DEVELOPMENT OF CALIFORNIA REGULATIONS TO GOVERN THE TESTING AND OPERATION OF AUTOMATED DRIVING SYSTEMS

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ABSTRACT

Higher levels of road vehicle automation pose a regulatory challenge in the U.S. At the national level, the National Highway Traffic Safety Administration (NHTSA) has been responsible for ensuring vehicle safety through the mandatory Federal Motor Vehicle Safety Standards (FMVSS) and the voluntary New Car Assessment Program (NCAP). Although NHTSA typically regulates the technology aspects of vehicle safety, state agencies, such as a Department of Motor Vehicles (DMV), are responsible for the regulations governing training, evaluation, and licensing of drivers, and the registration of vehicles. Automation that allows drivers to disengage from monitoring and control tasks introduces safety concerns related to the vehicle technology (typically regulated by NHTSA) and to the Automated Vehicle's (AV) driving behavior and compliance with vehicle codes (typically regulated by states).

This paper details a variety of issues that need to be addressed in support of state regulations for manufacturers' testing of AVs on public roads and the general public's operation of automated driving systems. The key challenges for these regulations are how to ensure public safety without discouraging technical innovations and how to define meaningful requirements in the absence of existing technical standards for automated driving systems. The topics covered in this paper include regulatory models of certification, driver training and licensing requirements, and a discussion of the distinction between behavioral competency (how well the automation handles the environment) and functional safety (how well the vehicle handles internal faults and failures). This information is reported here so that other jurisdictions and institutions that will need to grapple with the same issues will be able to benefit from what we have learned in the process of developing the first comprehensive set of state regulations governing road vehicle automation.

INTRODUCTION

Research and development on road vehicle automation systems has been active in the U.S. since Vladimir Zworykin's team began its work at the RCA Sarnoff Laboratories in 1949, ten years after the concept of automation was introduced at the 1939 New York World's Fair's Norman Bel Geddes Futurama exhibit, sponsored by General Motors (*1*). Under the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), a congressional mandate started the first national automated driving program, culminating in a 1997 demonstration of highway automation in San Diego, CA, by the General Motors-led National Automated Highway Systems Consortium (NAHSC). Vehicle automation R&D has since gone through several cycles of progress and retrenchment, but the most recent resurgence came from the Defense Advanced Research Projects Agency (DARPA) Grand Challenge (2004, 2005) and Urban Challenge (2007). However, vehicle automation did not achieve enough political visibility to stimulate regulatory activity until Google announced its automated driving program in 2010.

Although some postulated that automated vehicles were probably already legal in the U.S. (*2*), several states began to clarify existing laws and start creating regulations for automated vehicles, motivated by Google's lobbying. In June 2011, Nevada became the first state to pass legislation on automated vehicles, California became the second in September 2012, and others have since followed suit (*3*). California SB 1298 created California Vehicle Code (VC) 38750, establishing definitions and authorizing and requiring the California Department of Motor Vehicles (DMV) to adopt regulations for the testing and deployment of "autonomous vehicles" on public roads by January 1, 2015.

The California law defined "Autonomous Vehicles" (AVs) as having the capability to drive the vehicle without the active physical control or monitoring of the human operator, but specifically excluded collision avoidance and driver assistance systems such as forward collision warning and mitigation systems, park assist, adaptive cruise control, lane keeping assist, and even traffic jam assist. Although the law uses the word "autonomous", this is based on the common error of substituting "autonomous" for the correct word "automated". "Autonomous" refers to a system that is independent, self-organizing, or self-determining, while an "automated" system replaces human labor with machine activity, which is the relevant concept in the context of the driving regulations. The law applies to SAE Level 3 (Conditional Automation) systems and above, based on the definitions in SAE J2016 (*4*), approved after the law. It established that permit processes must be created for testing and deployment, that a driver must be seated in the driver's seat and capable of taking control during AV testing, and that all AVs be equipped with an independent Event Data Recorder (EDR) to record AV sensor data for at least 30 seconds before a collision and store the data for at least 3 years. It also specified that test vehicles must have an internal visual indicator of the automation state, several means to disengage the automation (including steering and braking overrides), and fault detection. Specifically, if a fault is detected, the system must alert the test driver and be capable of bringing the vehicle to a stop if the driver does not respond.

