Markings?
  – Static: Decal or License Plate
  – Dynamic: Light

• Pros & Cons
  – Warns other in case test vehicle does something unexpected
  – 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 – probably not a need
AV Test Program Performance Metrics

• How do you evaluate a test permit program’s safety?
  – Crashes
  – Need Exposure
  – Surrogate Safety Metrics (Near Crashes)?
  – EDR Data

• Crash Reporting
  – CA VC 16000 requires reporting of crashes ($750 damage or injuries)
  – Might take time to filter from police reports to DMV
  – Report all crashes (with some minimum threshold)?
  – Report only crashes where AV system active?
  – Report only crashes where AV system active & at fault?
  – Testing safety relies on (driver + system) ➔ Report all crashes
EDR Data

- **Surrogate Safety Metrics (Near Crashes)**
  - Many studies analyzing naturalistic data (VTTI 100-Car, SHRP2)
  - Much research on driver monitoring systems (phone apps)
  - Both use combinations of hard accelerations (braking, lateral)
  - No clear metrics in literature without video analysis (false alarms)
  - Hard to catch near misses when the sensors didn’t anything

- **Should EDR data be submitted to DMV?**
  - Each vehicle will have a different sensor suite & data definitions
  - Standardization difficult, especially during testing phase
  - Focus on defining a report from manufacturers
  - CA requiring safety critical disengagements
  - Controversial because disengagements may not indicate safety problems or risky behavior
AV Public Deployment Regulations

- Ensuring Safety Prior to Deployment
  - Behavioral Competency
  - Functional Safety
  - Certification
- AV Registration and External Marking
- Driver Training & Licensing
- Cybersecurity & Maintenance
- Driverless Operation
Ensuring Safety: Behavioral Competency

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

• Why is Behavioral Competency not just an adaptation to the *Driving Performance Exam*?
  – DPE looks at benign conditions (sometimes only urban)
  – A basic vehicle control test is going to be easy for an AV manufacturer to tune to perfection: stopping, starting, staying in the lane, obeying traffic laws
  – DPE infers potential driving performance potential based on where the driver is looking, sequences of maneuvers, etc.
  – AV sensors always looking everywhere they can see, so how do you infer what the system does with that data?
  – Safety more related to abnormal condition behavior
Behavioral Competency Testing

- Behavioral Competency could eventually be distilled into performance standards and tests (DMV, NHTSA, SAE, ISO)
- Define AV Operating Scenarios:
  - Freeway Pilot
  - Rural Highway Pilot
  - City Street Pilot
  - Valet Parking
  - Low-Speed Shuttles
- Define High-Level Minimum Competencies (Maneuvers)
  - Differs by SAE Level of Automation (Assumed Level 3)
- Define Test Conditions for Each Competency
  - Could be DMV, NHTSA, MFG, SAE/ISO
  - NHTSA NCAP FCW Confirmation Test (34 Pages)
- Conduct Tests
  - Could be DMV, NHTSA, MFG, 3rd Party
<table>
<thead>
<tr>
<th>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 (Advisory)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Detect Passing and No Passing Zones</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect Work Zones, Temporary Lane Shifts, or Safety Officials</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect and Respond to Traffic Control Devices</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detect and 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 Freeway Merge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<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 (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></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>
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</tr>
<tr>
<td>Detect &amp; Respond to Encroaching Oncoming Vehicles</td>
<td>✓</td>
<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 Emergency Vehicles</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ensuring Safety: Functional Safety

- **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 AV Levels 4+
  - Also not entirely considered are interactions between the AV system and driver: *Errors, Misuse, and Abuse*
  - Efforts to modify ISO 26262 for AVs will take time

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

- **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

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

- **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
3rd Party Certification Questions

• What is Being Certified?
  – Behavioral Competency
  – Functional Safety

• What is the Depth of the Review?
  – Driving Test (Benign Conditions)
  – More Comprehensive Testing (Standards, Hazards, Abnormal Conditions)
  – Review of Mfg. Tests & Data
  – Functional Safety Process
  – Functional Safety “Hazard Analysis” by Behavioral Competency Requirement
  – Full Code Review (Aviation)
AV Registration & Driver Licensing

• AV Registration and External Marking
  – Key Registration Issue: Understanding AV capabilities (resale, CHP)
  – External Marking: Do the benefits outweigh the cons?

• Driver Training and Licensing
  – License endorsements proposed/mandated by NV, NJ, other states
    • Is the AV driver training universal or vehicle-specific?
    • What special knowledge (written test) must be demonstrated?
    • What special skills (driving test) must be demonstrated?
  – Without an endorsement program, how do drivers get trained?
    • Current ADAS owners often unaware of vehicle features
    • New Vehicles vs. Used Vehicles vs. Borrowed/Rented Vehicles
    • PSA Campaign
      – General license testing should exclude AV usage
AV Cybersecurity & Maintenance

• Cybersecurity
  – Most vehicle hacking required physical access to vehicle (CAN)
  – Tesla website/server hacked, allowing limited access to cars
  – 60 Minutes (2015) showed remote hacking a GM Impala over 4G
  – Sen. Ed Markey (D-MA) commissioned a report
  – No known incidents as of today
  – NHTSA will probably need to act for all cars, not just AVs

• Maintenance
  – System will need to self-diagnose, and prevent activation (faults, failures, or required maintenance)
  – Dealers will need to train their staff to repair & calibrate systems
  – Similar concerns when hybrids were introduced

• Focus on Self-Diagnosis Regulation Language
Driverless Operations Issues

- Multiple concepts will be driverless
  - Valet Parking, Low Speed Shuttles, NEV Taxi
- Clear marking such as a special license plate?
  - CA CHP wanted some way to quickly identify an unmanned AV vs. runaway vehicle
- What is the desired response to emergency vehicles?
- 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 AVs
  - ISO has both vehicle & HF groups looking at AV issues
  - SAE ORAV (J3016, J3018), S&HF AV Task Force
  - European Commission funded project on AV standards & certification 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

- Diversity of state approaches ➔ AAMVA