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Road Vehicles — Test scenarios for automated driving systems — Taxonomy for operational design domain

Véhicules routiers — Scénarios d'essai pour les systèmes de conduite automatisée — Taxonomie pour le domaine de conception opérationnelle

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 22, Road vehicles, Subcommittee SC 33, Vehicle dynamics, chassis components and driving automation systems testing.

This document belongs to a series of Standards series consisting of ISO 34501, ISO 34502 and ISO 34503.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The move towards Automated Driving Systems (ADS) [1] is being driven by the many potential benefits of the technology, such as increased safety, reduced traffic congestion, lowered emissions, and potentially increased mobility for those unable to drive. In order to realize these benefits, it is essential that the ADS technology is introduced safely.

The development of automated vehicle technology has received wide public attention, with countries worldwide focussing on:

- Ensuring that the introduction of ADSs for testing/trialling purposes and for commercial operations is done safely, securely and legally; and
- Building public and consumer trust and acceptance of the technology.

A key aspect of the safe use of automated vehicle technology is defining its capabilities and limitations and clearly communicating these to the end user, leading to a state of "informed safety". The first step in establishing the capability of an ADS is the definition of its Operational Design Domain (ODD) [1]. In addition to safe operation, ODD definition is also required for conformity with laws and regulations and compliance with vehicle goals e.g., mobility and comfort needs.

The ODD represents the operating conditions within which an ADS can perform the Dynamic Driving Task (DDT) [1] safely during a trip. This document focuses on a taxonomy and format for the ODD definition for a given ADS to create a common understanding of the ODD.

The ODD taxonomy and definition format specified in this document will enable ADS manufacturers to specify, implement and communicate minimum safety requirements in their designs, and allow end users (e.g., insurers, national, local, and regional government), operators and regulators to reference a minimum set of ODD attributes and performance requirements in their procurements. It will also enable ADS manufacturers, developers and suppliers of components and subcomponents to define the operating capability and assemble sets of evidence that will improve confidence in the safety of the resulting product (such as component specifications) and in the data obtained from test and verification activities.

While there are a number of different testing, trialling and deployment environments, this document provides a generic taxonomy for defining each of these environments. For a scenario-based verification methodology for ADS, a hierarchical taxonomy for ODD definition and a definition format also enables an efficient scenario creation and scenario parametrisation. Such a definition format standard is in development – ASAM OpenODD.

Road Vehicles - Taxonomy for Operational Design Domain for an Automated Driving System

1 Scope

This document specifies the requirements for the hierarchical taxonomy for specifying operating conditions which enable the definition of an Operational Design Domain (ODD)[1] of an Automated Driving System (ADS) [1]. This document also specifies requirements for the definition format of an ODD using the taxonomy. The ODD comprises specific conditions (which include the static and dynamic attributes) within which an ADS[1] is designed to function.

This document is mainly applicable to level 3 and level 4 ADS [1]. An ODD for level 5 ADS is unlimited (i.e., operation is possible everywhere).

This document is for use by organizations taking part in developing safety cases for automated vehicle, in particular, for organizations conducting trials, testing and commercial deployment. This document is also for use by manufacturers of Level 3/4 ADS to define the ADS' operating capability. It is also of interest to insurers, regulators, service providers, national, local and regional governments to enable them to understand possible ADS deployments and capabilities.

This document does not cover the basic test procedures for attributes of the ODD. It does not cover the monitoring requirements of the ODD attributes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/SAE PAS 22736: Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles

ISO/DIS 34501: Road vehicles - Terms and definitions of test scenarios for automated driving systems

ISO/DIS 34502: Road vehicles - Scenario-based safety evaluation framework for Automated Driving Systems

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/SAE PAS 22736 and ISO/DIS 34501 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
dynamic elements
all movable objects and actors in the ODD within the DDT timeframe.

{SOURCE: Ulbrich et. al, 2015 [5], modified}

3.2
environmental conditions
weather and other atmospheric conditions (as well as information technology connectivity)

NOTE to entry: Environment conditions does not contain scenery elements.

3.3
Minimal Risk Manoeuvre (MRM)
tactical or operational manoeuvre triggered and executed by the ADS to achieve the Minimal Risk Condition (MRC)

3.4
operational driving task
dynamic Driving Task [1] that involves split-second reactions that can be considered pre-cognitive or innate

NOTE to entry: Examples include making micro-corrections to steering, braking and accelerating to maintain lane position in traffic or to avoid a sudden obstacle or hazardous event in the vehicle's pathway.