In addition to the limited time frame and intense public scrutiny because of its pioneering status, the development of these regulations has been challenging for several reasons. First, although the DMV has experience with complex driver licensing regulations, it has limited history in regulating technology-intensive issues because automotive safety regulations have been a federal responsibility, managed through the National Highway Traffic Safety Administration (NHTSA) since the National Traffic and Motor Vehicle Safety Act of 1966. Furthermore, SB 1298 required regulations to be defined prior to, and in the absence of, technical standards that could be referenced as baselines for acceptable performance and safety. Second, the regulations need to be general enough to simultaneously handle many unique AV deployments, spanning the multiple levels of automation and operating scenarios that may be introduced by various manufacturers in the near future. Finally, the overriding challenge is to find a balance between nurturing technological innovation in California and protecting the traveling public from being exposed to safety hazards from immature implementations of automation technology.

REGULATION DEVELOPMENT PROCESS

Pursuant to VC 38750, the DMV is ultimately responsible for writing the new sections of the California Code of Regulations (CCRs) dealing with automated vehicles. To aid in the development, the DMV set up a statewide steering committee of potentially affected agencies such as the California Department of Insurance, California Department of Transportation (Caltrans), and the California Highway Patrol (CHP). Based on the framework prescribed in the vehicle code, the DMV proposed two regulation packages, the first regarding AV testing on public roads and the second regarding the deployment of AVs to the driving public. For each package a public workshop was held to hear industry concerns and gather ideas and feedback before drafting regulations. The drafts were first reviewed by the statewide steering committee, and then by the California State Transportation Agency, Governor's Office, and Office of Administrative Law before they were released to the public for a 45-day comment period, followed by a public hearing. Subsequent changes to the regulations triggered a 15-day public comment period, and the final regulations could not take effect without additional review by the California State Transportation Agency, the Office of Administrative Law, and the Governor's Office.

California SB 1298 directed the DMV to consult with the CHP, the Institute of Transportation Studies at the University of California, Berkeley, and any other entity with expertise in the subject. The California PATH Program (Partners for Advanced Transportation TecHnology), a research program within the Institute of Transportation Studies, has provided technical support to the DMV on these regulation topics with effectively only 11 months to conduct the supporting research in order to meet the deadlines set by the legislation. Beginning in July 2013, PATH set up an internal panel of experts and an external industry advisory committee composed of experts at automotive manufacturers, suppliers, and other transportation safety research centers, gathered from a half-day kick-off workshop held during the 2013 TRB summer *Workshop on Road Vehicle Automation*. PATH explored the regulation topics that had been identified by DMV and conducted interviews with manufacturers and suppliers engaged in AV research and development in California, providing the DMV with a preliminary report in August, a draft report in September, a final report in December 2013, and a supplementary report in March 2014.

Given the schedule constraints, the first regulation package, covering AV testing on public roads, needed to be drafted by the DMV before the PATH research findings were available, and the DMV released a draft regulation package on November 29, 2013, with comments due by the public hearing on January 14, 2014. The final AV testing regulations were adopted May 20, 2014, subsequently taking effect on September 16 (*5*). The second regulation package draft, covering AV deployments to the public, should be released for public comment late in 2014 (*6*).

AUTOMATED VEHICLE REGULATORY ISSUES FOR TESTING

Overview

California VC 38750 provided a framework for the DMV to create a regulatory process for AV testing, with the primary concern being how to ensure public safety by preventing risky testing practices and procedures and precluding immature AV implementations from being tested on public roads. The regulations need to accommodate the diversity of system concepts that might be tested by manufacturers, recognizing that not every technology will become a product. Testing could also include specific component tests, complete system tests, human factors studies, or long-term Field Operational Tests (FOTs), which may blur the line between testing and deployment.

In safeguarding the public interest, the primary challenges for the DMV include how to document that the technology has reached a maturity sufficient for public roads testing and that the manufacturer is performing their public roads testing without taking unnecessary risks. This section discusses the challenges in determining when AV technology is ready for testing on public roads, characteristics of good manufacturer testing programs, and what models of certification could be adopted by the DMV. Several additional AV testing issues to be considered include the external marking of test vehicles and metrics that could be used to evaluate a manufacturer's testing program.

Ensuring AV Safety During Public Roads Testing

AV testing does not progress linearly from design to test track testing to public roads testing to deployment, so the number of miles or hours of test track testing cannot be specified *a priori* to sufficiently ensure safety prior to public roads testing. Furthermore, a wide range of automation concepts could be tested, ranging from CityMobil2's low-speed urban shuttles in dedicated/segregated lanes (*7*) to high-speed freeway automation. Simply requiring, for example, 1000 miles of test track testing does not empirically prove the safety or readiness of a system. For a low-speed shuttle, the requirement would be excessively burdensome, but for a highway system, the requirement could be accomplished in a few days.

