SURFACE VEHICLE INFORMATION REPORT

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Guidelines for Safe On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving Systems (ADS)

RATIONALE

This document provides general safety-relevant guidelines for performing tests of prototype *automated driving system*s (*ADSs*) equipped on test vehicles operated in mixed-traffic environments on public roads. The levels of automation addressed in this document include conditional (*level 3*), high (*level 4*), and full (*level 5*) as defined by SAE J3016; when activated, these *ADSs* do not rely on a *human driver* for *monitoring* and responding to the vehicle or traffic environment. (SAE J3016 defines the italicized terms in this document.) These guidelines apply to the testing of all types of motor vehicles including light-duty, passenger, freight or transit vehicles, but are not concerned with component-level testing. These guidelines address only the safety-related prerequisites for on-road testing and conduct of such tests. They do NOT establish performance criteria or test procedures for production vehicles equipped with *ADS*s.

Mixed traffic environments are active public roadways, closed campuses (such as military bases, factories, ports, and enclosed communities), and other contexts that involve a risk of injury to road users or damage to their property. These environments will (variously) include motor vehicles of all types and classes, pedestrians, and pedal cyclists, as well as animal and object hazards. Accordingly, these guidelines address analytic, laboratory, simulation, or closed-course test methods only to the extent that these methods are part of, or predicates to, tests of vehicles equipped with prototype *ADS*s conducted in mixed-traffic environments on public roadways. The guidelines assume that any such tests will be conducted under some form of human supervision; this assumption applies even if the *ADS* being tested is considered to be a *level 5* "full automation" system. Licensing and registration requirements for test vehicles equipped with prototype *ADS*s should be checked with relevant local jurisdictions. This document also provides guidance on test driver training and test program management; graduated road testing; test data capture; safety override guidelines, and software development and release requirements.

Safety guidelines for the on-road testing of vehicles equipped with prototype ADSs do not currently exist. The information given in this report will assist interested parties in the creation of guidelines for the on-road testing of such prototypes.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
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1. SCOPE

This document provides guidelines for the safe conduct of on-road tests of vehicles equipped with prototype conditional, high, and full (levels 3-5) *automated driving system*s (*ADSs*), as defined by SAE J3016. It does not include guidance for testing production *ADS*s intended for sale to the general public. The scope is further limited to testing of automated prototype vehicles on public roads.

These guidelines do not address:

- Testing of driver assist (Level 1) or partial (Level 2) automation systems, which rely on a *human driver* to *monitor* the environment. (See SAE J3016 for Definitions of Levels of Automated Systems.)
- Closed-course testing.
- Component-level testing.

The precise regime of road testing for a particular prototype will depend on the intended level of automation and the targeted capabilities of the prototype (see SAE J3016 for more information).

A prototype suitable for testing on public roadways is presumed to have already passed laboratory and/or closed-course testing, which are not addressed by this document.

1.1 Purpose

The purpose of this document is to provide information and guidelines for use by automotive designers, test engineers and policymakers concerned with the safe on-road testing of vehicles equipped with *Level 3* (Conditional), *Level 4* (High), or *Level 5* (Full) *ADS*s, which are characterized by their ability to perform the complete *dynamic driving task* whether or not such performance is limited to specific *driving modes* and/or roadways/locations.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE International

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3016 Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems

SAE J1698 Event Data Recorder

SAE J1698-1 Event Data Recorder - Output Data Definition

Sheridan, T.B. (1970). Big Brother As Driver: New Demands and Problems for the Man at the Wheel. Human Factors, 12(1), 95-101.

3. DEFINITIONS

3.1 AUTOMATED DRIVING SYSTEM (ADS) (SAE J3016)

The hardware and software that is collectively capable of performing all aspects of the *dynamic driving task* for a vehicle (whether part time or full time).

3.2 DRIVING MODE (SAE J3016)

A type of driving scenario with characteristic *dynamic driving task* requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, etc.).

3.3 DYNAMIC DRIVING TASK (SAE J3016)

All of the real-time functions required to operate a vehicle in on-road traffic, excluding the selection of destinations and waypoints (i.e., navigation or route planning) and including without limitation:

- Object and event detection, recognition, and classification;
- Object and event response;
- Maneuver planning;
- Steering, turning, lane keeping, and lane changing;
- Acceleration and deceleration;
- Enhancing conspicuity (lighting, signaling and gesturing, etc.).

