Peer Review of Behavioral Competencies for AVs

University of California PATH Program

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1. Introduction

The University of California PATH Program has conducted an international peer review of the proposed behavioral competencies for "autonomous vehicles" at the request of the California Department of Motor Vehicles. A 15-page document called "Deployment Regulations Peer Review Discussion Paper" was circulated to invited experts from industry, research institutions and public interest groups from across the world. Most of these experts took the time to review the document and provide feedback in a variety of forms:

- 20 experts from 14 organizations participated in a 3.5-hour workshop meeting in Washington DC
- 31 experts from 8 organizations participated in private meetings with the PATH staff in California and by WebEx
- 43 experts from 23 organizations submitted written comments (some of whom also participated in the meetings).

In total, 76 experts, representing most of the key centers of international expertise on driving automation systems, have provided inputs to help guide the development of the behavioral competency requirements. Comments were received from:

- 9 established automotive vehicle manufacturers
- 8 other vehicle developers
- 4 tier-one automotive suppliers
- 4 testing organizations
- 10 research organizations
- 5 interest groups.

The full list of peer reviewers is attached as Appendix A.

Their inputs were diverse. In some areas, there was broad consensus on the direction that should be followed, but in other areas the inputs were less consistent. In this report, the peer review comments are summarized, and in most cases specific recommendations are provided for adjustments to the behavioral competencies based on those comments. In a few cases, the peer review inputs are not sufficiently definitive to lead to specific recommendations.

The subsequent sections of this report cover the following topics in sequence:

- comments on definitions and requirements in the Express Terms document
- comments on the general approach to defining behavioral competencies
- comments on the individual behavioral competencies.

2. Peer Review Comments on Definitions and Requirements Specified in Express Terms

Although review of the Express Terms document was not part of the scope of this effort, the behavioral competency requirements refer explicitly to terms and concepts contained in the Express Terms. The peer review feedback included some very important comments about problems in the Express Terms, indicating ways in which some of the definitions and requirements included there need improvement. Therefore, this report begins with the peer review inputs that point toward recommended changes in the Express Terms.

2.1 Continuous monitoring of the driving environment

Several reviewers noted confusion about the requirements for continuous monitoring of the vehicle by the driver, which appears to be in conflict with the basic definition of "autonomous technology", which does not require monitoring by a human operator.

Section 227.56 (b)(5)(B)3 calls for the vehicle owner's manual to provide information on *"the operator's responsibility to monitor the safe operation of the vehicle at all times."* The definition of "autonomous technology" in the Vehicle Code is *"technology that has the capability to drive a vehicle without the active physical control or monitoring by a human operator."* The stated requirement for continuous monitoring appears to preclude use of "autonomous technology" in systems to be deployed on public roads in California.

Similarly, Section 227.84 (c) states "The operator shall be responsible for monitoring the safe operation of the vehicle at all times and be capable of taking over immediate control of the vehicle in the event of an autonomous technology failure or other emergency." This has the same problem with operator responsibility as the earlier section, since it appears to have the net effect of preventing any use of "autonomous technology" as it was defined in the Vehicle Code.

The intended relationship of the requirements in these two sections of the Express Terms to the definition of "autonomous technology" needs to be clarified so that the industry can understand whether any kinds of autonomous technology can be used in California. If the intent is to permit use of autonomous technology, these two sections should be deleted or modified.

2.2 Complete safe stop

Section 227.56 (b)(6) requires manufacturers to submit with their application:
"a description of how the vehicle will safely come to a complete safe stop when there is an autonomous technology failure and the operator does not or is unable to take manual control of the vehicle, including but not limited to, all of the following:
(A) Activation of the emergency/hazard lights.
(B) Moving the vehicle as far from the travel lanes as possible.
(C) Alerting emergency services."

The peer reviewers identified a variety of issues with this requirement:

(a) The words “safely come to a complete safe stop” appear to have redundant usage of the words “safely” and “safe”. One or the other of these should be deleted to improve clarity. Since the original legislation used the term “complete stop” rather than “complete safe stop”, we suggest deleting that second instance of “safe”.

(b) Most reviewers believe that it is necessary to be more precise about the severity of the “autonomous technology failure” that should trigger the safe stop, so that this severe response is not triggered for every minor failure, but only for failures that exceed a certain threshold severity level (such as “safety-critical autonomous technology failure”, “mission-ending autonomous technology failure” or “autonomous technology failure that would endanger the safety of the vehicle occupants or other road users”).

(c) Several reviewers thought that it would be more appropriate for this requirement to be for the vehicle to take a “minimum risk maneuver” or to “bring the vehicle to a safe condition” without specifying a stop because in some conditions stopping is not the safest action to take (especially in high-speed traffic). There should also be provisions to enable a vehicle to “limp home” in a degraded mode of operation following a failure that does not completely disable the vehicle. Some manufacturers would also like to have the option of an intervention by a remote supervisor at a control center to provide guidance to an impaired vehicle.

(d) The stated condition of “the operator does not or is unable to take control of” would be better stated as simply “the operator does not take control of” because there is no way to detect the ability of the operator in real time, and all that counts is what action the operator takes (or does not take).

(e) Activation of the emergency/hazard lights creates a conflict with FMVSS 108, which requires that the hazard lights should be activated manually. Furthermore, as one of the manufacturers pointed out, the hazard lights are on a separate electrical circuit by design and not on the vehicle’s data bus so there is no physical means of activating those lights based on internal vehicle signaling from the malfunctioning automation system. The recent NHTSA letter to Google indicates some possibility of a future relaxation of this FMVSS 108 restriction, but that cannot be counted upon.

(f) “Moving the vehicle as far from the travel lanes as possible” was a problem for many reviewers because it is potentially too strong an action and could create new hazards. “As far as possible” was a particularly troublesome requirement because it could cause the vehicle to go off the side of a cliff or run into a tree or other hard obstacle. Alternatives that were suggested included “as far from the travel lanes as reasonable” or “move a safe distance from the active traffic”.

(g) The requirement to alert emergency services was also a problem for many reviewers because this will generate many false alarms for non-hazardous conditions that do not require emergency service interventions. There were suggestions to require this only for crashes above a certain severity threshold, such as crashes that would trigger airbag activation or fuel cutoff systems.

Based on these peer review inputs, the recommended revision to the safe stop requirement is:

"a description of how the vehicle will bring itself to a minimum risk condition when there is an autonomous technology failure that would endanger the safety of vehicle occupants or other road users and the operator does not take manual control of the vehicle, including but not limited to, the following:
(A) Moving the vehicle to a safe location.
(B) Alerting emergency services if a crash occurs of sufficient severity to injure the vehicle occupants."

Efforts should be made to achieve this clarification of the language within the constraints of what can be done under the related Vehicle Code language:

> "*The autonomous vehicle has a system to safely alert the operator if an autonomous technology failure is detected while the autonomous technology is engaged, and when an alert is given, the system shall do either of the following:*
> *(i) Require the operator to take control of the autonomous vehicle.*
> *(ii) If the operator does not or is unable to take control of the autonomous vehicle, the autonomous vehicle shall be capable of coming to a complete stop*."

Note that the Vehicle Code language does not say that the AV "shall come to a complete stop", but only says that it "shall be capable of coming to a complete stop", so the complete stop is not a mandatory response under all failure conditions.

2.3 Adherence to Legal Requirements in California Vehicle Code

Many reviewers commented on the challenge of taking a strictly literal interpretation of the California Vehicle Code when driving under the full range of real-world driving conditions. They pointed out diverse examples in which it is virtually impossible to avoid violating one provision or another of the Vehicle Code because of traffic conflicts, incidents, or evasive maneuvers needed to avoid crashes. They want to ensure that their vehicles will not be disqualified for making judgements similar to those that drivers regularly make in traffic now.

Some of these concerns have been addressed by the qualifying language in the Part C Critical Driving Error listing in Form OL318, but some of the criteria listed there do not provide for any mitigating circumstances:

- disobeys other traffic signs and/or lane markings
- fails to detect and respond to an emergency vehicle (this should be limited to an emergency vehicle flashing its lights and using its siren)
- blocks an intersection so that it impedes cross traffic
- ANY action or inaction requiring another driver or pedestrian to take evasive action
- drives straight ahead from a designated turn lane

- turns from a designated forward (straight) lane
- makes a turn from the wrong lane.

Under some abnormal conditions, vehicles may need to take any of these actions in order to avoid hazards, yet the current language does not provide for such mitigating conditions. Along similar lines, it would be better to soften the language in Section 227.56(b)(4), to change from "compliance with all provisions of the California Vehicle Code" to "compliance with the California Vehicle Code" to provide some leeway for handling abnormal conditions.

2.4 <u>Definitions of Driver and Operator</u>

Several reviewers commented on the need for more precise definitions of the seemingly mundane terms "driver" and "operator". This becomes important when we get into more subtle considerations about who or what is taking what role in governing the movements of a vehicle, and how those roles change under a wide variety of conditions. In addition, the definition of "operator" proposed in the Express Terms is different from the definition in the Vehicle Code.

According to the Vehicle Code (Section 305), a driver is *a person who drives or is in actual physical control of a vehicle*. When automation enters the picture, the meaning of "actual physical control of a vehicle" can become unclear, especially with features such as "drive by wire", which involves no physical connection between the driver's hands and the front wheels of the vehicle.

The Vehicle Code (Section 38750) states that: *An "operator" of an autonomous vehicle is the person who is seated in the driver's seat, or if there is no person in the driver's seat, causes the autonomous technology to engage.* This definition is broad enough to encompass driverless operations, and even operation of vehicles that lack a driver's seat. However, the Express Terms Section 227.02(p) created a different definition that excludes the driverless option and adds other requirements: "Operator" is the person who possesses the proper class of license for the type of vehicle being operated, has direct control over the operation of an autonomous vehicle, and has engaged the autonomous technology while sitting in the driver seat of the vehicle."

The difference from the definition in the Vehicle Code creates a problem in itself, because there are now two distinct definitions of the same term, which creates an ambiguity about which one is intended each time it is used (leading to confusion among the reviewers). It is also not a good practice in general to embed requirements inside definitions.

As currently written, the person sitting in the driver's seat of a vehicle could be considered to be both a driver and an operator, but it's not clear whether he or she would be both at the same time or whether he or she would transition between the one kind of status and the other. Although the term "driver's seat" has a well-established meaning in conventional vehicles, newer design vehicles specifically intended for automated use may have other configurations that would make it unclear which seat is the driver's seat. Indeed, some manufacturers of specialized low-speed shuttle vehicles would prefer to have the operator in one of the back seats rather than a front seat, but do not understand whether that could be classified as a driver's seat for purposes of the California regulations.

To reduce confusion, based on the peer review inputs, it would be better to delete the definition of "operator" from the Express Terms document and instead rely on the definition that is already contained in the Vehicle Code.