Testing programs are iterative, including frequent software and hardware modifications, and occasional failures are to be expected. The overall safety of a testing program is not just dependent on the technology reaching any specified levels or goals; rather, safety is achieved through the combination of the AV system design, the test driver capabilities, and the safety procedures that have been implemented. Thus, ensuring AV testing safety starts with test driver selection and training and depends heavily on the manufacturer's safety management process throughout the development and testing procedures.

Test Driver Selection and Training

A good AV testing safety program begins with test driver selection and training. Potential test drivers should be screened for a safe prior driving record, and the criteria for a safe driving record should be at least as stringent as the criteria for obtaining and maintaining a commercial vehicle driver's license, given the obvious parallels. However, the details of the driver training program can vary depending upon the specific AV concept and the scope of the testing to be conducted.

A good training program will recognize the need for graduated test driver qualification levels associated with testing systems with different levels of maturity, so that the least experienced drivers only test the systems that are the most mature and the more experienced drivers would test the systems that are technically less mature and considered more unpredictable or risky. The training program should include familiarization with the automated driving system technology, basic technical training regarding the system concept, capabilities, and limitations, and ride-along demonstrations by an experienced test driver. It should then proceed to behind-the-wheel training, while accompanied by an instructor, first on test tracks and then on public roads, so that the instructor can verify the test driver trainee's driving skills and judgment.

Although a driving simulator may be included as part of the training program, simulator experience alone is not sufficient to qualify a test driver. Similarly, some programs include commercially available defensive driving school training, but this type of training alone is not sufficient to qualify a test driver, nor is it necessarily required, depending on the system concept being tested. As an example, practical experience in recovering from hazardous scenarios such as losses of stability and imminent crashes is useful when testing higher speed applications, but would not be a prerequisite for testing low-speed applications.

Safety Culture and Safety Management in the Development Process

The second set of common elements in good AV testing safety programs can be seen in the company's safety culture and safety management and are reflected in the decision making in the design, development, and testing process. A clear management process to make safety-related decisions is critical to maintaining the safety of the AV testing program. Although many issues were investigated to try to help ensure safety during testing, the answers to the questions listed below varied based on the stage and purpose of the testing so it did not make sense to require a single uniform answer for all testing. In each case, a good AV testing program needs to demonstrate that safety policies have been put in place, and a clear decision making process exists that prioritizes the potential impacts on public safety as a key criterion.

- How many test drivers should be required in the vehicle?
- How much test track testing needs to be conducted?
- Should there be restrictions on testing locations?
- Should test vehicles or tests in progress be identified to the driving public?

The early stages of testing may require test track testing and multiple testers in the vehicle, while in later stages of testing, only a single test driver may be required. A manufacturer should have a policy stating that the test driver's primary responsibility is to monitor the road and be ready to take over the vehicle in the event of a system malfunction or failure, and the manufacturer should have a process to decide when a second tester is necessary to monitor the system status, allowing the driver to focus on the safe operation of the vehicle. Since the development and testing process is iterative, there would not be a strict progression from multiple testers to a single tester or from test track to public roads testing. Even as development progresses, some revisions may require the manufacturer to take a step back from public road testing to test track testing or to limit the public road testing to certain lower risk locations, and a safety management process must exist to ensure that safety is considered when making those decisions.

Finally, a company's safety culture will also factor in to the overall safety of the testing program. Safety policies and decision making protocols will not be effective if the stated processes are not followed. A good safety culture includes provisions such as allowing anyone on the team, especially the developers and test drivers, to halt or delay testing, without repercussions, when safety concerns arise.

Certification Models

One of the most controversial aspects in the context of an agency reviewing an application for public roads testing is the concept of certification. In its simplest form, people or organizations may certify that something is true or valid to the best of their knowledge by signing a document. However, more specialized forms of certification are common in some industries and countries. As an example, product certifications are common for electrical devices, such as a cell phone charger. A product certification would state that a particular product passed all the standards and applicable tests for that product, and furthermore, the certification could be a self-certification by the manufacturer or a third-party certification by an independent testing laboratory.