3.4 EXPERT TEST DRIVER

Expert test drivers are specifically skilled and trained personnel who are able to activate, *monitor*, and de-activate the *ADS* using experimental software and/or hardware interfaces, and who are capable of safely handling the vehicle in a variety of hazardous driving situations.

3.5 HUMAN DRIVER (SAE J3016)

The person who drives a particular vehicle, and who, in a vehicle equipped with an *automated driving system*, exchanges the *dynamic driving task* with such a system as necessary during vehicle operation.

3.6 LEVEL 3 - CONDITIONAL AUTOMATION (SAE J3016)

The part-time or *driving mode*-dependent performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a request to intervene.

NOTES:

- Conditional automation requires a *human driver* to initiate an *automated driving system* at the appropriate point during a trip and requires a *human driver* to resume the *dynamic driving task* when s/he receives a request to intervene (e.g., due to a vehicle or system malfunction or a change in driving conditions that exceed the *automated driving system's driving mode*-dependent capability).

- As a technical matter, a *human driver* need not *monitor* the *automated driving system's* performance while it is engaged, but must be prepared to resume the *dynamic driving task* when the *automated driving system* issues a request to intervene.

- A *conditional automated driving system* will alert (i.e., by issuing a request to intervene) the *human driver* of the need to resume the *dynamic driving task* with sufficient time for a typical *human driver* to respond appropriately.

- An "appropriate" response by a *human driver* to a request to intervene may vary depending upon immediate circumstances (e.g., steering, braking, or simply maintaining current input levels), but otherwise entails the timely, safe and correct performance of the *dynamic driving task* for the prevailing circumstances.

3.7 LEVEL 4 - HIGH AUTOMATION (SAE J3016)

The part-time, *driving mode*-dependent, or geographically-restricted performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* fails to respond appropriately to a request to intervene.

NOTES:

- *High automation* generally requires a *human driver* to engage an *automated driving system* at the appropriate point during a trip (e.g., a *human driver* may activate the *automated driving system* during a specific *driving mode*, such as freeway driving, for which the high *automated driving system* is designed).

- Examples of exceptions to the general case: - A *high automation* parking application for which a *human driver* is not present in the vehicle during the maneuver. - A *high automation* shuttle system that is geographically restricted to operation on a closed or semi-closed campus (e.g., residential community, military base, etc.)

- As a technical matter, a *human driver* need not *monitor* the *automated driving system's* performance while it is engaged, but should in the general case be prepared to assume performance of the *dynamic driving task* when the *automated driving system* issues a request to intervene.

- A *high automated driving system* will alert a *human driver* several seconds in advance of the need to resume the *dynamic driving task* (i.e., by issuing a request to intervene); however, the *automated driving system* is capable of restoring the vehicle to a minimal risk condition automatically if a *human driver* fails to resume the *dynamic driving task* when prompted. This capability to automatically restore the vehicle to a minimal risk condition is the only difference between *high automation* and *conditional automation*, above.

3.8 LEVEL 5 - FULL AUTOMATION (SAE J3016)

The unconditional, full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under, at minimum, all roadway and environmental conditions that can be managed by a *human driver*, including the ability to automatically bring the motor vehicle into a minimal risk condition in the event of a critical vehicle or system failure, or other emergency event.

NOTES:

- As a technical matter, a *human driver* need not monitor the *automated driving system's* performance.
- When the *automated driving system* reaches the limits of its functional capabilities, it will restore the vehicle to a minimal risk condition automatically.

3.9 MONITOR (J3016)

The activities and/or automated routines that accomplish comprehensive object and event detection, recognition, classification, and response preparation, as needed to competently perform the *dynamic driving task*.

NOTE: When driving vehicles that are not equipped with *automated driving systems*, *human drivers* visually sample the road scene sufficiently to competently perform the *dynamic driving task*, while also performing secondary tasks that require short periods of eyes-off-road time (e.g., adjusting cabin comfort settings, scanning road signs, tuning a radio, etc.). Thus, monitoring does not entail constant eyes-on-road time by the human driver.

