In green text adopted at IWG ADS#17
In yellow text amended later on

Annex 7

ODD-based Behavioural Competencies and Scenario Identification Approach

1. Introduction

This annex provides an overview on an approach that may be used to derive verifiable performance criteria for the approval or, as relevant, for self-certification of ADS, based on the manufacturer's description of the Operational Design Domain (ODD) of the ADS. Such criteria would be developed by identifying behavioural competencies that embody and correspond to specific ADS safety requirements and relevant ~~[~~scenarios and situations~~]~~ that may be used to validate the ADS's competencies.

The suggested approach includes a description of how such competencies can be classified into nominal, critical and failure and mapped to the relevant ~~[~~scenarios ~~and situations]~~, selected either from existing databases or identified through the application of different approaches.

Different approaches may exist to perform such an activity; therefore, the approach herein presented should be considered as a recommended guideline for both manufacturers and authorities.

1.1. Operational Design Domain

The external conditions constituting the ODD in which the ADS was designed to operate will help determine which ADS competencies are required. For example, if an ADS has an ODD which comprises of roads with non-signalised junctions, one of the required behavioural competencies for the ADS in that ODD could potentially be "unprotected left or right turn". However, the same behavioural competency may not be required if the ODD of an ADS is limited to motorways or highways.

1.2. Behavioural competencies

Behavioural competencies track the three broad categories of driving situations that may be encountered in the performance of the DDT: nominal, critical, and failure.

~~[Nominal driving situations are those in which behaviour of other road users and the operating conditions of the given ODD are reasonably foreseeable (e.g., other traffic participants operating in line with traffic regulations) and no failures occur that are relevant to the ADS's performance of the DDT.]~~

~~[~~Critical ~~driving~~ situations are those **requiring a prompt action of the ADS to avoid or mitigate the risk of a collision, that could result in adverse consequences on human health or property damage. For example, those** in which the behaviour of one or more road users (e.g., violating traffic regulations) and/or a sudden and not reasonably foreseeable change of the operating conditions of the given ODD (e.g., sudden storm, damaged road infrastructure) **requires the ADS to take prompt actions.** ~~creates a situation that requires a prompt action of the ADS to avoid or mitigate a collision.~~ In this case, it is recognised that the ADS may not be able to avoid a collision, but mitigation may be possible.~~]~~

[Failure situations involve those in which the ADS or another vehicle system experiences a ~~fault or~~ failure that compromises the ADS's ability to perform the DDT, such as sensor or computer failure or a failed propulsion system.]

[Nominal ~~driving~~ situations are those **that are neither critical nor failure, such as those** in which behaviour of other road users and the operating conditions of the given ODD are reasonably foreseeable (e.g., other traffic participants operating in line with traffic regulations) and no failures occur that are relevant to the ADS's performance of the DDT.]

2. Approach Description

The ODD-based behavioural competencies and scenario identification approach is based on the interaction of the following elements:

(a) Behavioural competencies and scenario generation

(b) Competencies and scenario mapping

(c) Assumptions

(d) Performance and acceptance criteria evaluation

Figure 1 describes the overall approach. Once acceptance criteria are defined based on **the** overall requirements, different approaches (described below) are used to generate nominal, critical and failure scenario~~s~~ tests. Testing is performed using various test methods, and the outcome is evaluated to see if there is sufficient evidence to support the safety case claims and the acceptance criteria. The following section describes the different stages and steps.

2.1. Behavioural Competencies Identification

The approach suggests a series of analytical frameworks that could help to derive measurable criteria appropriate for the specific application. These frameworks are divided into:

(a) ODD Analysis

(b) Driving interactions analysis

(c) OEDR analysis.