In the U.S., automotive manufacturers self-certify that all motor vehicle equipment sold to the public meets all applicable Federal Motor Vehicle Safety Standards (FMVSSs) set by NHTSA in the Code of Federal Regulations, Title 49, Part 571. Third party testing and certification of automobiles also exists in the form of the voluntary NHTSA New Car Assessment Program (NCAP), often known as the 5-star crash rating system. In the NCAP, NHTSA defines performance standards, randomly purchases vehicles from manufacturers, and hires third-party laboratories to conduct the tests.

In some European countries, third-party certification is commonly used in the automotive industry, and there are two types offered. Most commonly, a third party would test a product and certify that it meets certain government or industry standards. However, there is a second type of third-party certification, such as that offered by the German certification organization TÜV Süd, called the *Safety Concept Certification* for advanced electronics, hybrid vehicles, and AVs (*8*). The safety concept certification reviews hazard analyses, risk assessments, and functional safety concepts for a prototype system, as well as testing procedures and safety-related decision making processes. As an example, the safety concept review may examine the driver training program, the hardware and software safeguards that have been implemented on the test vehicles, and the process for continually making decisions as to what hardware and software changes will require a vehicle to be tested on a test track before continuing public road testing. Also, as part of the safety concept review, the third party examines how diligently the company under review actually follows their stated company policies and procedures.

The third-party safety concept certification would be an appropriate certification model prior to allowing the public roads testing of AVs, and it has two advantages. First, it provides an independent verification that the manufacturer is following their stated policies. Second, since the review is done by a third party, it can be kept confidential, unlike documents provided to a public agency, which may become available to the public under open records laws. This may appeal to manufacturers who consider that their development and testing process affords them a competitive advantage. However, the primary disadvantage of the safety concept certification models is that there does not appear to be an equivalent to this type of certification in the U.S. for automotive safety systems. Requiring third-party certification would essentially require the formation of a new certification industry in the U.S., while giving a competitive advantage to European manufacturers who are already utilizing this type of certification.

Additional AV Testing Issues

Marking of Test Vehicles

There are pros and cons when considering regulations to require marking AV test vehicles for the purpose of identifying these vehicles to the driving public, similar to marking student driver vehicles. The markings could be static decals or special license plates, or they could be dynamic such as a light that illuminates when the automation is active. The only argument in favor of marking test vehicles would be to indicate to other road users that the vehicle may do something unexpected. However, the countering consideration is that the test drivers are required to be paying attention and ready to take over should the automation do something unexpected. The primary argument against marking test vehicles is that markings will distort the behavior of the drivers around the vehicle and identify the test vehicle as a target for hackers or insurance fraud scams. Since one of the purposes of testing on public roads is to capture system performance under normal traffic, there should be no reason to conspicuously identify these vehicles. Nevertheless, manufacturers must still have a decision process to decide what kinds of tests can safely be conducted on the public roads with unmarked vehicles and what kinds of test might require additional protective measures such as a trailing car with its hazard lights activated or a (rolling) lane closure.

AV Testing Program Evaluation Metrics

A number of issues were considered for regulations related to the evaluation of the AV testing program safety, both on an individual manufacturer basis and on a statewide basis across manufacturers. California VC 16000 already requires the reporting of crashes in which the damage exceeds $750 or injuries were sustained, and VC 38750 requires that all AVs be equipped with a separate Event Data Recorder (EDR) capable of recording AV sensor data for at least 30 seconds prior to a collision, preserving the data for a minimum of three years.

The first question that arose was regarding the threshold for reporting crashes to the DMV. A high rate of AV crashes during testing could indicate a problem with the manufacturer's testing policies or training. On one extreme, reporting could be limited to crashes that occurred when the AV system was engaged or when the AV was determined to be at fault. However, there may be scenarios when the AV would not be considered at fault for the crash, such as when the AV is hit from behind, but some aspect of the AV behavior may have contributed to the crash. Since the safety of the testing program relies on the combination of the AV technology and the test driver, all crashes that would typically be reportable under the normal DMV rules should continue to be reportable under the AV testing program, whether or not the AV system was engaged at the time of the crash. On the other extreme, reporting could include not just crashes, but crash surrogate events, near misses, or system failures requiring immediate driver intervention. However, an examination of the literature found no clear consensus on the definition of crash surrogate events without the need to review video and make judgment calls to weed out false alarms, suggesting that near miss or crash surrogate events are of limited value.