3.10 NOVICE TEST DRIVER

Novice test drivers are licensed, but are not familiar with the *ADS* and are not trained to activate, *monitor*, and de-activate it using experimental software and/or hardware interfaces, nor are they trained to safely handle the vehicle in a variety of hazardous driving situations..

3.11 SAFE/SAFETY

The absence of unreasonable risk to humans, animals, and property.

3.12 TRAINED TEST DRIVER

Trained test drivers are informed about the *ADS* and are trained to safely handle the vehicle in a variety of hazardous driving situations, but are NOT specifically qualified to activate, *monitor*, and de-activate the *ADS* using experimental software and/or hardware interfaces..

4. SAFETY TESTING GUIDANCE

4.1 Test Driver Training

Driver training is a primary component of a safe testing program because it prepares the test driver for both complex and routine situations likely to be experienced during test-driving. Training ensures that a test driver will know the best actions to take in any situation to minimize risk. In order to react correctly to various situations, a test driver needs to be very familiar with the *ADS* under test, any applicable malfunction warning systems, software, hardware, and how the vehicle and *ADS* perform under normal conditions. Initially, test drivers should become familiar with the *ADS*-equipped vehicle performance characteristics.

For example, test driver can participate in informational briefings or classes. After classroom training, hands-on training can be provided to prepare the test driver for operating the vehicles under a variety of on-road scenarios. Such hands-on training may introduce drivers to routine maneuvers, road environments, and general operating conditions, and gradually introduce progressively more difficult test procedures, such as emergency maneuvers, as test drivers become more experienced.

All drivers are trained to maneuver the general position and speed of the vehicle safely, systematically and smoothly, using road and traffic conditions to progress unobtrusively and skillfully through on-road traffic under a wide range of road and weather conditions. In addition to these routine skills, test drivers benefit from a high level of driving competence based on concentration, effective all-round observation, anticipation, and planning, as well as excellent vehicle handling skills. Furthermore, the trained test drivers must be qualified to activate and deactivate the *ADS* in order to do their job.

There are multiple ways to organize a test driver-training program, and established vehicle manufacturers and many automotive suppliers have already implemented their own internal test driver training programs. For entities wishing to test prototype *ADS*s on public roadways that do not already have an established test driver-training program, the following guidance is provided.

The responsibilities of test drivers can be divided minimally into three main groups:

- Expert test drivers are specifically skilled and trained personnel who are able to activate, *monitor*, and de-activate the *ADS* using experimental software and/or hardware interfaces. Expert drivers are trained to respond correctly to emergency situations due to *ADS* and/or vehicle failures. Expert test drivers are typically engineers and/or designers of the *ADS* under test.

- Trained test drivers are informed about the *ADS*, but are NOT specifically qualified to activate, *monitor*, and de-activate it using experimental software and/or hardware interfaces. Trained drivers are able to respond correctly to emergency situations due to *ADS* and/or vehicle malfunctions or failures by exercising a dedicated system override that restores the vehicle to non-automated operation.

- Novice test drivers are not informed about the *ADS*, nor trained in its use. Novice test drivers may be accompanied during a test drive by a trained test driver in the front passenger seat equipped with dual accelerator and/or brake pedals; this trained test driver would be responsible for maintaining safe operation of the test vehicle at all times that a novice test driver occupies the driver's seat. If not accompanied by a trained test driver capable of maintaining operational safety, novice drivers need to be able to respond to emergency situations due to *ADS* and/or vehicle failures by activating a failsafe switch that automatically restores the vehicle to a minimal risk condition (see SAE J3016).

Test drivers need to be educated on how to correctly respond to emergency situations when operating a vehicle equipped with an activated *ADS*. Test drivers need to also be able to recognize when the *ADS* and/or vehicle is not functioning properly so that they compensate and report as needed. The test driver needs to know the limitations of the *ADS* and the vehicle so they do not inadvertently exceed those limits. For example, if the software is not capable of correctly gauging the gradient of steep hills while descending, the driver should know that s/he needs to brake at some point during the descent. Test drivers need to know how to take over the steering, braking, and acceleration of the vehicle when necessary, and how to handle vehicle appropriately when operating in degraded modes.