3.5
scenery elements
non-movable elements of the ADS equipped vehicle's operating environment

NOTE to entry: in the context of an ODD

3.6
tactical driving task
dynamic driving task which involves drivers or an ADS exercising manoeuvre control, allowing them to negotiate the directly prevailing circumstances

{SOURCE: Michon, 1985 [9], modified}

3.7
vulnerable road user
non-protected road user such as motorcyclists, cyclists, pedestrians and persons with disabilities or reduced mobility and orientation.

3.8
traffic agents
anyone who uses a road including sidewalk and other adjacent spaces

3.9
Target Operational Domain (TOD)
real-world conditions that an ADS may experience in during its deployment.

NOTE to entry: While the ODD constitutes of the operating conditions that an ADS is design to operate in, the TOD is the area where the ADS will be deployed and may have conditions outside the ODD of the ADS.

3.10
Current Operational Domain (COD)
real-time real-world conditions that the ADS is experiencing.

3.11
Operational Domain (OD)
real-world conditions that an ADS may experience

4 Symbols (and abbreviated terms)

ODD Operational Design Domain

ADS Automated Driving Systems

DDT Dynamic Driving Task

MRM Minimal Risk Manoeuvre

MRC Minimal Risk Condition

AV Automated Vehicle

V2I Vehicle to Infrastructure

ASAM Association for Standardization of Automation and Measuring Systems

OD Operational Domain

TOD Target Operational Domain

COD Current Operational Domain

5 Operational Design Domain (ODD) and Target Operational Domain (TOD)

An ODD defines the operating conditions under which an ADS is designed to operate safely. However, the target operational domain (TOD) constitutes of the real-world conditions that an ADS may experience. Often, the OD will generally be a superset of the ODD properties.

In real world deployment of ADS, the difference between an ODD and TOD highlights the limitations of the ADS. In all practical cases, an ODD definition will not be exhaustive enough to cover all attributes or occurrences in a TOD. Therefore, it is important to ensure the boundary between ODD and OD is defined objectively and have design mechanisms in the ADS to execute fallback manoeuvres when an ODD exit is encountered to ensure safe operation in a TOD. Current operational domain (COD) refers to the real-time operational domain, i.e., real-time real-world conditions that the ADS is experiencing (Figure 1).

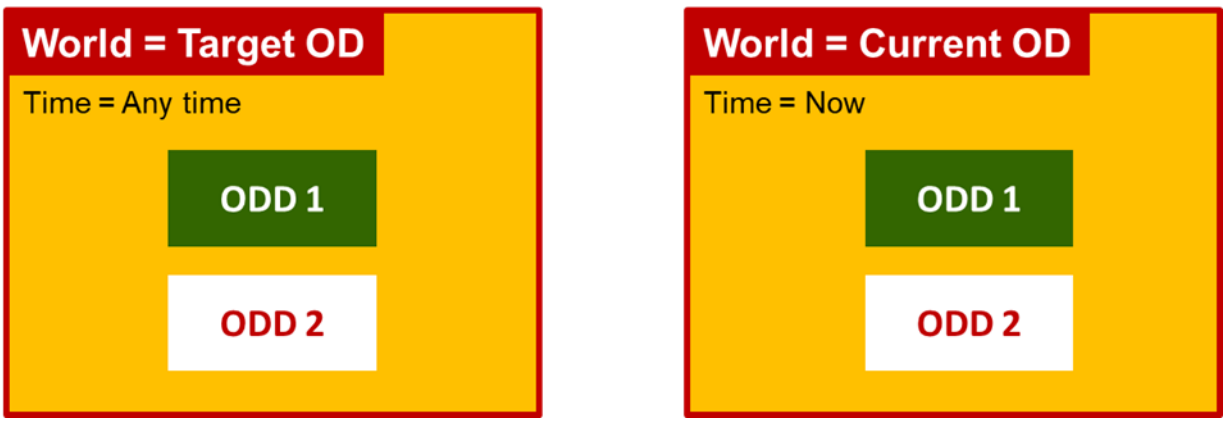

Figure 1. Relationship between ODD, TOD and COD

6 ODD and scenario relationship

As an ODD definition needs to be testable, ODD attributes and its definition play a key role in scenario-based testing. It is important to highlight that ODD and scenarios are two distinct but related constructs. While ODD describes the operating conditions of the ADS in which it is designed to operate in, a scenario along with parts of the scenery elements and environmental conditions, describes the behaviour of the traffic participants and may also define the desired behaviour of the ego vehicle in an instantiation (part) of an ODD or outside of an ODD.

NOTE See Annex A for the overall ADS-Constraining factors apart of the ODD.