The second question that arose was whether the DMV should require the EDR data to be submitted in the event of a crash. Unfortunately, for the EDR data to be useful for analysis by a third party, it would need to be standardized or data dictionaries would need to be provided. Different systems will produce different sets of data depending on the type and quantity of sensors on the vehicle, and without standards, the manufacturer will likely be the best party to extract and summarize the EDR data. Rather than requiring raw EDR data, evaluators would be better served by a crash report containing summarized driving data (including a timeline of AV speed, brake activation, AV system state, and test driver interventions) along with the test driver's narrative of the crash.

AUTOMATED VEHICLE REGULATORY ISSUES FOR DEPLOYMENT

Overview

California VC 38750 defines a framework for the DMV to create a regulatory process for the deployment of AVs to the general public. This set of regulations is particularly challenging because automated vehicles are still in the prototype phase and manufacturers are unwilling to disclose potential future products, timelines, or business strategies. The first AVs may resemble low-speed urban shuttles, high-speed freeway autopilot systems, or automated valet parking systems. Similar to the testing permit, decisions will need to be made on a case-by-case basis given the range of operating concepts and system limitations. The ultimate goal of the deployment regulations is to ensure public safety, but safety evaluation prior to deployment is difficult because there are currently no SAE, ISO, or FMVSS standards for AVs on which to rely. Furthermore, the deployment permit process must be sensitive to protecting a manufacturer's proprietary designs and test data, without overburdening the reviewing agency with documentation quantity or complexity.

It is also recognized that individual AV deployments may not live up to expectations, and ensuring public safety after AVs are deployed is also critical. Currently, the DMV ensures public safety through driver licensing. The driver licensing system is based on individual driver responsibility, with points allocated to individuals responsible for violations or crashes. The point system is not only used to assign risk to individuals by insurance companies, but ultimately, is used by the DMV to revoke an individual's driver's license if they are deemed too risky. This model works only up to SAE Level 2 automation, where drivers remain responsible for monitoring the roadway, but systems meeting the SAE Levels 3 through 5 definitions, the focus of California VC 38750, would not require the driver to remain actively attentive or engaged. Since the California DMV does not have the authority that NHTSA has to enforce recalls or impose fines, the issuance of an AV deployment permit is the only mechanism that the DMV will have available to try to ensure that safety issues or bad AV performance are corrected by the manufacturers in a timely manner.

This section discusses the challenges in ensuring AV safety prior to public deployment, introducing the concept of AV behavioral competency and discussing functional safety, and what models of certification could be adopted by the DMV. Several additional AV deployment issues include the external marking, driver training and licensing, and vehicle maintenance and cyber-security concerns. Finally, special considerations for deployments of driverless AVs are discussed.

Ensuring AV Safety Prior to Deployment

When discussing the safety of AV systems, it is important to distinguish between the capabilities or competency and the functional safety of the automated driving system. Competency describes how well the automation behaves when dealing with hazards in the normal external driving environment. Functional safety describes how well the system, or the combination of system and driver, deals with internal faults and failures. Both are prerequisites for achieving a safe system, but they are developed and assessed differently.

Behavioral Competency

Behavioral competency refers to the ability of an automated vehicle to operate in the traffic conditions that it will regularly encounter, including keeping the vehicle in the lane, obeying traffic laws, following reasonable etiquette, and responding to other vehicles, road users, or commonly encountered hazards. At first, it might seem that behavioral competency could be evaluated in a manner similar to a current driving performance exam. However, driving performance exams focus on nominal urban driving maneuvers in benign conditions. Although a simple, on-the-road driving test would reveal if the AV could stay in the lane or obey a small subset of the traffic laws, it could not evaluate responses to abnormal driving conditions, extreme events, or emergency scenarios, which are far more important to safety than lane keeping or smooth accelerations or decelerations. Furthermore, much of the scoring for a typical driving performance exam is based on the driver's conduct, such as where the driver is looking or the sequence of glances and actions during maneuvers such as lane changes. Although these behaviors can give insight into that individual's training and future potential, an exam of an automated driving system cannot provide such types of observations.

Behavioral competency could potentially be specified and evaluated through performance standards and tests, but currently, there are no SAE, ISO, NCAP, or FMVSS for AVs and the development of such standards will take years or even decades. In the given time frame, the most that could be accomplished with regulations would be to identify *minimum* behavioral competencies for automated vehicles and require that manufacturers have tested their products for those behaviors. These would represent necessary, but by no means sufficient, capabilities for public operation.