The *ADS* experts should prepare a curriculum to present the information that test drivers will require in order to safely operate an *ADS*-equipped vehicle under applicable on-road test conditions. This information should include relevant instruction regarding the normal, compromised, and emergency operation of the vehicle during *ADS* activation, as well as instruction for managing emergency situations that pertain to all motor vehicles, such as a brake or power steering system failure. Situations covered by instruction should include, if applicable for the *ADS* under test, high/low speed driving, parking, high/low volume traffic, city/rural roadways, merging, following distance, turning and stopping. Test drivers should be informed in advance of any updates to the *ADS* that will or may affect *ADS* and/or vehicle performance.

Test drivers should also be given specific instructions on when and how to report various *ADS* and/or vehicle behaviors of interest. Test drivers should be provided with means that are compatible with the test driving environment, such as on-demand data recording via command input for capturing and/or reporting on incidents. Otherwise they should report such incidents after the test drive.

Test driver training should also include any "rules of engagement" generally expected of all test drivers. For example, rules about whether or when another vehicle may be passed during an on-road test drive; prohibitions on excessive speeding and consequences of failure to observe speed limits and other rules of the road, including local laws and ordinances; maximum number of consecutive hours a test driver may operate a test vehicle, restrictions on use of portable electronic devices (PED) and other non-driving-related-tasks while driving.

4.2 Test Driver Workload

When testing vehicles equipped with an active *ADS*, test drivers will need to *monitor* multiple functions in addition to those already required of non-*ADS*-equipped vehicle drivers. For example expert test drivers need to be able to activate, *monitor*, and de-activate the *ADS*, including when using experimental software and/or hardware interfaces when necessary. Moreover, they need to be able to respond to emergency situations due to *ADS* and/or vehicle failures by activating a system override that restores the vehicle to non-automated operation. If, in addition, a test driver is also attempting to read the *ADS*'s engineering output data in order to capture specific data streams or to make real-time adjustments, the driver is likely to become over-loaded (visually, manually and/or cognitively), rendering him/her unfit to operate the test vehicle safely at the same time. Therefore, the test driver assigned to operate an *ADS*-equipped vehicle must not also be simultaneously assigned to engineering activities common to vehicle testing; such engineering activities must be performed by a second person in the vehicle, other than the test driver who is assigned to operate the test vehicle.

The test vehicle should provide the test driver responsible for safe vehicle operation with status information necessary for maintaining safety, and should not provide extraneous information that could otherwise overload the test driver. An alert system should be installed in the vehicle to inform the driver of critical malfunctions. The alerts may consist of visual, haptic, and/or audible warnings that cue the test driver to the need to disable the *ADS* and resume driving. Other information regarding the timing, nature, and circumstances of the malfunction should either be *monitored* by another person in the vehicle, or be captured and stored by a data acquisition system (see section 4.8) for retrieval following the test drive.

4.3 Managing Test Drivers

The proper management of test drivers plays a key role in ensuring that drivers maintain safety while conducting tests, and that they report incidents accurately and consistently. For example, in cases where larger numbers of test drivers are employed, it may help to divide them into smaller teams with a manager assigned to each. The manager is in charge of the following:

- Explaining the organization's specific rules about test driving,
- Explaining software and/or hardware updates to drivers as needed,
- Coaching test drivers through difficult situations as needed,
- Encouraging safe behaviors during testing, and
- Sharing their team's experiences with other managers.

Managers should periodically reinforce training instructions as needed. Managers should be experienced test drivers and know the correct actions that a driver should take in various situations. For example, a driver might ask whether they made the right decision in taking over performance of the *dynamic driving task* when the warning system told them that they were too close to a vehicle, even though they did not think that they were. The manager should then review correct following distance and how to gauge it with the entire team of test drivers so that they can react accordingly in a similar situation. This also alerts the manager to a potential weakness in the software that should be shared with the software development team.

During briefings, managers should record any information that would be beneficial for other test drivers to know, and should send out an update to the other teams, if appropriate. For example, a driver might report that during their test drive, the vehicle was displaying false speed indication. This would be important information for other test drivers to know, as incorrect speed data might otherwise mislead those analyzing the test results. At the beginning of every test drive, managers should share any important updates with their team.

Managers are also responsible for enforcing any rules that test drivers are required to follow. Conventional restrictions on driver behavior are appropriate including speed limits and other rules of the road, local laws and ordinances; maximum number of consecutive hours a test driver may operate a test vehicle, restrictions on use of portable electronic devices (PED) and restrictions of other non-driving-related-tasks while driving.