2.5 Areas of Operation

One of the most troublesome topics in the peer review was the definition and indeed even the concept of Areas of Operation. As specified in Section 227.02(a):
"Areas of operation" means the areas in which an autonomous vehicle is designed to operate. An area of operation is one of the following:
(1) Urban, which for the purposes of this article is any developed contiguous area in which there are more than 10,000 residents.
(2) Rural, which for the purposes of this article is all other areas of the state not included in urban areas, except for a Freeway/highway.
(3) Freeway/highway, which for the purposes of this article means "freeway" as defined in Vehicle Code section 332.

The large majority of the reviewers objected to this definition and classification scheme, so it should be one of the primary candidates for modification. The problems that were identified include:

(a) Although "rural" explicitly excludes freeway/highway, there is no parallel exclusion in the "urban" definition, which means that freeways going through urban areas would be classified as urban rather than as freeways (which makes no sense). Also, the competency tables use Arterial/Urban rather than simply Urban, which is not consistent.
(b) The 10,000 population cutoff for urban is essentially meaningless because a jurisdiction with a larger population could still be a very low density rural environment while a jurisdiction with a smaller population could have the density and traffic attributes of an urban area.
(c) If any general classification scheme such as this is to be applied, it needs to be defined based on the operational characteristics of the road system (traffic density, roadway types, traffic control devices, etc.) rather than based on population.
(d) These classifications are not consistent with national definitions, so they will not be directly extensible for national use in the future, but will leave California incompatible with the rest of the country. For example the freeway definition at the national level is based on the operational characteristics of total access control and lack of grade crossings. The Federal Highway Administration, National Census, and NHTSA crash data each have a different population threshold to define urban areas.
(e) There is a need for a clear definition of the boundaries between the public road network that is subject to the DMV regulations and private locations that are not subject to the regulations (such as which kinds of parking facilities).

(f) This type of classification scheme is not useful because it is too blunt and indiscriminate to be applied to very diverse automation systems designed to operate under significantly different conditions – virtually all reviewers preferred that the concept of the Operational Design Domain (ODD) for each system be used as the basis for selecting the relevant behavioral competencies to test.

Based on all of the peer review inputs, the concept of the "area of operation" should be deleted from the regulations and replaced by the concept of the "operational design domain" for each specific system, recognizing the significant diversity of systems that will be developed and offered to the public. It appears that this can be done by a direct substitution of the words "operational design domain" for the words "area of operation" throughout the Express Terms document (See Section 3.6 for definition and discussion of "operational design domain" (ODD)).

2.6 Remote Supervisor

The concept of a remote supervisor or dispatcher was of great interest and concern to several of the peer reviewers. This was not defined or described in the Express Terms, but multiple organizations thought that it was important enough to include. There was general agreement among most of the reviewers who expressed opinions on this topic that it should be possible for a person at a remote location, such as a fleet or traffic management center, to provide strategic guidance to an automated vehicle that has been impaired by a malfunction or that does not recognize or understand the environment in which it is located. There was only limited support for enabling a remote supervisor to provide direct operational control of vehicle motions (e.g., driving by joystick) because of security concerns, while on the other hand one organization was opposed to providing any remote supervisor capabilities (also based on security concerns).

One organization made specific recommendations for new language to define a remote operator and its functions:

"Remote operator" is a person who is not located in the driver seat of the vehicle and is capable of influencing the behavior of the vehicle's autonomous technology which enables the vehicle to execute one or more dynamic driving tasks.

Another organization favored the approach of calling for remote emergency assistance for the vehicle occupants rather than assuming a fleet operation context.

In the course of the meetings with peer reviewers it became apparent that the term "remote operator" had different meanings to different people. Some assumed that it involved a person with a joystick giving direct motion commands to the vehicle over a wireless communication link, like a military drone operator, while others envisioned it having more of a supervisory or dispatching function. In order to reduce that confusion, it would be better to account for use of a "remote supervisor" who can provide tactical direction for a vehicle that is unable to perform some of the tactical functions of the dynamic driving task (helping to diagnose and respond to unusual or confusing traffic or road conditions)..

It is not clear whether any of the existing language needs to be modified to account for fleet managed operations of AVs within strictly geofenced locations, but DMV should remain aware that the functional safety of such systems is likely to be based on the interactions between the vehicles, the local infrastructure and a fleet management system. In cases such as this, the vehicle is not the entire system to be evaluated for functional safety, but rather it is the combination of the vehicle, the infrastructure and the fleet management processes.

2.7 Behavioral Competency Definition

In the Express Terms, Section 227.02(f) defines:
"Behavioral Competency" means the ability of the autonomous vehicle to operate in all of the driving situations that may be encountered by an autonomous vehicle while operating on public roads that the autonomous vehicle must respond to either, by performing a driving maneuver, or requiring the operator to take control.

This definition is broader than the reality of how the behavioral competency is being used in the testing and licensing process because of its use of the qualifier "all". It would more accurately reflect the reality of its actual use by replacing "all of the" with "typical", because only typical situations are being specified in the behavioral competencies. One of the reviewers also suggested that it would be better to define the behavioral competencies separately by level of automation, and another reviewer suggested adding "and relevant to" after "encountered by". Both of these were superseded by a more general recommendation that the behavioral competencies be linked to the specific operational design domain for which each system is designed (to be covered in more depth in a later section).

2.8 Conditions for Re-certification of Systems

There was considerable concern among the reviewers about reaching a common understanding about what level of system change would require a re-certification of the system. In a software-based system, any software change, regardless of how small, could create a new fault condition. Many of the automation system concepts are based on frequent updates of software, yet it would not be practical or affordable to repeat the testing and certification process each time anything is changed in software.

It seems clear that a completely new vehicle would require testing and certification, but the situation is not so clear when existing vehicle models are updated. These modifications could vary widely in scope, from major to minor:

- addition of some completely new automation functionality or behavioral competency
- expansion of the operational design domain for an existing automation feature to include a broader range of operating conditions
- enhancement of the performance capabilities of an existing automation function
- fine-tuning the performance parameters of an existing automation function
- patching a defect discovered in the existing software
- updating a map database with more detailed information or newly constructed roads

- updating a real-time database of hazards in the roadway environment
- learning software on the vehicle adjusting its behavior based on accumulated data over extended periods of operation.

At the minor end of the scale, the ratio of benefits to costs of re-testing would clearly not justify the effort, but somewhere toward the higher end of the scale re-testing could be warranted. At this early stage of introduction of automation systems, it is probably only practical to require the full approval process for newly introduced vehicles, but in the longer term it will be important to consider extending the process to some of the more substantial modifications, as suggested by the definition of “material change” in Section 227.64(b). The certification of learning software is a huge technical challenge that is beyond the current state of the art in software engineering – nobody knows how to do it at this point.

2.9 Relationship of Functional Safety and Behavioral Competency

The approach until now has kept the functional safety and behavioral competency elements distinct from each other. However, some of the reviewers have expressed skepticism about this separation and have said that they must be connected and mutually supportive.

More specifically, most of the reviewers believed that the first cluster of behavioral competencies, the ones associated with fault detection and self-diagnosis, should have been treated as functional safety requirements rather than tested as behavioral competencies. That argument is a strong one, since these functions are entirely internal to the vehicle and do not depend on random external events in the driving environment. Furthermore, it is very difficult to create test conditions and to observe test results in a way that shows convincingly that the requirements have been met. These arguments will be revisited in more detail in the discussion of the self-diagnosis and failure response behavioral competencies.

Similarly in other categories of competency, many scenarios will be difficult to create experimentally and to quantify the test results as acceptable or unacceptable. The assurance of safety and reliability or robustness of an AV system can only be evaluated in a systematic manner if these requirements of behavioral competency are integrated and certified within the whole concept of functional safety. These arguments and test cases will be revisited in Section 4 about the individual competencies.

2.10 Other Items Specified in the Vehicle Code

Reviewers requested changes to a variety of items that are already specified explicitly in the California Vehicle Code and are therefore not subject to modification by the DMV as part of the current process. These are noted here as points of interest:

- definition of autonomous vehicle – clarify whether off-road vehicles are included and provide a mapping into the SAE Levels of Automation;

- definition of autonomous technology – should be clearer about whether it includes lower-level automation functions such as drive by wire;
- definition of driverless operation – call it driverless technology to be parallel with autonomous technology, and clarify roles of remote drivers.

3. General Approach to Behavioral Competency

3.1 General Comments about Importance of Behavioral Competency and Scope of Coverage Applied Here

A large majority of the peer reviewers were supportive of the general approach of using behavioral competency as a screening tool to eliminate the least-capable vehicles from use by the general public. Many of them commented on its limitations, in that executing the specified behavioral competencies successfully cannot provide any proof of the safety of the vehicle. However, they also recognized that given the immaturity of the automation technology and the lack of precisely specified technical standards or testing procedures there do not appear to be any other alternatives that can be applied at an affordable cost.

Some reviewers were concerned about the lack of specificity in the definition of the behavioral competencies, in that no quantitative performance thresholds were defined and the testing procedures were also not specified. One even commented that “manufacturers can pretty much do as they please” in the absence of specific requirements.

Several reviewers commented on the relationship between behavioral competency and functional safety, recommending that they be coupled more closely in the development of the regulations so that they are mutually supportive. Several made explicit reference to the ISO 26262 standard for automotive functional safety and recommended that its concepts and provisions be applied directly. It was not clear whether they were aware of the separate references to functional safety requirements in the Express Terms Section 227.56 (b)(2).

Although the question of self-certification versus third-party certification was declared to be outside the scope of this peer review, the topic still arose in the discussions. Several organizations suggested that the behavioral competency certification could be done in a similar way to the functional safety certification, with a focus on demonstrating a proper process for designing and verifying the behavioral competencies by the manufacturer, rather than relying on independently-run and witnessed testing.

3.2 Severity of Test Conditions and Acceptance Criteria

Extensive comments were offered on the cluster of issues associated with the strictness of the criteria for acceptance and the severity of the test conditions that should be imposed on the vehicles. These are all related to the philosophy of how the behavioral competency testing should be viewed in the context of approving vehicles for public use. This can be summarized in several dimensions:

- Are we assessing the automation system relative to a novice driver or relative to a safe, experienced driver?
- Are we testing for the normal, commonly-encountered situations, or are we aiming for the most challenging “corner cases” to stress the systems to the maximum?

- Are we focusing on single hazards or on the ability of the system to handle the rare simultaneous occurrences of multiple faults?
- If the tests cannot be comprehensive, or if the test results are not reproducible or fairly judged, how can such an approval process be enforceable?

Most of the reviewers were in agreement with the focus on testing for the equivalent of novice driver capabilities in dealing with commonly encountered situations with single hazards. However, there were a few who advocated for significantly stricter criteria that would come closer to "proving" the safety of a system in spite of the significantly larger investment of effort that would be required. Most reviewers were skeptical about the practicality of defining a set of challenging test cases that could "prove" safety within a number of tests that would be affordable to conduct, but a couple of reviewers advocated strongly for focusing on the "corner cases". One advocated selecting test conditions based on a measure of "criticality" of hazardous events, combining the probability of occurrence, severity of consequences and "controllability" (the ability of the system to respond).