The ODD definition shall be used as one of the inputs for scenario-based safety evaluation framework according to ISO/DIS 34502. Therefore, one of the first steps in a verification and validation process of an ADS would be to analyse the designed ODD of the ADS to create a set of test scenarios. Second step would involve testing the desired behaviour of the ADS by choosing a set of behaviours from a behaviour competency library. The choice of the behaviours may include undesired behaviours to test the ADS' response. An instantiation of the ODD together with a desired behaviour and the description of the traffic participant behaviour according to events and triggers will provide a scenario definition for the ADS. Such qualitative scenario can then be further detailed into functional, abstract, logical and concrete scenarios to create a scenario library (Figure 2).

Furthermore, the ODD definition can be used as a plausibility check, whether individual test scenarios are inside, outside or at the boundary of an ODD. Such scenarios also enable the test for activation and deactivation of the ADS depending on ODD. It is important to test against scenarios outside the ODD in order to ensure that the ADS is not misused in situations for which it is not designed for. Also, a comparison between a test scenario set and the ODD definition shall be performed to analyse the test space coverage.

As centralised scenario library will potentially have a large number of scenarios for different ODDs, ODD attributes (see clause 8) and behaviour labels (ASAM OpenLabel [3]) can play a key role in enabling efficient scenario search for an ADS. For the proposed three types of scenarios mentioned in ISO 34502, perception-, traffic- and vehicle stability, there will exist an ODD instantiation. For example, a perception related scenario focussed on blind spot detections may exist on a motorway or on a road in a city centre, where motorway and city centre roads are ODD instantiations. Compared to an ODD definition, a scenario has additional constructs like events, triggers and other dynamically changing behaviour. Such scenario attributes may be classified according to ASAM OpenLabel [3].

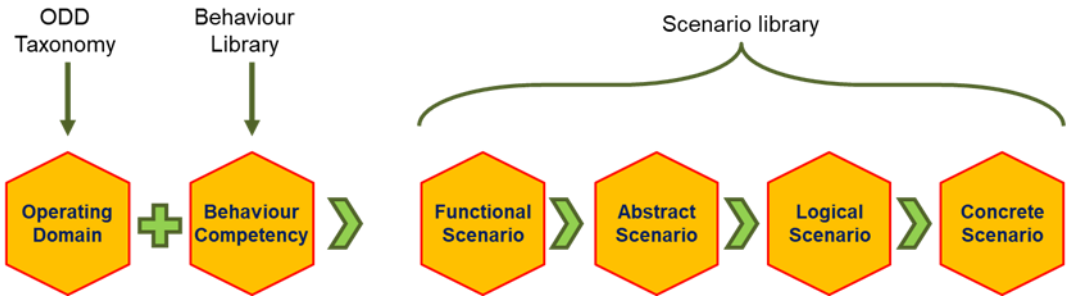

Figure 2. Relationship between ODD, behaviour and scenarios

7 ODD requirements and application

7.1 Abstraction of ODD definition

Based on the taxonomy and definition format in this document (clause 8-12), an ODD definition shall be developed by an ADS developer and before deployment should be compared with the stakeholders'

requirements of the operating domain (OD), either individually or in consultation, for the safe operation of the ADS in the operating domain.

An ODD may be defined from the perspective of an end user or a system specifier. Depending on the perspective, the abstraction of the ODD definition may vary.

Note: Although end users and specifier may have different abstractions of ODD, the ODD definition should be done objectively to avoid any misunderstandings.

Stakeholders or end users may include local authorities, regulators, ADS system user, service providers, manufacturers, developers of an ADS or suppliers of components and subcomponents. A city council, for example, may develop an ODD definition as part of a procurement specification for an ADS mobility service, while a manufacturer may develop an ODD definition in order to convey the ADS' capabilities and limitations and create the corresponding safety case. Different stakeholders may develop their ODD definition with varied level of detail.

The abstraction hierarchy to be used for the ODD definition, see clause 8-11, shall be at the discretion of the stakeholder. Irrespective of the abstraction level chosen, stakeholders shall specify the ODD attributes used to inform the scenario-based testing of the ADS.

A stakeholder who defines an ODD choosing an attribute at a higher abstraction level shall ensure that all the pre-defined sub-attributes are also within the ODD definition, even if they have not been explicitly mentioned in the ODD definition. In case it is necessary for a specific defined system to have a detailed ODD, the ODD definition shall be described with a higher level of detail. For example, if an ADS is designed to be able to handle light rain (< 2.5 mm/hr) only and is not able to operate in higher intensity of rainfall, the defined ODD shall be specified at this granularity (i.e., with additional sub-attributes).