A major problem with trying to identify a minimum set of critical driving situations or maneuvers required of an automated driving system stems from the fact that there are many, vastly different, concepts of the near- and long- term futures of automated driving systems. The process used to define exemplar minimum behavioral competency goals consisted of three steps. In the first step, five automated vehicle operational scenarios were defined based on a review of concepts that have been publicly discussed by manufacturers.

1. Interstate Freeway / Limited Access Highways
2. Rural Highways
3. Arterial / Urban / City Streets
4. Automated Valet Parking Systems (Parking Lot Only)
5. Low-Speed Driverless Shuttles in Segregated Lanes

In the second step, potential critical driving maneuvers were defined for each operational scenario. The potential critical driving maneuvers represent the combinations of driving tasks, maneuvers, and situations that will be encountered by the vehicle in the operational scenario. In the third step of the process, a determination was made as to whether it should be mandatory for the automated driving system to perform each critical driving maneuver (see Table 1). Generally, this determination was made based on the assumptions that the automated driving system is an SAE Level 3 system, the driver is not paying attention to the driving task, and the driver could not be reasonably re-engaged in the driving task for at least 5 to 10 seconds. A distinction is made between a requirement that the system simply detect a condition versus a requirement to both detect and respond to the condition.

Table 1. Minimum Behavioral Competency Requirements.

Critical Driving Maneuvers	Freeway	Rural Highway	City Streets	Valet Parking	Low-Speed Shuttles
Detect System Engagement/Disengagement Conditions Including Limitations by Location, Operating Condition, or Component Malfunction	✔	✔	✔	✔	✔
Detect & Respond to Speed Limit Changes (Including Advisory Speed Zones)	✔	✔	✔		✔
Detect Passing and No Passing Zones					
Detect Work Zones, Temporary Lane Shifts, or Safety Officials Manually Directing Traffic	✔	✔	✔		
Detect and Respond to Traffic Control Devices		✔	✔		
Detect and Respond to Access Restrictions such as One-Way Streets, No-Turn Locations, Bicycle Lanes, Transit Lanes, and Pedestrian Ways			✔	✔	✔
Perform High Speed Freeway Merge					
Perform a Lane Change or Lower Speed Merge			✔		
Park on the Shoulder or Transition the Vehicle to a Minimal Risk State (Not Required for SAE Level 3)					
Navigate Intersections & Perform Turns			✔		✔
Navigate a Parking Lot & Locate Open Spaces				✔	
Perform Car Following Including Stop & Go and Emergency Braking	✔	✔	✔	✔	
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 Bicycles, Pedestrians, Animals, or Other Moving Objects		✔	✔	✔	✔
Detect Emergency Vehicles	✔	✔	✔		

Additional requirements would be expected for higher level (SAE Levels 4 and 5) automation systems, but these additional requirements are not considered because behavioral competency has been defined in terms of minimum requirements for a system to be classified as an SAE Level 3 system. Higher level automation may optionally handle some of the critical driving maneuvers that are not listed as mandatory, such as the detection of no passing zones, performing freeway merges, and parking on the shoulder, but regulatory agencies may also decide that minimum behavioral competency for an SAE Level 3 system is not sufficient to ensure public safety.

Functional Safety

Functional safety refers to the ability of the automated driving system to accommodate *internal* failures, which could be failures of electrical or mechanical components or software bugs. Unlike competency, functional safety cannot be effectively evaluated through testing, but rather, it is determined by the design and development process that the manufacturer follows. A methodology for achieving automotive functional safety already exists in the international standard ISO 26262 (*9,10*), but this methodology assumes that the driver is always available as a backup. At higher levels of automation, that assumption will not be true. Additionally, ISO 26262 requires systems to have low complexity in software and system architecture, and it is not designed to cover highly intelligent learning systems whose behavior will not be entirely deterministic. Finally, ISO 26262 does not address the safety of the interaction between the driver and the vehicle. Although there is discussion within ISO about updating the functional safety standard to better accommodate automated vehicles, that will not be completed for years.

In the absence of standards, there are very few avenues available for defining sensible functional safety regulations. Manufacturers could be required to certify that they are using ISO 26262 or a similar process in their AV design and development, but given the complexity of the standard and its current shortcomings related to AVs, it is likely that such regulations would be viewed negatively by many in the industry. An even less appealing strategy would be to require the use of ISO 26262 and stipulate that drivers are still responsible for being available to take over in the event of an emergency, effectively limiting the deployment of SAE Level 4 and 5 systems until such time as ISO 26262 has been modified to accommodate AVs. However, even if the use of ISO 26262 were to be required, the process itself is not deterministic and such a requirement would not be strictly testable as an acceptance criterion.