A few reviewers recommended modeling the testing approach on the Euro-NCAP and NHTSA NCAP test procedures for driving assistance systems. However, they also acknowledged that those test procedures were designed to apply to systems with much simpler functional requirements and that design of equivalent tests for more highly automated systems would become extremely complicated. Most of the reviewers thought that this would be far too complicated to be practical.

A couple of reviewers suggested that different test approaches should be applied to correspond to different levels of automation, since different driver roles and responses are expected at each of those levels. Many others went further than that, recommending that the test conditions need to be chosen to be relevant to the specific functionality and operational design domain of each system.

After going over the full set of comments, the recommendation is to maintain the current general approach, but to shift some of the requirements out of the category of behavioral competency testing and into functional safety. In addition, there need to be specifications about which tests should be conducted in controlled facilities or on public roads, which will be discussed in more detail on those specific cases in Section 4 of this report.

3.3 Criteria for Passing and Failing

Most of the reviewers commented with concerns about the lack of explicit criteria for passing and failing the behavioral competency tests. This means that they don't know what target performance levels they need to achieve to be considered acceptable, which introduces uncertainty for their design process. However, the advantage of this uncertainty is that it deters them from "designing to the test" and forces them to think more seriously about what the real-world requirements should be (which are more demanding than any simple test could specify).

The lack of predefined passing and failing criteria is closely related to the philosophy of depending on the third-party testing organization to design and conduct specific tests, because the passing and failing criteria would only have meaning if they are coupled with precisely defined test cases. This is not a primary issue in itself but is one of the dimensions of the overall approach focusing on third-party testing.

3.4 Promoting Uniformity of Approach Across Third-Party Testers

There was widespread concern among the peer reviewers about how to ensure fairness in the third-party testing and evaluation process. In the absence of specific standards and test procedures, a great deal of responsibility and judgment is vested in the third-party testing organizations. The vehicle developers are justifiably concerned that there could be significant differences across the third-party testers in the level of rigor that they apply to the testing process, in terms of the design of their test procedures and in the pass/fail thresholds that they apply. They made several suggestions for how to manage this problem:

- DMV hires a single third-party tester directly and supervises the testing that they do to ensure uniformity across cases.
- DMV reviews and approves the qualifications of multiple organizations in advance and has them available under an (IDIQ type) contract to perform tests when an application is submitted.
- DMV requires the testing organizations to submit their qualifications and testing approaches for prior review and approval by DMV, so DMV can verify that they are all within a reasonable range before they are certified by DMV to be qualified to do this work.

One organization also suggested using a process to analogous to FAA certification of aircraft testing procedures but that does not appear to apply here because that process is based on certifying adherence to clearly defined standards.

This is an important issue, and DMV would be well advised to adopt one of these approaches to provide some level of fairness and uniformity, with suitable modifications to Section 227.58 and/or Section 227.60.

3.5 Identifying a Possible Role for Simulation as an Alternative to Testing

Many of the peer reviewers were concerned about the cost and complexity of testing vehicle systems, especially if they need to be tested for a wide range of scenarios. This becomes an even more acute concern when the tests get into safety-critical situations or the need for multiple precise repetitions of conditions and situations that require precise control of multiple experimental variables, especially those that are difficult or impossible to control, such as weather. One potentially safer and less costly alternative is the use of simulation as an alternative to testing, which was proposed by a few reviewers. In this case the challenge is how to verify that the simulation is an accurate representation of reality, a topic that is currently the subject of considerable research.

Until that research has matured further, there does not appear to be a strong case for making regulatory decisions on the basis of simulations. Simulation, however, can be adopted as one of the approaches in the evaluation of functional safety. It can be expected that results from simulations may be submitted as part of the supporting evidence by some manufacturers.

3.6 Operational Design Domain (ODD)

Many of the peer reviewers emphasized the diversity of the automation systems that will be developed and the difficulty of accommodating that diversity within a single rigid evaluation framework. This was particularly problematic for the definition of the "areas of operation" as a simplified representation of the different operating conditions in which the automation systems will have to function. That led to the idea of focusing on the specific operating conditions in which each system is designed to operate, which has been termed Operational Design Domain in SAE J3016.

Operational Design Domain: The specific operating conditions under which a given driving automation system or feature thereof is designed to function. An operational design domain may include geographic, roadway, environmental, traffic, speed, and/or temporal limitations.

The reviewers were consistent in noting that each system will have its own distinct ODD restrictions based on the capabilities that its manufacturer has chosen to provide, and it does not make sense to test a system for conditions outside its ODD as long as the manufacturer has made sure that it cannot be activated for use outside its ODD. This type of ODD restriction was addressed as behavioral competency #3 (Detect and respond to system engagement and disengagement restrictions), but the reviewers were strongly in favor of handling this as a functional safety requirement instead (to be discussed in more detail in Section 4).

Several reviewers also noted that some systems could be designed to provide high levels of automation within very restrictive ODDs, and those should not be discouraged by requiring them to be tested across a much wider range of conditions. Focusing on the ODD could also be a very clean way of accommodating the specific needs of the most likely near-term systems such as automated valet parking systems, low-speed urban shuttles for pedestrian zones or campuses, or systems that would take over all highway driving responsibilities for short periods of time within narrowly defined speed ranges.

To accommodate this recommended focus on Operational Design Domain, several things would have to be done in the regulatory documents:

(1) Include definition of Operational Design Domain in Section 227.02
(2) Edit other text to focus requirements on the ODD for the specific system being evaluated, especially for the behavioral competencies
(3) Require the manufacturer to specify the ODD for their system in their application, with a listing of the minimum set of ODD characteristics that they need to address. If DMV agrees with this approach, PATH can help on refining the ODD language.

(4) Delete the Areas of Operation from the definitions and any other places where the term is used, and replace it with ODD
(5) Delete the separate columns for Areas of Operation in OL318 Part B and replace them with two columns to indicate how each behavioral competency is to be tested (closed-track testing or public road testing).

3.7 Range of Environmental/Weather/Lighting Conditions for Tests

Several reviewers noted that the behavioral competency testing requirements did not address the potentially wide range of environmental, weather and lighting conditions that systems will have to handle in the real world. On the one hand, this is a serious limitation because those diverse conditions impose significant burdens on the developers of the systems, especially for sensor performance, and there are large differences between systems that only operate under benign conditions and those that operate under a full range of conditions. On the other hand, it would be complicated and expensive to create realistic test scenarios to cover a wide range of these conditions in full-scale vehicle tests, especially for weather conditions that are not commonly encountered in California.

This problem can be overcome by emphasizing the ODD for each system, combined with a functional safety requirement that the automation not be engaged when it is outside its ODD. As suggested in a previous section, some of these difficult-to-test or difficult-to-quantify scenarios will fall under the categories of competencies to be handled in the functional safety plan. Some examples will be given in Section 4 when individual competencies are discussed.

3.8 Handling Automated Valet Parking Systems

Several vehicle manufacturers are developing automated valet parking systems with diverse characteristics. Some of these systems are designed to perform complete parking maneuvers with no driver in the vehicle, but with an operator supervising its parking while watching from a nearby location and manipulating a personal electronic device. Other systems will soon allow the parking to be done without the supervisory operator. The current behavioral competency requirements make no special provisions for this very limited type of automation, but instead require it to meet the full set of urban requirements if it is to be used in an urban area. That is a significant impediment to market introduction of this limited-capability system.

The recommendation from one of the peer reviewers is that this should be handled by focusing on the ODD for each valet parking system and the specific functions that it needs to perform. If the manufacturer can show through a behavioral competency test that the valet parking system can perform all of the specific functions that it needs to perform within the ODD where it can be activated, it should be approved for public use. It does not need to show that it can perform all urban driving functions. This will then also be applicable to parking systems that are not necessarily limited to urban areas.

3.9 Handling Low-Speed Urban Shuttle Systems

The low-speed urban shuttle systems represent another specialized near-term application of automation that is not well accommodated within the existing framework of behavioral competencies. Several reviewers commented on the more limited range of operations that these vehicles would have, so that they should not be required to show the full range of urban driving behavioral competencies, and they even made finer grade distinctions among different categories of low-speed shuttle systems. They also noted that these are generally not equipped with a designated driver's seat, so regulatory references to a driver's seat are not relevant to them. One developer of these systems indicated an intention to have an operator on board the vehicle, with the ability to take over control of the vehicle as necessary, but to be arbitrarily positioned within the vehicle.

To accommodate the more diverse and specialized needs of this class of vehicles, the references to a conventional vehicle layout with a designated driver's seat should be relaxed. As long as the operator has the ability to intervene to ensure vehicle safety, it should not matter where that operator is located.

(1) In Section 227.02 (b) the definition of "autonomous mode" does not need to include the words "sitting in the vehicle's driver's seat", so those can be deleted without any loss of meaning.
(2) In Section 227.02 (e) the definition of "autonomous vehicle test driver" should replace the words "seated in the driver's seat of an" with "located in the" so that the test driver can be positioned with more flexibility inside the vehicle.
(3) In Section 227.02 (g) the definition of "conventional mode" does not need to include the words "sitting in the driver's seat", so those can be deleted without any loss of meaning.
(4) In Section 227.02 (p) the definition of "operator" can replace the words "while sitting in the driver seat of the vehicle" with "while located inside the vehicle" without any loss of meaning.
(5) Section 227.80 (c) does not need to include the words "next to the driver's seating position".

The concept of the ODD is also directly applicable to the low-speed urban shuttle vehicles and the proposed change to the behavioral competency tables in OL318 Part B will allow the tests to be tailored to the situations that are actually relevant to the operations of these vehicles.

3.10 Infrastructure Requirements

Several reviewers commented on the importance of infrastructure interactions with the automated driving systems. Most of these systems depending on their ability to detect features in the roadway infrastructure, and if those features are not easily detectable the automation may not function satisfactorily. In some cases, infrastructure features are used to exclude some categories of hazards (the most obvious example being freeways, which exclude cross traffic and vulnerable road users). Several reviewers expressed concern that the proposed competencies did not take proper account of the importance of infrastructure variations and the need for infrastructure support (especially for low-speed urban shuttles).

It is not clear that much can or should be changed to address these concerns about infrastructure. The primary means of ensuring that the driving automation system is compatible with the roadway infrastructure it is using is likely to be geo-fencing by the system developer, to ensure that the automation can only be activated when the vehicle is positioned in locations with suitable infrastructure characteristics.