Novice test drivers may require special preparation depending on the vehicle, the test environment, and other relevant circumstances for the demonstration or vehicle test.

4.4 Safety Development Process

Employing standardized methods of safety development that have been tailored to the particular *ADS* under test and its prototype limitations may help to ensure safe on-road testing of such systems. The main aspects to be considered include:

- The definition of the *ADS* application(s) under test, including its specified operational domain and environmental restrictions, if applicable.
- The performance of a hazard analysis and risk assessment for identified hazards, as well as the definition of the *ADS* application's safety goals
- The concepts and strategies for mitigating these hazards
- The definition and development of an architecture (system/hardware/software levels) capable of implementing the mitigation concepts and strategies.
- Analysis and testing of the mitigation strategies (whether implemented in hardware or software).

The results of these analyses and tests should provide confidence in the performance of the system and associated mitigation strategies to meet the safety goals.

4.5 Software Development and Modifications

Current *ADS*-equipped prototype vehicles are based on existing production vehicles. As such, the manufacturer of the base vehicle necessarily defines the software architecture. Add-on prototype *ADS* software which is flashed onto existing hardware modules, or provided via added hardware modules, should be checked to ensure that it does not interfere with base vehicle hardware or software systems. As such, they should abide by the following general principles:

- All hardware and software interfaces between production- and development-level hardware and software should be analyzed and tested for operational integrity.
- All developmental software added to a vehicle (including that equipped on added hardware modules) should be *monitored* and/or include self-diagnostics for safety critical measurements and variables, and such *monitoring* and/or self-diagnostics should be verified for efficacy prior to on-road testing.
- The testing of the software itself is conducted with standard software testing conventions.

If the software or calibration is modified after all of the above activities have been completed, an impact analysis should be performed to check whether such modifications have any adverse effects on the *ADS* or other vehicle systems. If an adverse impact is found, it will need to be resolved before clearing the prototype vehicle to again be tested on public roads. Testing on closed courses prior to on-road testing may be necessary in cases where safety-critical software is modified.

Finally, while testing on public roads, real-time calibration/tuning of *ADS* software should be allowed only after evaluation by qualified personnel (e.g., development engineer, lead calibrator, and/or designated safety engineer) indicating that the change is acceptable from a safety standpoint. While simulation can help reduce the effort in validation, major changes should be tested on a closed course prior to release on public roads.

4.6 Selection of Test Routes

Operational design domains inherent to *level 3* (conditional) and *level 4* (high) *ADS* applications introduce additional variables that impact the safety and effectiveness of on-road testing of *ADS* application prototypes. (*Level 5* (full) *ADS*s are not subject to operational design domain limitations.) These should be accounted for when planning test routes. Many on-road variables are interdependent. For example, expected speed on a given road segment may vary by the time of day due to congestion or lighting.

Level 3 (conditional) and *level 4* (high) *ADS* applications are subject to specific limitations with respect to operational design domain (i.e., they are designed to operate only in limited *driving mode(s),* conditions, and/or locations). In the case of prototype *ADS* applications, such limitations may be quite large in number, but in any case will vary by implementation and need to be considered in the preparation of any testing regime. For example, when testing conditional and high *ADS* applications, it is expected that the test drive will be interrupted by multiple transfers of *dynamic driving task* between the test driver and the *ADS* as the test vehicle passes into and out of the *ADS* application's operational design domain. In some cases, this can distort testing statistics by, for example, by indicating that a given vehicle required a larger number of *dynamic driving task* transfers compared to other vehicles with different prototype *ADS* applications that have broader operational design domains.

Examples of test route variables that should be considered include:

- Roadway Type
  - Limited access freeway
  - Highway (single or multi-lane),
  - Arterial roads
  - Residential streets
  - Driveway, parking lot or structure.
- Time-of-day
  - Traffic congestion.
  - Lighting conditions (day vs night).
- Seasonal
  - Weather conditions.
  - Temperature.
- Traffic Environment
  - Traffic density
  - Vehicles.
  - Pedestrians.
  - Signage.
  - Irregular - construction, crash scenes, road detours, flooding.
  - Complex intersections, merges.
  - Regional variations in road design.
  - Traffic control devices (signals, signs, curbs, guardrails, etc.)