Certification Models

Similar to the AV testing application, the most challenging and controversial aspect of the deployment application is the issue of certification. As described earlier, the regulation of vehicle safety, in the U.S. automotive industry, is based on the concept of self-certification of adherence to FMVSS, and NHTSA does not receive detailed technical documentation prior to the deployment of a new vehicle model or technology. However, third-party safety certification models exist outside the U.S., and for vehicle emissions in the U.S., the EPA requires manufacturers to submit test data and acquire a type approval for new engines prior to sale. Although the DMV could implement a permit process for issuing type approvals analogous to the EPA's certification model, the major difference is that the EPA process is based on emissions standards that are clearly defined and easily testable.

In contrast, a certification that a vehicle meets the minimum behavioral competency requirements and was designed using a process that considered functional safety would be unavoidably subjective until specific AV standards are eventually developed. This poses challenges for any certification process. The third-party certification process has the merit of added credibility because of the independence of the certifying organization, but it also raises new problems involving protection of manufacturers' intellectual property (including trade secrets), lack of organizations qualified to do the work in the U.S., and the cost associated with an additional team of people having to develop an in-depth understanding of a complex system. Requiring third-party certification would essentially require the development of a new certification industry in the U.S.

Additional AV Deployment Issues

AV Registration and External

Beyond assessing the maturity of the AV technology, other deployment related issues include vehicle marking and registration documentation, driver requirements, and maintenance and cyber-security concerns. The issue of external vehicle markings was already discussed related to marking AV test vehicles, and the conclusion that no external markings are required holds for most AV deployments, at least when a driver is still required to be in the vehicle. If the AV must already behave in a reasonable and normal manner to be approved for public operation, there is no reason to mark the vehicle because there is no threat to warn the rest of the driving public about and there is no law enforcement need for the markings. The recommendations for vehicle registration documentation center around law enforcement needs, informing used vehicle purchasers about the capabilities of the vehicles they are acquiring, and the data needs of future studies to evaluate the relative safety benefits of AV technology. At a minimum, the vehicle registration should indicate if a vehicle possesses AV technology, the operational scenarios for which the AV technology was designed and certified, and whether the AV is capable of operation without a licensed driver in the vehicle.

Driver Training, Licensing, Privacy, and Disclosure Requirements

The next major regulatory question is whether drivers of AVs should need specialized training that could be tested under a driver's license endorsement program. Such a program would only be effective if the driver training could be standardized across all AVs. However, the primary training that a driver will need on an AV system is related to the specific system's limitations and the driver-vehicle interface, and thus, the training must be vehicle dependent and not a candidate for a license endorsement program. While the question of how to provide effective vehicle-specific AV training to drivers remains open, manufacturers will need an end user or operator's training plan, and the AV system limitations should be included on the vehicle registration documentation to help alleviate some of the concerns related to AV driver training, especially when vehicle ownership is transferred between private parties. Finally, since an AV EDR is mandated by the vehicle code, the question of AV data recording privacy needs to be addressed. Manufacturers will need to provide disclosures in the operator's manual regarding the vehicle's data recording capabilities, along with the associated data privacy protection policies.

AV Maintenance, Repair, and Cyber-security

A final set of AV deployment regulatory questions centers around vehicle maintenance and cyber-security concerns. Just as a driver relies on sight, AVs rely on sensors. Should periodic inspections or calibration tests be mandated for AV systems, and should there be regulatory safeguards to ensure that repair shops are certified to do the work? Similarly, should there be regulations to address threats related to cyber-security? Although some states require periodic vehicle safety inspections, California does not, but the California Bureau of Automotive Repair licenses and regulates automotive repair facilities. In answer to the first question, the simplest solution is to require self-diagnostic capabilities in the AV. If the self-diagnostic system determines that the AV is not in proper working condition, then the system should prevent itself from being engaged, while still allowing the vehicle to be driven manually. This is already the strategy employed by automotive Advanced Driver Assistance Systems (ADAS) such as Adaptive Cruise Control (ACC), and it is reasonable to assume that this strategy will also work with AV systems.