3.11 Distinguishing Between Tests that Must be on Closed Courses and Tests that Can or Should be Done on Public Roads

Many of the reviewers expressed concerns about identifying where the different behavioral competency tests should be conducted, based on considerations of cost, repeatability, safety and the amount of time that would have to be spent to encounter all of the necessary conditions. There were multiple recommendations that the type of location for each test should be specified so that the test conditions are as uniform as possible. Although a few reviewers recommended that the public road testing be done on specific designated roads, most recognized that this would be too much of a temptation for developers to game the test by tailoring their systems to the peculiarities of those roads.

Based on these review inputs, the type of location where each of the behavioral competency tests should be performed will be recommended in Section 4 of this report. The closed test courses will be recommended for the tests that would be too dangerous to do on public roads and the tests that require staging specific types of scenarios that will not be encountered frequently in normal driving. The public roads will be recommended for the tests of typical driving situations and random encounters with vehicle traffic and other road users. One of the main concerns is also the poor availability of closed test courses available for use by organizations other than the facility owners in California. With these requirements being specified for each behavioral competency individually, the language of Section 227.58(d)(5) should be deleted or else it should directly reference the updated OL318 Section B to indicate where each test should be performed.

4. Behavioral Competency Requirements.

It was expected in the development process, and it became more evident during the peer review, that the proposed demonstration tests of behavioral competency as part of the AV regulations will encounter numerous challenges in their implementation. It is particularly noted that the fairness, clarity, comprehensiveness, and reproducibility of tests results will be difficult to monitor, control or scrutinize in order to systematically establish the basis for evaluating the target AV systems.

4.1 Three-Stage Evaluation and Demonstration of Competency

A revised framework is proposed in which the behavioral competency will be examined in three stages. The first stage is certified within the functional safety plan. The second stage is tested by driving the AV at a controlled environment test track. The third and final stage involves driving the AV on public roads. The test scenarios at the three stages are not necessarily mutually exclusive.

(1)The first stage of evaluation corresponds to §227.56(b)(2) in the Express Terms, where the current language is as follows:

"Certification that the manufacturer adheres to an established functional safety plan for the design and development of the subject autonomous vehicles. The functional safety plan shall, at a minimum, cover each area of operation and behavioral competency, identified in the form OL 318, Part B that includes all of the following: "

Note: The use of "areas of operation" to define competency requirements was discussed in previous sections. If that is changed as recommended in this report, then the language here will be modified as well.

There are some operating scenarios in which the AV system will be required to perform safely, but for which the test cases are challenging to set up and cannot be comprehensively conducted. For example, weather conditions such as rain, fog, snow, ice and environmental conditions such as lighting and visibility will prevent a demonstration test from being conducted in a practical manner. If these conditions are within the ODD, it will be reasonable to expect that a safety case and design process has been established to ensure that the AV can perform per design. If some of these test scenarios are outside of the ODD of the subject AV, then it is also to be defined in the functional safety plan how the AV will recognize the limitations and respond accordingly. The requirements for these competencies will fall within the functional safety requirement that the manufacturers should meet, and they will be part of the overall functional safety plan in the manufacturers' application.

(2) Once the first-stage requirement has been certified or met, a selected set of test cases will be suggested by the third-party organizations as currently described in the draft regulations to demonstrate the behavioral competency. In particular, these test cases will represent those

scenarios that are not frequently encountered and those that may involve relatively more challenging maneuvers than those taken in everyday driving. This stage of demonstrations is to be conducted in a controlled environment, to guard against potential safety risks, to avoid unnecessary hazards to the public and the testing party, and to create specific scenarios that would not be encountered frequently enough to be sure that they will occur in a reasonable-length drive on public roads.

(3) If the test results are satisfactory from the testing in the controlled environment, then a third stage of tests will be performed in real-world settings on public roads. This is analogous to the driving performance exam for people who are taking their driver's license test. Although the examiner may direct the tested system to make various maneuvers and driving tasks on public roads, the expectation is that the test conditions are mostly benign. The purpose of this last stage of tests is to observe and judge if the AV system can perform in a safe and an appropriate manner when it is interacting with other road users and the typical road infrastructure.

In the following sections, this three-stage framework will be referenced, and some examples of test cases will be given. However, the actual required test cases will have to depend on the actual design implementation and the level of functionality offered by the specific AV being evaluated, and thus will be determined in a case by case evaluation, for which the third-party organization should submit a test plan for review and approval.

4.2 Roles of Manufacturers, Third-Party Organizations and DMV

According to the current draft regulations, the manufacturers will need to certify that the AV systems meet the functional safety requirements, as described in Stage 1 above. For Stage 2, a third-party organization is involved. It is well reasoned from a check-and-balance point of view to require a third-party organization to design and perform this stage of tests. However, it is also noted that the U.S. automotive industry currently follows a self-certification model for federal safety standards. Since it is not a prevalent practice to use a third-party organization in the U.S., there is a shortage of infrastructure and supporting systems to execute the new approach efficiently. It is challenging to manage the third-party involvement in a fair and comparable manner in a field where no standards exist and it will be necessary to establish a procedure for qualifying the third-party organizations.

As for the third stage of testing on public roads, this could be conducted by a third-party organization or under the supervision and evaluation of DMV, depending upon the level of involvement that DMV prefers to have. The test scenarios are not pre-defined, but rather some elements of the test scenarios will be random encounters with other road users and infrastructure. DMV may need to establish and train a group of its staff to specialize in this task if it chooses to take on this direct responsibility.

One major change to the current OL318 is the recommendation to describe the competency by the operational design domain (ODD) for the specific system, as explained in a previous section. If that is accepted, then the three columns on the right of OL318 need to be removed. In their place, columns should be inserted to specify which of the three stages of evaluation defined above are required. For almost all competencies, it is implicitly required per §227.56(b)(2) that Stage 1 is required. Thus, this does not need to be repeated in OL 318 and only two columns are added for Stage 2 and 3 testing.

4.3 Self-Diagnosis and Failure Response Requirements

General Review Findings on this Entire Category:

Summary of Comments:

- One primary issue is that self-check or diagnosis functions are embedded inside the algorithms or system architecture, and it is difficult to observe and recognize through testing if they are functioning as designed.
- Furthermore, the self-check or diagnosis will depend on the system configurations, which unavoidably lead to the issue of comprehensiveness or completeness of the tests that can be performed on the AV system.
- The consensus of the peer reviewers was to treat this competency under the umbrella of functional safety.
- One other issue is that there will be redundancies or degraded modes of operations that are built into the AV systems, so the requirement for total disengagement is not the best option as long as a system is designed to operate in a fail-safe manner.
- The requirement implicitly assumes a "go/no go" operational status. Certain elements of the system (e.g. localization) will operate on a continuum of performance. The regulations should allow for degraded modes of operation for the vehicle to "limp home" rather than making it a strict go/no go contrast after a fault.
- As the competencies seem to be relevant in all areas of operation, this could be reframed by automation capability level, based on the SAE levels.

Recommendation:

- Treat this entire category of competency under functional safety (Stage 1).

Competency 1:
Prior to engagement, perform a system self-check to verify that the system is operational.

Summary of Comments:

- Similar comments as stated in the general comments above about the practicality and feasibility of conducting tests that will reflect the proper functioning of self-check and diagnosis.

Recommendations:

- Handle this under functional safety.
- Change the second bullet to:

"prevents activation *or transitions to a fail-safe mode* if faults *that are safety-critical and essential to the safe operation of* the autonomous technology are detected"

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
1. Prior to engagement, perform a system self-check to verify that the system is operational	• Performs a system self-check prior to engagement of the autonomous technology • Prevents activation **or transitions to a fail-safe mode** if faults **that are safety-critical and essential to the safe operation of** the autonomous technology are detected		

Competency 2:
Visual indicator to indicate when the autonomous technology is engaged

Summary of Comments:
- Many comments were centered around the meaningfulness and implications of an indicator, and the availability or simple illumination of the indicator may not fully indicate the status of the system.
- The requirement should focus on the state transition into operation, so that a failed indicator light doesn't cause a system shutdown in the middle of operation – this would be "Does not allow autonomous technology to *become* engaged…"

Recommendations:
- There can still be a demonstration of this feature in the final test (Stage 3) to validate the requirement, but it is also appropriate for certification under functional safety (Stage 1).
- Although there were multiple suggestions about the necessity of this element, the first bullet needs to stay because it was required by the original legislation.
- Change in the second paragraph:
  "Does not allow autonomous technology to *become* engaged if visual indicator is not functional"

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
2. Visual indicator to indicate when the autonomous technology is engaged	• Displays visual indicator inside the cabin when autonomous technology is engaged • Does not allow autonomous technology to **become** engaged if visual indicator is not functional		X

Competency 3:
Detect and respond to system engagement and disengagement restrictions

Summary of Comments:
- Many reviewers raised questions about whether the response to restrictions should be complete disengagement and whether degraded modes could be allowed.
- Examples should be added to the last paragraph to describe restrictions in the language; such as weather or geographical location.

- Restrictions may not necessarily require complete mission ending or a decision for total disengagement.
- The appropriate response, safe or unsafe mode of operation, will be determined by threat assessment and risk analysis, which can be conducted under functional safety.
- It's not practical to test all of these adverse conditions, such as under all levels of foggy, rainy, icy, or snowy conditions.
- There could be an operational concept in which the engagement and disengagement are dictated by the users' choices within relatively short time windows.

Recommendations:

- Handle this under functional safety
- Allow for a degraded mode of operation (reduced performance operating mode to ensure safety) as an alternative to the complete stop (and delete the modifier "safe" because it does not add value)
- There is a problem in the Express Terms description of this test in Section 227.58 (d)(1), which says "ensure that the vehicle is incapable of operating outside of the intended area of operation". In this context, "vehicle" should be replaced by "autonomous technology" because the vehicle could still be driven manually anywhere, but the restriction is meant to apply to the autonomous technology.

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
3.Detect and respond to system engagement and disengagement restrictions	• Allows autonomous technology to be engaged when the vehicle meets all conditions for autonomous mode • Detects any restricted condition under which the vehicle is not intended to operate and: – If autonomous mode is not already engaged, prohibits the operator from engaging autonomous mode – If autonomous mode is already engaged, responds to disengagement condition by either transferring control to the operator, **switching to a reduced performance operating mode to ensure safety**, or coming to complete ~~safe~~ stop System engagement and disengagement restrictions could include, **for example**: area of operation; geo-fencing by location or road type; weather conditions (rain, snow, fog, extreme heat or cold, etc.); roadway conditions (black ice, wet road surface, degraded lane markings); and time of day or lighting conditions		

Competency 4:
Detect and respond to failure of autonomous technology

Summary of Comments:

- Similar comments as given above regarding focusing on safety-critical failures only and providing the option of operating in degraded modes

- However, there were some opposing opinions to not allow a degraded mode of operation, which may increase the safety risk to the operator and public.
- Use language of “not take control” instead of “unable to take control.”
- The vehicle should be required to transition to a minimal risk condition rather than specifically to a complete stop.
- In the first bullet, the operator should be alerted to the existence of *an* autonomous technology failure, not “the” failure, because that would be too specific and distracting.
- In the second bullet, the system can only “Request” the operator to take control, but cannot “Require” that.
- In the first bullet, “Alerts the operator of the autonomous technology failure or if functionality is not performing at nominal level.”

