AAMVA AV Best Practices Working Group Meeting
February 25-26, 2015

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

Christopher Nowakowski

Steven E. Shladover

Ching-Yao Chan

Han-Shue Tan

California PATH Program
Institute of Transportation Studies
University of California, Berkeley

Overview

- **Automated Vehicles Levels (Continuum)**
- **Fundamental Regulatory Challenges**
- **Regulatory Issues Considered for Public Roads Testing**
- **Regulatory Issues Considered for Deployment**
- **What's Next?**

CALIFORNIA PATH

SAE J3016 Levels of Automation

Level	Name	Dynamic Driving Steering/Speed	Roadway Monitoring	Fallback Steering/Speed	System Capability
Human Driver Monitors the Driving Environment					
1	Driver Assistance	Driver + System	Driver	Driver	Limitations
2	Partial Automation	System	Driver	Driver	Limitations
System Monitors the Driving Environment					
3	Conditional Automation	System	System	Driver	Limitations
4	High Automation	System	System	System	Limitations
5	Full Automation	System	System	System	Everywhere

http://www.sae.org/misc/pdfs/automated_driving.pdf

Driver Takeover!

Event	Mean PRT	85%
BRT to Tail Lights (1978)		1.6 - 1.9 s
Distracted BRT to FCW (2000)		1.18 s
BRT to Vehicle Pull-Out / Objects (2000)	1.28 - 2.3 s	1.3 - 1.9 s
PRT to Freeway Lane Drop Sign (1990)		3.7 - 6.6 s

- **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

Level	System Description	Examples
Human Driver Monitors the Driving Environment		
1	**Driver Assistance** • Adaptive Cruise Control OR Lane Keeping Assistance	Acura/Honda, Audi, Cadillac/GM, Chrysler, Ford/Lincoln, Hyundai, Infiniti, Lexus/Toyota, Mercedes, Volvo
2	**Partial Automation** • Adaptive Cruise Control AND Lane Centering • Traffic Jam Assist (Low Speed) • Parking Assist	ACC+LC (LKA/LC may not handle all marking/curves) Acura, Audi, Hyundai, Infiniti, Mercedes GM's Super Cruise (High Speed / Freeway) Cadillac (2017?) Traffic Jam Assist (Low Speed / Freeway) Mercedes (2014), BMW (2014), Audi (2016?)
Automated Driving System Monitors the Driving Environment		
3	**Conditional Automation** • Test Vehicles • Other Applications Unclear	Google Lexus Test Cars (2010-Current) Volvo 100-Car Gothenburg Tests (2017?)
4	**High Automation** • Driving Pilot (w. Limitations) • Closed Campus Driverless Shuttle • Driverless Valet Garage Parking	Long-Term Target for Most Manufacturers Google's Target for 2-Seat NEV Test Vehicle CityMobil2 (Low Speed / Segregated Routes)
5	**Full Automation** • Automated Taxi (Even for Children)	

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**

2015 Infinity Q50
ACC+LKA/LC

2015 Mercedes S-Class
ACC+LKA/LC

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**

CALIFORNIA PATH

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**

CALIFORNIA PATH

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 3rd Party *Safety Concept Certification* (Bosch received this type of certification from TÜV Süd, 2013)**
- **Test Drivers**
  - **Qualifications ➔ minimum equivalent to commercial drivers**
  - **Training ➔ 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**

CALIFORNIA PATH

Critical Driving Maneuvers	Freeway	Rural Highway	City Streets	Valet Parking	Low-Speed Shuttles
Detect Operating Envelope & System Malfunctions	✓	✓	✓	✓	✓
Detect & Respond to Speed Limit Changes (Advisory)	✓	✓	✓		✓
Detect Passing and No Passing Zones					
Detect Work Zones, Temporary Lane Shifts, or Safety Officials	✓	✓	✓		
Detect and Respond to Traffic Control Devices		✓	✓		
Detect and Respond to Access Restrictions (one-way, no turn,…)			✓	✓	✓
Perform High Speed Freeway Merge					
Perform a Lane Change or Lower Speed Merge			✓		
Park on the Shoulder (Minimal Risk State)					
Navigate Intersections & Perform Turns			✓		✓
Navigate a Parking Lot & Locate Open Spaces				✓	
Perform Car Following (Including Stop & Go)	✓	✓	✓	✓	
Detect & Respond to Stopped Vehicles	✓	✓	✓	✓	✓
Detect & Respond to Intended Lane Changes / Cut-Ins	✓	✓	✓		
Detect & Respond to Encroaching Oncoming Vehicles		✓	✓	✓	
Detect & Respond to Static Obstacles in Roadway	✓	✓	✓	✓	✓
Detect & Respond to Bikes, Peds, Animals, or Moving Objects		✓	✓	✓	✓
Detect Emergency Vehicles	✓	✓	✓		

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**

CALIFORNIA PATH

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)**

CALIFORNIA PATH

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**

CALIFORNIA PATH

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**

CALIFORNIA PATH

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**

CALIFORNIA PATH