The ODD attributes shall be extensible in a way that allows new attributes or sub-attributes to be added as a result of stakeholder consultation and ensuring consistency with the existing attributes.

7.2 Monitoring ODD

While performing the DDT, ADS shall perceive the operating environment, i.e., shall be aware of the near real-time ODD attributes' values, so that the ADS can compare the external conditions (i.e., the COD) with the defined ODD. This is essential for the ADS to be able to decide on triggering of the minimal risk manoeuvre (MRM) or issuing a transition demand by the ADS. During trials, the monitoring of the ODD attributes may be performed by the safety operator or dispatcher.

ODD attributes may have interdependence and their relationship shall be defined in a prescribed format (clause 12). For example, an ADS may have a maximum allowable speed of 70 km/h in the absence of rainfall, and a reduced maximum allowable speed of 40 km/h in the presence of rainfall. The dispatcher or the ADS itself shall decide, for example, to reduce the maximum allowable speed when it is raining as compared to sunny conditions in order to ensure operation within ODD boundaries.

Defining an ODD boundary is up to the manufacturers' discretion and may involve sub-attributes or qualifiers, such as temporal elements. For example, an ODD boundary may be defined as up to 2 minutes of heavy rainfall by adding a relevant sub-attribute. ODD attributes shall be defined in such a way to allow awareness on the part of the ADS, so that the ADS remains within the designed and defined ODD attribute definition. The ODD monitoring is needed for forecasting an upcoming ODD boundary with sufficient time buffer). In case of an imminent ODD exit, the ADS should be designed to trigger a transition to a Minimal Risk Condition (MRC) or issue a transition demand to the fall-back ready users or change the operating mode to a degraded mode, i.e., lower performance capability mode.

While the role of the human driver/dispatcher is not part of the ODD definition, the ODD is to be defined in a way that it is understandable to the user (driver/dispatcher) to enable them to take into account the ODD limits for the safe use of the ADS feature (see Clause 12).

7.3 Implication to scenario-based testing

As part of the ADS development cycle, the ODD definition may be an iterative process with a gradual increase or decrease in ODD attributes and attribute value coverage. An ODD definition is one of the steps in developing a safety case for an ADS. As part of the scenario-based testing process of an ADS as defined in ISO/DIS 34502, test scenarios shall be identified according to the constraints given by the ODD definition. As part of the process to show compliance with the defined ODD, test procedures shall be demonstrated for the specific defined ODD attributes. Testing should cover correct ADS operation within the ODD, across ODD boundary, and responses outside ODD boundary (e.g., reject attempts to engage outside ODD).

8 ODD Taxonomy

8.1 General

ODD attributes (and their sub-attributes) are specified below in 8.2 and 9-11. If they do not adequately represent a specific operating environment, stakeholders may extend them, including the introduction of relevant measurement units (which might reflect temporal or other aspects). While the taxonomy is extensible, any extensions to the taxonomy which conflict with attributes specified shall be avoided. Furthermore, while extending the attributes, stakeholders shall ensure that the additional attributes are placed at the correct hierarchy and group in the taxonomy while providing justification for the same. For all attributes, the specifier shall provide the objective measurement for the attribute. In case any of the attributes are not relevant for the operating condition of the ADS, such attributes may be ignored from the ODD definition (depending on the format definition, see clause 12). Stakeholders may add additional layer of attributes between parent and child attributes in order to aid grouping of the attributes.

NOTE For examples of regional ODD definitions see Annex B.

8.2 Top level ODD classification

At the top level, the ODD shall be classified into the following attributes:

- Scenery elements
- Environmental conditions
- Dynamic elements

The “scenery elements” attribute (in the context of defining an ODD) shall consist of the spatially fixed elements of the operating environment (e.g., roads, traffic lights, etc.), relative to the ego vehicle (in terms of position of the elements).

The “environmental conditions” attribute shall consist of weather and atmospheric conditions (including information technology connectivity).

The “dynamic elements” attribute shall consist of the movable elements of the ODD, e.g., traffic, subject vehicle etc.

Figure 3 illustrates a top-level taxonomy of the ODD attributes. All attributes are considered to have equal importance.

While scenery elements ODD attributes consist of spatially fixed objects, flow of traffic may change with time on or around scenery elements attributes. For example, traffic flow direction on some roads (drivable surface) may change with time of the day or day of the week. Similarly, some bridges may close and open to let boats and ships to pass. While the state of the bridge changes, the location of the bridge itself doesn’t change. Therefore, all attributes with fixed location are considered to be part of scenery elements attributes, while their state may change with time.