Competency 4a:
Detect and Respond to Failure of Autonomous Technology (Driverless Operation)

Summary of Comments:
- What is the definition of remote operator?
- What actions or levels of control are to be carried out by the remote operator?
- The first set of responses about alerting the operator and requiring the operator to take control should not be applicable for a driverless system
- There is an issue with alerting the remote operator, based on the distinction between fleet vehicles and privately owned vehicle.
- The intent of the competency is to seek help for a stranded occupant. Specifying a “Remote operator” may inadvertently preclude individual ownership of autonomous vehicles

Recommendations:
- Handle this under functional safety
- Change the first bullet to:
  - “Detects a failure *that is safety-critical and essential to the functioning* of the autonomous technology while the autonomous technology is engaged and:
  - Alerts the operator of an autonomous technology failure *or if its functionality is not performing within design limits*
- Change the second paragraph to:

  “Request operator to take control of the vehicle or, if the operator does not take control of the vehicle, switches to a reduced performance operating mode to ensure safety , or comes to a complete stop.”
- If driverless operations become part of the regulations, add and clarify the requirements for driverless operations:

  “*Calls for assistance in the event of* the autonomous technology failure”

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
4.Detect and respond to failure of autonomous technology	• Detects a failure **that is safety-critical and essential to the functioning** of autonomous technology while the autonomous technology is engaged and:		

	– Alerts the operator of the autonomous technology failure **or if its functionality is not performing within design limits** – **Requests** operator to take control of the vehicle or, if the operator does not ~~or is unable to~~ take control of the vehicle, **switches to a reduced performance operating mode to ensure safety**, or comes to a complete ~~safe~~ stop ~~as defined in Section 227.56 (b)(6) Title 13 of the California Code of Regulations~~		
(Driverless case)	• **Calls for assistance in the event of** the autonomous technology failure		

Competency 5:
Moving to safe complete stop

Summary of Comments:

- This should only apply to serious failures, not all failures.
- Similar comments as above for the option of allowing degraded modes.
- Moving to a complete stop may not be the best option and there are complications for the surrounding traffic or road users.
- A more appropriate term may be "safe state" that is context-dependent.
- At some parts of roads like freeway junctions it might be safer to use an automated limp home to safe stop.
- The wording of autonomous technology versus autonomous vehicles in the first paragraph needs to be fixed. This should be autonomous technology.
- Driver takeover should be a permissible response so that the driver can use the vehicle's manual controls rather than compelling a vehicle stop.
- NHTSA's recent interpretation to Google has the potential to provide eventual relief on FMVSS108 for activation of hazard lamps by the AV. (This comment also applies to the previous section where the hazard lamp is discussed.)

Recommendations:

- Handle this under functional safety
- Apply the qualifier that this is applicable to failures that are safety-critical and essential to the functioning of the autonomous technology.
- Some tests of this competency are still needed in Stage 2, but probably not in Stage 3 because of safety considerations.
- Relabel this to be "moving to minimum risk condition" for consistency with proposed change to language of Section 227.56(b)(6).
- Allow for a reduced-performance mode of operation to ensure safety.
- Although the legislative language says that it "shall be capable of coming to a complete stop", that does not mean that it must come to a complete stop in all cases, so these applications of minimum risk condition and reduced-performance modes should still be acceptable within that legislative requirement.

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
5.Moving to **minimum risk condition**	•In the event of a failure **that is safety-critical and essential to the functioning** of the autonomous **technology** and the operator does not ~~or is unable to~~ take control of the vehicle, **switches** to a reduced **performance operating mode to ensure safety**, **or transitions to a minimum risk condition** as defined in §227.56(b)(6) Title 13 of the California Code of regulations •In the event of a planned transfer of control to the operator and the operator does not ~~or is unable to~~ take control of the vehicle, **switches to a reduced performance operating mode to ensure safety**, **or transitions to a minimum risk condition** as defined in §227.56(b)(6) Title 13 of the California Code of regulations	X	

4.4 Detection of, and Response to, Vehicular Traffic

General Comments in this Category:

Summary of Comments:

- There should be a clear indication of the testing environment to be expected for the competency, for example whether it should be done in real world driving or in controlled test facilities.
- The criteria for the appropriate response to traffic are not specified clearly, and there are concerns that "appropriate" is too vague and subjective a term to use as a passing criterion.
- The threshold for pass or fail is difficult to define, as it depends on the specific scenarios. For example, is "no contact at all" required under all circumstances? What about unavoidable crashes? Should post-crash behavior be considered?
- There is no consensus on the test scenarios that should be used, but most participants are not advocating extreme corner cases.
- There is also a question about AV behaviors being conservative or defensive and causing other vehicles to behave differently.
- There are numerous other maneuvers that may be added to the requirements, besides those listed, for example:
  - detection of low clearances above the vehicle (for trucks)
  - emergency braking of the preceding vehicle
  - detection and response to erroneous behavior of other vehicles
  - reaction to vehicles in special situations (skidding, out of control)
  - vehicles which are going to collide with the AV unintentionally (example: AV was overlooked in the blind spot)
  - Motorcycles that travel between lanes (lane splitting) can be a challenging case.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operations, as discussed in previous sections.
- This category of competency may include a mix of testing and verification requirements in all three stages.
- For example, safe following of lead vehicle can be conducted and observed in real-world driving (Stage 3) but situations involving hard braking maneuvers should be tested in controlled environments (Stage 2). Systematic evaluations of how the AV interacts with traffic should be part of the functional safety plan (Stage 1).

Competency 6:
Detect and respond to lead vehicle

Summary of Comments:

- Lead vehicles are not necessarily more threatening, e.g. there are threatening situations when big trucks are coming from behind.
- To require detection and response to proximate and pertinent vehicles will be more appropriate than just lead vehicles.
- However, the extension of requirements to other vehicles implies more extensive sensing capability for all AVs.
- If a maneuver (to avoid proximate vehicles) is not required under vehicle codes, then it may not be considered a requirement.
- Besides safety, there are other behavioral considerations
- Maintaining a safe distance leaves much room for interpretation; safe following distances are interpreted differently in different jurisdictions.
- Following distance varies by state and with driving conditions. Allow OEM to define the following distance. Currently, ACC following distance is tuned based on customer expectations.

Recommendations:

- This competency includes verification at all three stages.
- Selected demonstration cases should be conducted in controlled environment (Stage 2).
    - For example, tests of lead vehicle decelerating suddenly and AV need to brake or steer to avoid collisions
    - The detailed list of test cases and test results to be evaluated should be submitted by the third-party organization and reviewed by DMV.
- Test scenarios that are expected in everyday driving should be included in Stage 3.
- Change the competency to:

"Detect and respond to <u>*proximate and pertinent*</u> vehicles"

- Change the description of the competency to:

Detects <u>*proximate and pertinent*</u> vehicles in the travel path and <u>*maintain safe and reasonable*</u> distances <u>*from those vehicles*</u> over the full range of operating speeds".

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**

6.Detect and respond to **proximate and pertinent** vehicles	• Detects **proximate and pertinent** vehicles in the travel path • Maintains safe **and reasonable** distances **from those vehicles** over the full range of operating speeds Examples of **proximate** vehicle situations include: lead vehicles turning left or right, or changing lanes, stop and go traffic, and emergency braking in response to a rapid lead vehicle deceleration. A variety of ~~lead~~ vehicle types may be encountered in the vehicle's area of operation, including motor vehicles, motorcycles, and trailers.	X	X

Competency 14:
Detect and respond to merging traffic

Summary of Comments:

- Appropriate response maneuvers may include lane changes in addition to coming to a safe stop.
- There was confusion about whether this applied to general lane changing or only lane changing at highway merges.
- However, AV may not have full capabilities to respond with a lane change under certain circumstances.
- AV may need to respond to inappropriate lane changes of other vehicles in adjacent lanes.

Recommendations:

- This competency includes verification at all three stages.
- To avoid confusion, change from "merge" to "lane change" in the description of this competency.
- It will be necessary to include in the safety plan a systematic evaluation of how the AV reacts to lane changing vehicles in a variety of conditions, with variations in gaps between vehicles, relative speeds, speeds of other vehicles, traffic density, etc. (Stage 1)
- A set of test cases to be done in controlled environment should also be proposed by the third-party organization. (Stage 2)
- Test scenarios expected in everyday driving will be observed and reviewed in real world traffic. (Stage 3)
- Change the second bullet to:

"takes appropriate response to *<u>other vehicles that lane change into the travel path of the autonomous vehicle</u>*" for appropriate actions

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
14. Detect and respond to a **lane changing** vehicle	• Detects when another vehicle is attempting to **change lanes** into the travel lane ahead • Takes appropriate response to **other vehicles that lane change into the travel path of the autonomous vehicle**. Scenarios involving a **lane changing** vehicle include: **lane changes** when the other vehicle indicates intention to **change**	X	X

	lanes with turn signals; **lane changes** when the other vehicle does not use turn signal prior to **maneuver**; abrupt **lane changes** with short following time gaps; and gradual **lane changes**.		

Competency 16:
Detect and respond to oncoming traffic

Summary of Comments:

- There was a serious concern regarding whether the case of oncoming freeway vehicles should be a required competency. There is no uniform consensus but the majority thinks the requirement for responding to oncoming traffic on freeways is too extreme.
- Furthermore, it was pointed out that even on rural roads or urban corridors, to respond to oncoming traffic under all circumstances is extremely difficult based on today's automotive technologies, so a requirement for this would exclude most near-term deployment products.
- It is questionable what will constitute an appropriate action in these situations.
- It is also very difficult to conduct some of these tests.
- "Evasive" has been interpreted to mean steering specifically rather than the broader combination of steering and speed adjustments.

Recommendations:

- The requirement to deal with oncoming traffic is quite broad. It will be reasonable to require the subject vehicle to follow traffic rules and stay within its travel lane, according to the vehicle codes. However, it is difficult to quantify the response if the oncoming traffic encroaches into the travel lane of the subject vehicle, especially at the last second.
- The recommendation is to delete this competency. The situations of encountering oncoming traffic will be partially addressed by other competencies including:
    - Competency 6 that deals with proximate and pertinent vehicles.
    - Competency 7 that deals with obstacles.
    - Competency 12 that deals with traffic control devices.
    - Competencies that deal with navigation and maneuvers.
- If this competency still remains,
    - Change the second bullet to:

"Take appropriate <u>*avoidance or mitigation maneuvers*</u>" instead of "evasive actions".