2.1.1. ODD analysis

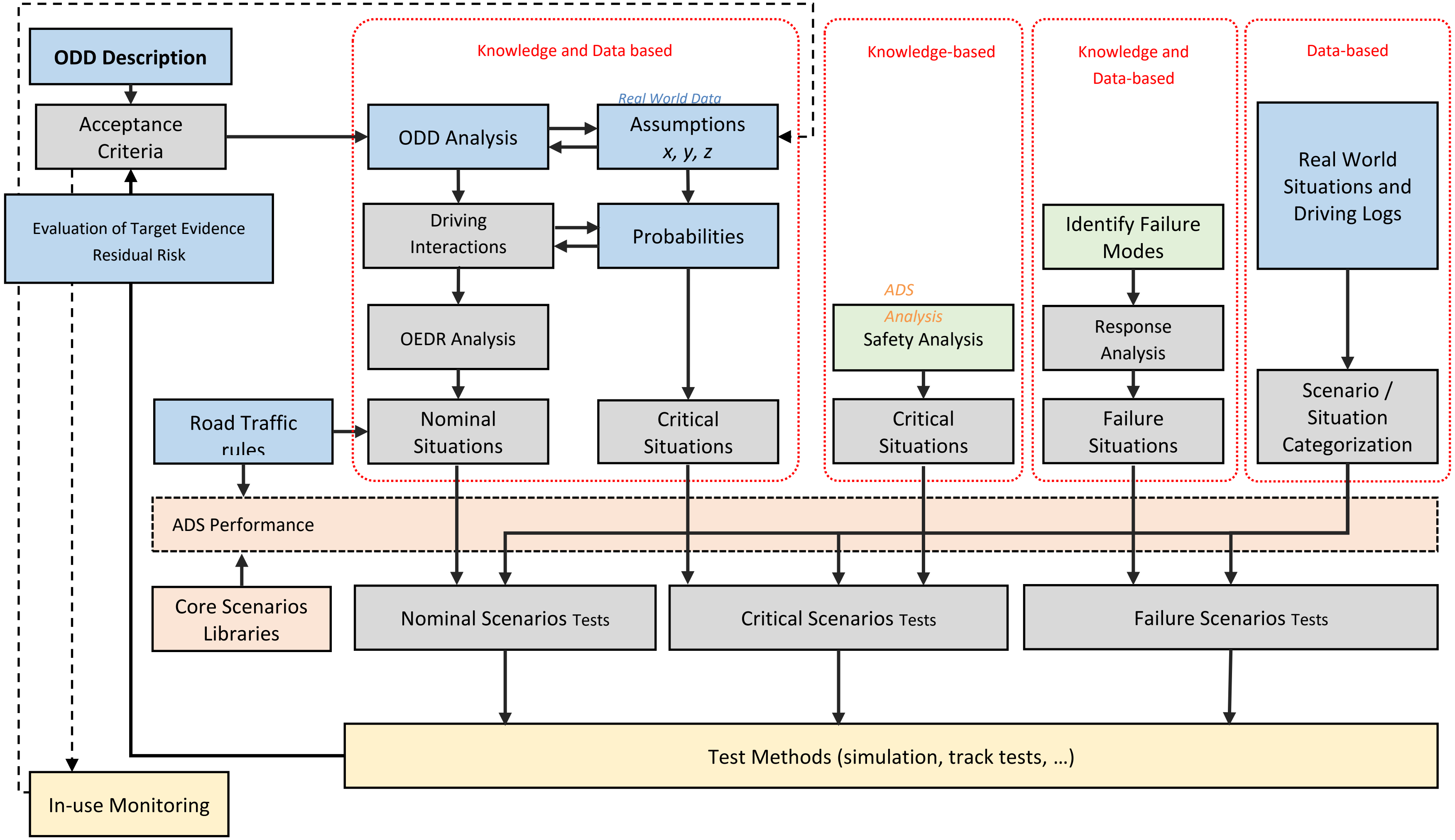
This analysis represents the first step with the aim to identify the characteristics of the ODD. An ODD [~~specification/~~description] can consist of stationary physical elements (e.g., physical infrastructure), environmental conditions, dynamic elements (e.g., reasonably expected traffic level and composition, vulnerable road users) and operational constraints to the specific ADS application. **The output consists of a list of elements to be considered in the subsequent analysis.**~~[Various sources provide useful guidance for precisely determining the elements of a particular ODD and their format definition….]~~

2.1.2. Driving interactions analysis

In the driving interactions analysis, the behaviours of other road users that are reasonably expected and the presence of roadway characteristics in the ODD are explored in more detail by mapping actors with appropriate properties and defining interactions between the objects.

Figure 1

Example of a possible approach to identify behavioural competencies and scenarios



An example of this analysis is given in Table 1, where static and dynamic behaviours of other objects (including other road users) that the ADS is reasonably expected to encounter within the ODD are described. In the case of vehicles, this includes behaviours such as “acceleration”, “deceleration”, “cut-in”; for pedestrians, examples of dynamic behaviours include “crossing road”, “walking on sidewalk”, etc.