On the question of repair facilities, the auto repair industry has experienced past examples of concern when new technology is introduced. When hybrid-electric vehicles were first introduced, there was concern that the new propulsion systems would be more complicated than conventional ones, and only dealers would be able to service the vehicles. However, as the technology became more commonplace, the auto repair industry, including independent shops, has managed to handle those new systems without difficulty and without requiring additional regulations.

Special Considerations for Driverless AV Deployments

Although California VC 38750 requires that a driver be present in an AV during testing, it does allow for the deployment of AVs that are capable of operating without the presence of a driver onboard. However, the receipt of an application for the deployment of a driverless AV triggers notification of the California Legislature and a 180 day minimum waiting period to allow the legislature time to evaluate the application and act if necessary. By this simple definition, low-speed driverless shuttles and automated valet parking systems are likely to be the first driverless AVs on the market.

Low-speed driverless shuttles will most likely operate on dedicated infrastructure including segregated roadway lanes or special lanes along pedestrian ways as envisioned in the European CityMobil2 project, which has already considered safety requirements for such systems (*11*). Some of these requirements include infrastructure restrictions such as boarding gates at loading zones, curbs to provide physical segregation, central monitoring and oversight, and passenger-accessible emergency stop buttons. Similarly, several driverless valet parking system concepts are likely to be introduced in the near future, but currently no distinction is made among the different concepts in VC 38750. With some valet parking systems, although the driver exits the vehicle, continuous remote monitoring will be required using a key fob or mobile device until the vehicle has finished parking, while with other systems, the vehicle only reports back if there is a problem. Additionally, some valet parking systems work only in certain parking lots or structures with infrastructure cooperation and strict restrictions on access. The requirements for these types of systems should be lower than for systems that perform the parking maneuver street side, in traffic, and without continuous remote monitoring.

The question of external marking of automated vehicles was revisited for the driverless cases. Law enforcement believes that some external marking will be needed if the vehicle is capable of driverless operation; however, the markings should be subtle, such as a distinctive license plate. Law enforcement needs to distinguish driverless AVs from runaway vehicles, and in the event of a traffic infraction or crash, they need to know that the occupants may not be responsible for the vehicle. In the future, if current laws restricting activities such as use of mobile devices, watching video screens or drinking alcohol in cars are relaxed for driverless operations, law enforcement officers want to avoid unnecessary traffic stops. Other potential requirements include provisions for the vehicle occupants or law enforcement to contact the vehicle operator or owner or a remote monitoring or notification system when the vehicle encounters a problem such as a malfunction or crash.

CONCLUSIONS

In summary, the California DMV adopted their final AV testing regulations on May 20, 2014, and testing permits have been required since September 16, 2014. The second regulation package covering AV deployments to the public should be released for public comment late in 2014. Although California VC 38750 requires that the DMV adopt initial AV regulations by January 1, 2015, future regulatory packages are anticipated each year based on what is learned about forthcoming manufacturer plans and from the experiences with the testing and deployment permit application programs as implemented. Furthermore, the California legislature can act to modify the vehicle code, and the legislature specifically requires notification of a planned driverless AV deployment and a mandatory waiting period to allow time to act if necessary.

The discussion in this paper has been based on the pioneering experience in California, which is the first state to conduct an in-depth study of the issues that need to be addressed in developing regulations for automated vehicle testing and public operation. Some of the considerations have been specific to California, based on peculiarities of the California Vehicle Code, so other jurisdictions are likely to encounter different constraints based on their own existing codes, but others should be more broadly applicable. Eventually it will be necessary to have consistent regulations across the country, and hopefully internationally, so that developers of automated driving systems can do their work most efficiently and not be compelled to make complicated and costly changes to adapt to inconsistent rules. The original push for state-level legislation has abated for the time being, providing a window of opportunity to harmonize among the states that have acted already and to give NHTSA some time to catch up in the development of national regulations. The California Vehicle Code explicitly states that its rules will be superseded by the federal rules when those become available, so that national harmonization can be facilitated.

We hope that the experience described here is useful to others who are considering how to develop a regulatory framework for road vehicle automation systems, indicating the range and complexity of the issues that need to be considered. Several decades ago, California had to take the lead in developing motor vehicle emissions regulations when the national regulatory process was moving too slowly to clean up our air. In the current case, the California Legislature forced the development of regulations for automated driving systems that are somewhat premature, but hopefully in the long term these will have been a useful contribution toward national regulations.

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