Competency 7:
Detect and respond to stopped vehicles and obstacles in the roadway

Summary of Comments:

- There were numerous comments and serious concerns about the sizes and types of obstacles that are required to be detected.
- There are also significant variations in the way stopped vehicles of varying sizes are positioned relative to travel paths.
- There are environmental conditions, such as lighting or weather, to be considered and prioritized.

- There are obstacles that are lying relatively low on the surface or holes in the roads, which are critical but very difficult to detect.
- There are situations where some loose or moving objects are crossing the roads, or objects falling off a truck or car.
- There could be multiple objects, which may exist in real world situations, but detection is beyond technology limits.
- Many situations cannot be reliably detected by today's automotive technologies.
- "Taking appropriate maneuvers" is better than saying "evasive" because the appropriate maneuver may be braking or even doing nothing, depending on the specific circumstances.
- How will obstacle detection be verified? Consider testing only for traffic control devices (barrels, cones, flares etc.) and a standard obstacle to represent road debris.

Recommendations:

- This competency includes verification at all three stages.
  - It is necessary to conduct systematic evaluation of the safety design for determining the proper response to various types of obstacles. (Stage 1)
- Some test cases for this competency should be conducted in controlled environment (Stage 2)
  - For example, a selected set of conditions that requires the AV to apply hard braking and make lane changes can be suggested by the third-party organization.
- Real world testing should only include typical situations that may be encountered in everyday driving
- Limit the obstacles to be in the travel lane of the AV
- Limit the obstacles or stopped vehicles that can be "reasonably detected", while recognizing that this still leaves a significant subjective element until there is agreement on a standard test obstacle.
- Change the first bullet to:

"Detects stopped vehicle or obstacle in *the travel path of AV* *that can be "reasonably detected.*"

- Change the second bullet to:

"Take appropriate *avoidance or mitigation maneuvers*" instead of "evasive actions".

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
7. Detect and respond to stopped vehicles and obstacles in the roadway	• Detects stopped vehicle or obstacle in the **travel path of the autonomous vehicle that can be reasonably detected** • Responds by taking appropriate **avoidance or mitigation** maneuvers Stopped vehicles that could be encountered in a vehicle's area of operation include: disabled vehicles, parked vehicles, vehicles stopped for traffic, vehicles stopped for traffic control devices, and vehicles waiting to turn or enter an intersection. Obstacles that could be encountered in a vehicle's area of operation include: static objects, dynamic objects, and objects partially blocking the lane.	X	X

4.5 Detection of, and Response to, Other Road Users

General Comments in this Category:

Summary of Comments:

- Animals should be a separate case, because the response to all sorts and sizes of animals should be different and the legal requirements are completely different for animals compared to people.
- School buses should be a special case because of the traffic rules surrounding them. Consider driver handoff when encountering a school bus with flashing stop lights.
- Emergency vehicles should only include those on emergency calls (using lights and sirens).
- There are lots of other road users, for example, farm equipment, construction equipment, horse carriage, moped, e-bike, skateboarders, wheelchairs, personal mobility vehicles (Segway) that may be a real problem.
- Test conditions for vulnerable road users are potentially challenging: where and how should they be tested?
- The detection of all road users of varying types and sizes are in reality very difficult to achieve due to limitations of technologies
- In some cases, some infrastructure support and requirements are needed

Recommendations:

- Make requirements correspond to the ODD for the specific system, instead of areas of operation.
- This category of competency may include a mix of testing and verification requirements at all three stages. Some examples will be given in individual competencies.
- For example, proper and attentive response to pedestrians can be observed in real-world driving (Stage 3) but situations involving hard braking types of maneuvers should be tested in controlled environment (Stage 2). Systematic evaluation of how AV interacts with other road users should be part of the functional safety plan (Stage 1).

Competency 8:
Detect and respond to bicyclists, pedestrians, and animals

Summary of Comments:

- The detection of stalled vehicles on freeways is reasonable, but the detection of pedestrians on freeways under all circumstance is difficult and to avoid them properly may not be possible in all circumstances.
- The Emergency Brake Assist System test of Euro-NCAP may be worth checking out. It uses moving dummies.
- Realistic tests to ensure compliance could be performed through the use of standard dummies.
- There were many concerns about including animals because in most cases it is better to hit the animal than to take an avoidance maneuver that may risk a different crash, and also animals are particularly difficult to detect (especially to predict their trajectories).

Recommendations:

- Some competencies should be considered under functional safety (Stage 1)
  - For example, a systematic evaluation of safety design will be necessary to evaluate how the AV deals with pedestrians in its ODD
- Some selected test cases for this competency should be conducted in a controlled environment (Stage 2)
  - For example, a selected set of test cases that requires the AV to take risky maneuvers can be conducted.
  - Dummies for pedestrians and bicyclists should be used in these tests.
- Real world testing can cover only typical situations encountered in daily driving (Stage 3)
- Delete the requirements for animal detection and avoidance.
- Change the first bullet to:

"Detects stopped bicyclists and pedestrians *<u>in the travel path of AV</u>* *<u>that can be "reasonably detected.</u>*"

- Change the second bullet to:

"…takes other *<u>avoidance or mitigation maneuvers</u>*" instead of "evasive actions".

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
8. Detect and respond to bicyclists and pedestrians ~~and animals~~	• Detects bicyclists and pedestrians, ~~and animals~~ **in the travel path of the autonomous vehicle that can be reasonably detected.** • Takes appropriate action to yield the right of way or takes other **avoidance or mitigation** maneuvers Pedestrian scenarios that could be encountered in the vehicle's area of operation include: pedestrians moving at different speeds and in different directions; pedestrians in both marked and unmarked crosswalks, at intersections or midblock; pedestrians crossing the roadway who are not in crosswalks; and pedestrians partially in the roadway Scenarios related to bicycles that could be encountered in the vehicle's area of operation include: cyclists in the lane, on the shoulder, or in an adjacent bike lane, and vehicle approaching the cyclist from the rear and passing in accordance with Vehicle Code Section 21760	X	X

Competency 9:

Detect and respond to emergency vehicles

Summary of Comments:

- The emergency vehicle response should be restricted to EVs that are on emergency calls using their flashing lights and sirens to avoid many false alarm cases.
- No indication is given as to the types or configurations of emergency vehicles to be detected or of the circumstances in terms of the emergency vehicle(s)' distance, speed in relation to

the autonomous vehicle or indeed the driving context in terms of traffic density, roadway characteristics, nor are there any requirements.

- Recognize and allow for possible conflict between responding to emergency vehicles and adhering to normal rules of the road, so that these don't create a Catch-22 situation for vehicles.
- Stopping can be counter-productive in case of approaching emergency vehicles.
- What is the definition of emergency vehicles and the proper response to emergency vehicles as specified in CA vehicle codes, and how may that differ from one jurisdiction to another?
- In urban areas, handing control back to the driver should be an acceptable response to approach of emergency vehicles.
- Detection of EVs could be challenging on curving mountain roads in rural areas, and may not leave time for transition to driver.
- Drivers should be detecting and responding to EVs in Level 3 automated driving.
- The same general considerations apply to school buses, except that the appropriate response should be different, but is equally important.

Recommendations:

- This competency includes a mix of requirements at all three stages.
- For example, proper and attentive responses to emergency vehicles may be observed in real-world driving (Stage 3) but they are rarely encountered. Situations involving interactions with emergency vehicles are best to be tested in controlled environment (Stage 2) because the presence of emergency vehicles cannot be anticipated or arranged in advance on public roads. Additionally, the maneuvers may lead to some hazardous conditions that should not be tested on public roads. Systematic evaluation of how the AV interacts with emergency vehicles should be part of the functional safety plan (Stage 1).
- Change the first bullet to:

"Detects emergency vehicles <u>*on emergency calls*</u>"

- Change the second bullet to:

"Takes appropriate response, or alerts the operator and transfers control to the operator"

- Add comparable requirement for school buses because of their special significance.

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
8. Detect and respond to emergency vehicles **on emergency calls and to school buses with door opened**	• Detects emergency vehicles **on emergency calls** • **Detects school buses indicating opened door for passengers to enter or exit (based on flashing lights or stop sign signal)** • Takes appropriate ~~action in~~ response ~~to emergency vehicle~~, or alerts the operator and transfers control to the operator Scenarios requiring the vehicle to detect and respond to emergency vehicles include: approaching from behind, pulled over on a shoulder, blocking or closing off a lane, and approaching from opposite direction. Scenarios requiring the vehicle to detect a school bus with boarding or alighting passengers include approaching the stopped bus from either the same or opposite direction of travel, while the bus is flashing its red lights or	X	X

	displaying its stop sign signal.		

4.6 Speed Limits and Traffic Control Devices

General Comments in this Category:

Summary of Comments:

- What is considered appropriate speed? What if appropriate speed is beyond speed limit? Note: (Form OL318 Section C shows allowance for staying within 10 mph of posted speed limit)
- The velocity of the AV has to be adequate according to the situation.
- To which extent is the adaptation of speed (lower than the speed limit) due to weather circumstances (snow, ice, heavy rain) considered in this category?
- The appropriate response to speed advisories depends on whether the reason for the advisory is valid for the AV.
- It is reasonable to consider that testing should stress systems under consideration by verifying performance under a range of environmental conditions. Should these competencies have language to the effect that the systems must detect and respond to traffic signs/signals "over a range of expected environmental conditions"?
- There are other competencies such as the following scenarios: a) railroad crossing without gates, b) bascule bridges, swing bridges and lift bridges, c) detection of bumpy roads and potholes that require speed reductions.
- Recognition of permissible locations for passenger pickup and drop-off is a significant challenge for an automated taxi mode of operation, although it's not clear that it needs to be included in minimum competencies.
- Lane tracking does not appear to be mentioned anywhere in the competencies, yet it is a fundamental driving competency and should therefore be covered as a competency.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This category of competency includes a mix of testing and verification requirements at two or three stages. Examples will be given in the individual competencies.
- For example, proper and attentive response to speed limits can be observed in real-world driving (Stage 3). However, situations involving risky maneuvers in reacting to traffic control devices will be best evaluated in a controlled environment (Stage 2).

Competency 11:
Detect and respond to speed limits, speed zones, and speed advisories

Summary of Comments:

- Some support the idea of allowing AVs to run at speeds higher than speed limits, others oppose.
- Many manufacturers refer to the use of digital maps to identify speed limits.

- If a system uses computer vision to recognize speed limit signs, but signs are partially occluded or vandalized, is this competency satisfied?
- Temporary traffic signals located in a different place from the normal signal are a serious challenge because the sensor system doesn't necessarily know where to look for them. It's not clear whether this should be a minimum competency or more of a corner case.
- If an AV recognizes the speed limit sign on a freeway but it is actually driving on a service road with a lower speed limit adjacent to the freeway, what happens?
- The speed limit information could reasonably be included on a map. Perhaps instead of detection, the requirement should simply be accurate response.
- What about speed advisories that are advisory but not enforceable?
- The AV(Level 4+) should be expected to behave like a human driver when it encounters an advisory application.
- Consider adding "speed advisories" in the first bullet item explicitly.
- Consider wording changes of "enforceable speed advisories" in this competency.
- Consider wording changes to require only the <u>response to speed limits</u>, but remove the detection part (since some approaches are based on maps and it is not really critical if cameras are not able to detect the speed limit signs as long as the AV is actually observing a safe speed).