The behaviour of other road users and the condition of physical objects within the ODD may fall at any point along a continuum of likelihood. For example, deceleration by other vehicles may range from what is expected and reasonable in the traffic circumstances, to unreasonable but somewhat likely rapid deceleration, to extremely unlikely (e.g., a sudden cut-in combined with full braking on a clear high-speed road). The analysis of the ODD and reasonably expected driving situations within the ODD should make distinctions that include an estimate of the likelihood of situations to ensure that the ADS’s performance is evaluated based on response to reasonably likely occurrences involving nominal, critical and failure situations but not on the expectation that the ADS will avoid or mitigate the most extremely unlikely occurrences.

2.1.3. Object and Event Detection and Response (OEDR) Analysis: Behavioural competencies identification

Once the objects and their reasonably expected behaviours have been identified, it is possible to map the appropriate ADS response, which can be expressed as a behavioural competency. The detailed response is derived from more general and applicable safety requirements. The acceptable ADS response will vary depending on whether the driving situation involves nominal, critical, or failure characteristics.

The outcome of the analysis is a set of behaviour**al** competencies that can be applied to the events characterizing the ODD. Table 2 provides a qualitative example of a matching event – response.

The combination of objects, events, and their potential interaction, as a function of the ODD, constitute the set of potential situations pertinent to the ADS under analysis.

2.2. Scenario Identification

To ensure that the behavioural competencies identified in the previous paragraphs are ready to be assessed, ODD-relevant ~~[~~scenarios ~~and situations]~~ must be identified.

Scenarios can be described at different abstraction levels (i.e., functional, abstract, logical, and concrete) by focusing the scenario description on specific aspects, while leaving other details for further processing.

Sampling techniques can be used when selecting parameters to be used in creating logical and concrete scenarios for the ADS validation for a particular ADS and its ODD to avoid the ADS being optimized for a set of known test cases.

Table 1
Examples of static and dynamic objects and their properties

Objects	*Examples of events and interactions*
Vehicles (e.g. cars, light trucks, heavy trucks, buses, motorcycles)	Lead vehicle decelerating Lead vehicle stopped Lead vehicle accelerating Changing lanes Cutting in Turning Encroaching opposite vehicle Encroaching adjacent vehicle Entering roadway Cutting out
Pedestrians	Crossing road: inside crosswalk, Crossing road: outside crosswalk Walking on sidewalk/shoulder
Cyclists	Riding in lane Riding in adjacent lane Riding in dedicated lane Riding on sidewalk/shoulder Crossing road: inside/outside crosswalk
Animals	Static in lane Moving into/out of lane Static/moving in adjacent lane Static/moving on shoulder
Debris	Static in lane
Other dynamic objects (e.g., shopping cart)	Static in lane Moving into/out of lane
Traffic signs	Stop Yield Speed limit Crosswalk Railroad crossing School zone
Vehicle signals	Direction indicators

Table 2
Examples of elementary behavioural competencies for given events

Event	*Response*
Lead vehicle decelerating	Follow vehicle, decelerate, stop
Lead vehicle stopped	Decelerate, stop
Lead vehicle accelerating	Accelerate, follow vehicle
Lead vehicle turning	Decelerate, stop
Vehicle changing lanes	Yield, decelerate, follow vehicle
Vehicle cutting in	Yield, decelerate, stop, follow vehicle
Opposite vehicle encroaching	Decelerate, stop, shift within lane, shift outside lane
Adjacent vehicle encroaching	Yield, decelerate, stop
Lead vehicle cutting out	Accelerate, decelerate, stop
Pedestrian crossing road	Yield, decelerate, stop
Cyclist riding in lane	Yield, follow
Cyclist crossing road	Yield, decelerate, stop

This approach suggests complementary methodologies to derive reasonably expectable scenarios which might occur for a given ODD:

(a) Knowledge-based methods,;

(b) Data-based methods,; and

(c) Goal-based methods.

A knowledge-driven scenario generation approach utilizes domain specific (or expert) knowledge to identify nominal, critical and failure events systematically and create scenarios. Examples of knowledge-driven scenarios generation approaches include:

(a) Experience acquired during ADS development,;

(b) Synthetically generated scenarios from key parameter variations,;

(c) Engineered scenarios based on functional safety requirements and safety of intended functionality,;

(d) Composing complex scenarios from basic scenarios,;

(e) Random variations of scenario parameters, both for the ADS an ORUs.