Recommendations:

- Make the requirements correspond to the ODD, instead of areas of operation.
- This category of competency is mostly to be assessed at Stage 3.
- For example, proper and attentive responses when speed limit signs are clearly identifiable may be observed in real-world driving (Stage 3).
- Some test cases for this competency may be conducted in a controlled environment (Stage 2)
    - For example, a subset of tests with incomplete or erroneous or conflicting speed signs can be set up to check the response by the AV.
- Delete the first bullet:

<u>*"Identifies the speed limit or upcoming changes in the speed limit or speed advisories"*</u>

- Change the second bullet to:

<u>*"Adjusts and maintains an appropriate speed for traffic conditions, in response to speed limits and speed advisories."*</u>

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
11. Detect and respond to speed limits, speed zones and speed advisories	• ~~Identifies the speed limit or upcoming changes in the speed limit~~ • Adjusts and maintains an appropriate speed for traffic conditions **in response to speed limits and speed advisories** Speed limit changes that could be encountered in the vehicle's area of operation include: work zones or school zones, where the speed limit may be reduced during certain hours or when children are present Speed advisory zones that could be encountered in the vehicle's area of operation include: sharp curves, steep grades, S-curves, or	X	X

	wildlife crossing areas		

Competency 12:
Detect and respond to traffic control devices

Summary of Comments:

- Competency 12 should specifically mention the Manual on Uniform Traffic Control Devices (MUTCD). It should also note pavement marking detection and recognition. A complicating factor is that traffic control devices can vary even within a single state, depending on the jurisdiction, city, or state.
- Recognition of traffic control devices under all circumstances (such as varying environmental conditions) is very challenging.
- At highway exits, the behavior of the system may change as systems become more advanced. Metering lights at entrance ramps may be a relatively easy challenge for automated systems to deal with if they have appropriate capabilities to see the lights. Merging into traffic may be a more difficult challenge.
- The example list of traffic control devices is too comprehensive and too hard to satisfy with an automated vehicle response in urban areas. These could be in a database, making it possible to alert the driver early enough to take over control when approaching a problem location.
- The option of not allowing transfer of control back to drivers in urban areas is questionable, since there are ways of doing that transfer with a reasonable lead time.
- The requirement is imposing too heavily on design, which should be decided by OEMs.
- Handoff should not be allowed for rural highways—this could be violated with dangerous implications.
- The requirement of not allowing transferring control to drivers is too stringent. What if the system is able to detect most of the time, but it stops only when the sign is not recognizable and requests the driver to take over? This will seem like a competent system.
- Require only the response to traffic control devices, but remove the detection part since the detection may be challenging sometimes but the critical part is the response to such situations.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This competency includes a mix of requirements at all three stages.
- For example, a systematic evaluation of safety design for the AV to respond to traffic control devices is needed, even in situations where the traffic control devices are not easily visible or not available. There are also cases when there are conflicts with other road users who violate traffic control devices. (Stage 1)
- A subset of testing for this competency should be conducted in controlled environment (Stage 2). For example, include a subset of tests with special situations of traffic control, such as roadside CMS, flashing red lights or yellow lights.
- Consider for real world testing only typical situations encountered in daily driving.

- If areas of operation are maintained in the requirements, allow driver takeover in the urban/arterial category
- Delete first bullet: "*Identifies the presence of traffic control device*"
- Maintain second bullet: "Responds appropriately to traffic control device, or alerts the operator and transfers control to the operator"

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
12. Detect and respond to traffic control devices	• ~~Identifies the presence of traffic control device~~ • Responds appropriately to traffic control device, or alerts the operator and transfers control to the operator Traffic control devices that could be encountered in the vehicle's area of operation include: traffic signals, stop signs, yield signs, railroad crossing signals, signalized pedestrian zones, metering lights, and toll plazas.	X	X

Competency 19:
Lane Tracking (new)

Comments:

- Some reviewers noticed that there was nothing included in the current behavioral competencies to represent the basic functionality of recognizing lane boundaries and following the lanes when driving, so this has been suggested as a new competency to add to the list.
- The vehicle should be able to handle situations in which temporary lane dividers or markings are set up by safety officials in an incident recovery zone.
- There are situations in which markings are unclear but traffic follows the common-sense rule based on driving etiquette and where other vehicles are moving.
- Different systems using different methods of recognizing the locations of lane boundaries, which are subject to different potential limitations that would have to be assessed using different methods. These are primarily: video image processing to recognize visible lane markings, vehicle positioning using GPS and INS matched against a pre-existing digital map of the lane locations, and simultaneous location and mapping (SLAM), using laser scanners to match the reflections from surrounding objects against a digital map of these reflections from a reference run or a historical accumulation of runs by many other vehicles.

Recommendations:

- Insert this new behavioral competency in the grouping with traffic control devices, since the lane markings could be considered a form of traffic control device. This is being given the highest number of the current competencies because of its late definition, but when the next version of OL318 Part B is created the competencies should be re-numbered so that they fit in the general clusters used in this report, with those that are logically related to each other clustered together.
- Evaluate this using all three stages of the evaluation process, with particular emphasis on diverse weather and lighting conditions that can adversely affect the conspicuity of these markings and temporary or unclear lane markings.

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
19. Lane tracking	• Detect vehicle location relative to boundaries of the designated travel lanes • Maintain vehicle position within the desired lane unless there is a specific reason to deviate from the lane.	X	X

4.7 Navigation and Vehicle Maneuvers

General Comments in this Category:

Summary of Comments:

- Consider driving in unstructured environments (e.g. road sections with missing road markings); should it be part of this requirement?
- This section deals with maneuvers on public streets but not necessarily the interface and necessary transition between private and public. Clarification is necessary.
- It is better to frame the requirements according to the SAE levels of automation.

General Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- Add clarifications when AV operations involve transition between public roads and private properties, for example for automated parking systems and shuttle systems.
- Add clarification of testing environment for individual competency, and the allocation among the three stages of testing or verification. Some examples will be given in individual competencies.

Competency 16:
Detect roadway access restrictions

Summary of Comments:

- Detection of roadway access restrictions might also be relevant at access points for freeways or highways (e.g. minimum required speed).
- Two different cases for this competency: a) staying within allowed traffic space only, b) detecting of specific regulated parts of the allowed traffic space.
- Consider adding competency for detection of street-side parking spaces.

- Access restrictions would normally be included in a map database, but a temporary change in access would then be hard to handle and should be considered a corner case.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This competency includes a mix of requirements at all three stages.
- Some items of this competency are more suitable to be included under functional safety. (Stage 1) For example, the capabilities of an AV system to deal with various kinds of roadway restrictions and right-of-way limitations within its ODD should be thoroughly evaluated as part of the safety plan.
- A mistake in detection and response to restricted access scenarios may lead to dangerous situations on public roads. Such test cases are best to be emulated and tested in a controlled environment. (Stage 2)
- Consider for real world testing only typical situations encountered in daily driving (Stage 3).

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
16. Detect roadway access restrictions	• Detects one-way streets, access restrictions, crosswalks, and bike lanes • Takes appropriate action for road conditions Examples of roadway access restrictions include: one-way road segments, conditional intersections (e.g. turning maneuvers restricted by time of day), mid-block crosswalks, bicycle lanes, and bicycle/pedestrian path entrances.	X	X

Competency 17:

Intersection handling

Summary of Comments:

- Intersection handling needs to be split into passing across an intersection (straight driving) and turning at an intersection (maybe also a distinction between left and right turns).
- The description for intersection handling requires vehicles to "safely proceed through." Is "legally" implicit here?
- Intersection handling, in terms of driving etiquette, may require the AV to yield sometimes even if the AV has right of way.
- The prohibition against transferring control to drivers in urban areas is imposing on design, which should be decided by vehicle OEMs.

- The requirement of not allowing transferring control to urban drivers is too stringent. AV could have the problem intersections flagged in a map database and alert the driver early enough to retake control.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This competency includes a mix of requirements at all three stages.
- Very complicated intersections or roundabouts may not be handled by the AV and will require drivers to take over. A systematic evaluation of the AV system capabilities for this competency should be verified under functional safety. (Stage 1)
- For test cases that may incur hazardous situations, such as conflicting movements by other vehicles or road users, the testing should be carried out in controlled conditions. (Stage 2)
- Include real world testing of only typical situations encountered in daily driving. (Stage 3)
- Even though there was a suggestion from a reviewer on the second bullet, "to safely <u>and legally</u> proceed through," it does not seem necessary because following traffic rules is implicit in the competency requirement for traffic control devices.
- Change the second bullet to:
  "Safely proceeds <u>*straight*</u> through <u>*or turns at intersections*</u>, or alerts the operator and transfers control to the operator
- Allow driver takeover in the urban/arterial category, if the areas of operation differentiation is still maintained.

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
17. Intersection handling	• Detects an approaching intersection • Safely proceeds **straight** through **or turns at intersections,** or alerts the operator and transfers control to the operator Types of intersections that may be encountered in the vehicle's area of operation include: roundabouts, controlled and uncontrolled intersections. Types of intersection movements encountered include through movements, turns, and forks	X	X

Competency X:

Park safely on city streets (Driverless)

Summary of Comments:

- The following is recommended for addition: a) Entrance and exit of car parks and multi-story car parks, b) maneuvering in multi-story car parks

- The competency for AV to park should be extended to consider other aspects, e.g. the time needed to park and the effect on other traffic.
- While city is specifically mentioned, that car should also be able to perform the parking in rural areas as well.
- Clarifications are needed about what level of valet parking functionality is exempt from the regulations and which kinds of valet parking systems will be subject to the regulations based on their capabilities and where they are used.
- Consider Level 3 parking systems also

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation, so that they can be tailored to the specific limited needs of parking-only systems.
- Add this competency to requirements even if AV is not driverless, if the automated parking functionality is offered.
- Clarification is needed for applicability of regulations to public and private space with respect to parking, e.g. Safeway parking lot versus gated parking garage.
- This should be covered under functional safety (Stage 1), controlled condition testing (Stage 2), and on public roads (Stage 3), to verify the ability of the system to accommodate diverse parking area geometries and markings.
- Recommend addition of this as a new behavioral competency, as below:

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
X. Automated parking	• Parks itself within the boundaries of a parking space chosen by the operator This could include parallel parking along the side of a road or perpendicular or angled parking in a parking lot or garage.	X	X

Competency X:
Freeway Entrance ramp/merging onto freeway

Summary of Comments:

- The capability of AV to execute freeway to freeway merge may be important for AV systems that are designed to operate on freeways.
- Consider Level 3 systems that could do this

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.

- Add this competency to requirements even if it is not driverless, if the freeway entrance and ramp merging function is offered by any manufacturer.

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
X. Freeway entrance ramp/merging onto freeway	• Enters freeway • Safely merges into flow of traffic	X	X

Competency X:
Freeway Exit

Summary of Comments:

- Consider Level 3 systems that could do this

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operations
- Add this competency to requirements even if it is not driverless, if the freeway exit functionality is offered by any manufacturer

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
X. Freeway exit	• Exits freeway safely	X	X

Competency X:
Freeway to freeway merge

Summary of Comments:

- Consider Level 3 systems that could do this

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- Add this competency to requirements even if it is not driverless, if the freeway to freeway merge functionality is offered by any manufacturer

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
X. Freeway to freeway merge	• Detects need for freeway to freeway merge	X	X

	• Safely merges between freeways **or alerts operator to retake control of vehicle**		

Competency 13:
Lane change

Summary of Comments:

- Some do not agree that the vehicle (for designated lane shuttle operations) needs to know how to change lane. Furthermore, if this is a requirement it needs testing of all possible lane changing situations, which is more than a nightmare.
- There can be complications about laws governing use of directional signals for lane changes and turns.
- What about maneuvers by the AV that could require other vehicles to take evasive maneuvers? Should those be limited to minimize impacts on other vehicles?
- "Changing lanes" should be switched to "changing out of lane" to clarify the maneuver.
- Transfer of control back to the driver should be permitted, even in urban areas.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This competency includes a mix of requirements at all three stages.
- Some scenarios of this competency are difficult to specify in comprehensive testing cases due to the degree of variations in traffic conditions. A systematic evaluation of the AV system capabilities to handle this competency should be described and verified under functional safety. (Stage 1)
- Some test cases may involve hazardous situations, such as sudden lane changes that become a threat to other vehicles. These test scenarios should be conducted in a controlled environment. (Stage 2)
- Include real world testing only typical situations encountered in daily driving (Stage 3)
- Add a bullet item between the first and the second:
  "*activates directional signals before changing lanes*."
- Change the second bullet to:
  "Executes safe *and appropriate* lane changes."
- Revise the requirement in the urban/arterial category to allow driver takeover, if the area of operations classification is maintained.

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
13. Lane change	• Detects the conditions where a lane change is necessary. • **Activates directional signals before changing lanes** • Executes safe **and appropriate** lane change, or alerts the operator and transfers control to the operator Scenarios involving merging for the vehicle's area of operation include: lane drops; and freeway diverging points or exit ramps, passing slow, stopped, turning, or double-parked traffic on a multilane road; and switching lanes to be in the correct lane at an intersection.	X	X

Competency 10:

Detect work zones, temporary lane shifts, and other conditions where the normal roadway or travel path has been temporarily altered

Summary of Comments:

- One main question was about the degree of markings to identify a work zone. Will it only include MUTCD-compliant zones, or could it be as simple as a person standing and waving for doing some work on the road?
- If the intent is that vehicles should be able to detect work zones that are unmarked or poorly marked, that should probably be clarified, since the technical challenges are much more difficult.
- Work zones only marked by flaggers are very difficult to recognize as work zones, although the flagger could be recognized as a pedestrian. Standard markings for work zones should be a minimum requirement to recognize that it's a work zone.
- Don't make work zones a special case, but just handle the pedestrians and obstacles associated with them.
- Testing should be for work zones that are marked according to standards, not for the really poorly marked ones.
- Some argue that not every scenario can be accounted for; in all work zones the vehicle should automatically default to control by the operator.
- If the AV moves into the opposite lane in response to a work zone at a location where no central line crossing is allowed, will this be acceptable? Should the AV stop? This question relates to the criteria definition when more than one traffic rule must be obeyed and they are in potential conflict.

Recommendations:

- Make requirements correspond to the ODD, instead of areas of operation.
- This competency includes a mix of testing and verification requirements at all three stages.
    - Work zones cannot be comprehensively encountered or tested, so the functional safety plan should describe how the AV handles work zone situations (Stage 1).
    - Some selected test cases can be tested in a controlled environment (Stage 2).
    - If work zones are encountered in real world driving tests, then the AV response can be observed and evaluated. (Stage 3).
- Limit this to MUTCD compliant work zones, and let other situations be handled under other competency requirements. For example,
    - A flagger or a safety official will fall within the competency of pedestrian detection.
    - Temporary barriers, orange cones, and stopped vehicles will fall within the competency of obstacle detection.
    - Temporary traffic control devices will fall within the competency for traffic control devices.
    - Change the first bullet to:
        - "Detects work zones *that are MUTCD compliant*~~*, temporary lane shifts or restrictions, temporary traffic control devices, zones where workers or safety officials are manually directing traffic, or other conditions where the normal travel path has been altered*~~"
- Revise the requirement in the urban/arterial category to allow driver takeover, if the area of operations differentiation is still maintained.

Behavioral Competency	**Description of Behavioral Competency**	**Closed Course**	**On-Road**
10. Detect work zones, temporary lane shifts, and other conditions where the normal roadway or travel path has been temporarily altered	• Detects work zones **that are MUTCD compliant**~~, temporary lane shifts or restrictions, temporary traffic control devices, zones where workers or safety officials are manually directing traffic, or other conditions where the normal travel path has been altered~~. • Takes the appropriate actions to navigate the zone, or alerts the operator and transfers control to the operator.	X	X

4.8 Additional Functionality

Competency X:

Communication to remote operator (Driverless operations)

Summary of Comments:

- Regarding the level of control that can be exercised by remote supervisors, there are different opinions and concerns. The majority believe that the remote supervisor should only be able to take supervisory actions, issuing requests to the AV, but not directly manipulating its motions by joystick.

- The driverless vehicle has to be independently able to resolve situations, and in the case it gets stuck or does not know what to do, some service will have to be available as roadside rescue. The system should push information to remote responders.
- For communication with passengers, this should be the dispatcher, who is not directly controlling the vehicle motions.

Recommendation:

- Change this from "remote operator" to "supervisor" to make the responsibility clearer.
- Change the competency description to:

"*Communication to the supervisor about the vehicle's location and status and call for any needed assistance*".

Behavioral Competency	Description of Behavioral Competency	Closed Course	On-Road
X. Communication to a **supervisor**	• **Communication to the supervisor about** the vehicle's location and status **and call for any needed assistance** • Allows two-way communication between the supervisor and any passengers.		

Competency 18:
Additional functions designed by manufacturers

Summary of Comments:

- Besides to the communication with an operator also general communication aspects (V2V and V2X) should be discussed in this category.
- Add visible interaction displays on exterior of AV to communicate with pedestrians.
- The definition of "detection" should be strengthened by making it explicitly state that it is not limited to defined or mapped intersection points, i.e. no sensor should be in an inactive mode just because there is no identified intersection on the map.
- The operator shall be able to override the autonomous functionality, and the operator shall be able to switch off the autonomous functionality at any time, and the autonomous technology shall not be disengaged unintended by itself with or without any indication, which is critical in evasive maneuvers and emergency situations such as a) emergency braking, or b) active Electronic Stability Control (ESC), or c) active Electronic Stability Program (ESP), or d) active Dynamic Stability Control (DSC), or e) active Anti-lock Braking System (ABS)
- The vehicle must not move when a) one of the passengers has not been fastened, and b) a door is not closed.

- There are some automated functions that do not meet all the behavioral competencies described and may need to be either exempt or considered separately. For example, low speed and/or geo-fenced operation (e.g. within a parking structure or gated campus), should not have to meet all the behavioral competencies but only those relevant within its ODD.
- One group of reviewers made a very detailed set of proposals for new behavioral competencies associated with the interactions between drivers and vehicles. These were not consistent with the established models for representing the relative roles of drivers and automation systems, and were defined at a level of detail more appropriate for a system specification or design rather than at the broader level needed here for regulatory purposes, so they were not incorporated into the recommended behavioral competencies.

Recommendation:

- No further specific additions of behavioral competences.

Appendix A – Peer Reviewers

Organizations	Reviewers
Traditional Vehicle Manufacturers	
American Honda	Hideki Suzuki
BMW of North America	Paul Daman
Ford Motor Company	Dragos Maciuca, Tory Smith, Jim McBride, Emily Frascaroli, Melanie Wiegner, Michelle Chaka, Andrew Woelfing, Max Fenkell, Jim Carroll, Levasseur Tellis, Gurunath Vemulakonda
General Motors	Jeremy Salinger
Mercedes Benz	Ulrich Heine, Gritt Ahrens
Nissan Motor Co.	Maarten Sierhuis, Greg Dibb, Melissa Cefkin, John Tillman, Sarah Cardinali, Jacob Crawford
Toyota	Jade Nobles
Volkswagen/Audi	Barbara Wendling, Kaushik Raghu
Volvo Cars	Trent Victor
Other Vehicle Developers	
2getthere	Sjoerd van der Zwaan
Auro Robotics	Nalin Gupta, Jit Ray Chowdhury
Faraday Future	Jan Becker
Google [x]	Chris Urmson, Ron Medford, Dan Smith, Dmitri Dolgov
nuTonomy	Karl Iagnemma
Peloton	Josh Switkes
Yamaha	Hitoshi Watanabe
Zoox	Ivan Mihov, Sagar Behere, Colin MacGregor
First-Tier Automotive Suppliers	
Meritor Wabco	Alan Korn
Mobis	David Agnew
Robert Bosch GmbH	Nitin Thomas, Belen Aranda, Alma Meuwissen
Valeo	Christopher Nowakowski
Testing Organizations	
Battelle Memorial Institute	Joerg (Nu) Rosenbohm
IKA Aachen	Felix Fahrenkrog, Jens Kotte and Adrian Zlocki
SGS – TUV Saarland	Hans Kienzerle
TUV Sud	Udo Steininger
Research Organizations	
INRIA	Michel Parent

Liberty Mutual Research Institute	Ian Noy
Ohio State University	Guchan Ozbilgin, Peng Liu, Umit Ozguner
Stanford University	Wendy Ju, David Miller
Technical University Braunschweig	Markus Maurer, G. Bagschik, A. Reschka, T. Stolte
Technical University Darmstadt	Hermann Winner, Walter Wachenfeld
University of California Davis	Lew Fulton
University of Firenze	Adriano Alessandrini
University of Michigan	Huei Peng
Virginia Tech Transportation Inst.	Myra Blanco
Interest Groups	
AAA (national)	Jill Ingrassia, Russ Martin
Alliance of Global Automakers	Paul Scullion
Insurance Institute for Highway Safety	Eric Williams, David Kidd
National Society of Professional Engineers	Sam Wilson, Mark Golden
SAE International	Mary Doyle, Bill Gouse