A data-driven approach utilizes the available data to identify and classify occurring scenarios. Data-driven scenarios generation approaches include:

(a) Analysing human driver behaviour, including evaluating naturalistic driving data,;

(b) Collision data from accident databases, insurance records, and law enforcement authorities.;

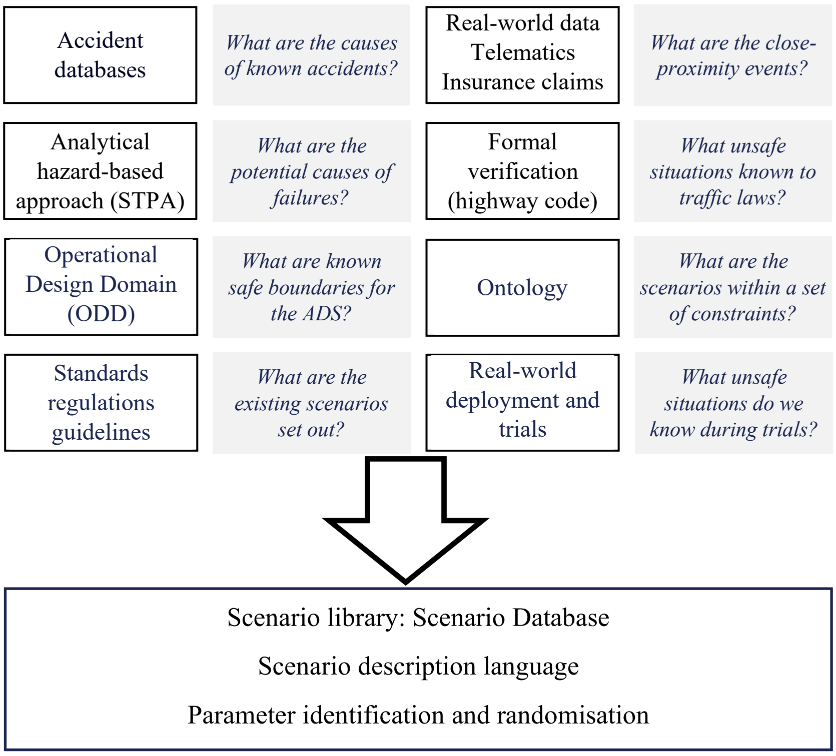
(c) Traffic patterns relevant for the ODD from real-world driving logs;

(d) Situations recorded using instrumented vehicles, the ADS vehicle's sensors, infrastructure or drones.;

(e) **In-Service Monitoring and Reporting findings.** ~~[ISMR ref]~~

Figure 2 illustrates various data-based and knowledge-based scenario generation methods.

Figure 2
Examples of data-based and knowledge-based generation methods



While many of the knowledge-based method are looking at existing data and knowledge, a different method is goal based. ~~[While many of the knowledge-based method are looking at existing data and knowledge, a different method is goal based. As the acceptance criteria are defined, they are actually setting the goals that should be demonstrated by testing and coverage and used as evidence for safety claims. Starting from these goals, and looking at the existing status of the evidence, gaps in testing and coverage can be identifies, and mapped back to missing scenarios that should be used for testing.~~

~~Furthermore, existing scenarios already defined in standards, regulations or guidelines can also be utilized for the testing of ADSs. Additional scenarios include those that occur during real world trials and deployments. Such scenarios might have not been considered pre-deployment but are key learnings. At the time of publishing this text, there is significant experience gathered with existing trials and tests, and thus a significant amount of driving logs and recording can be used.~~

~~For AI centric~~**Training of** ADS systems, training require**s**~~d~~ usage of a lot of data of driving logs and recordings. The same data resources can be used to test the behavioural competencies. The challenge is to map these into the scenario categories, in order to ensure that this testing and its results are counted correctly toward the acceptance criteria evaluation.

One method to categori**se**~~es~~ these logs and recordings is to match them to existing abstract scenario libraries, and classify them to nominal, critical and failure scenarios. With categorization and classification, the evaluation of ~~this scenarios~~**these scenarios**, and counting their contribution to the evidence and the success criteria, can take place.

The scenario-generation method should include adequate coverage of relevant nominal, failure, and critical ~~[~~scenarios and situations~~]~~ to effectively validate the ADS. “Coverage” refers to the degree to which scenarios sufficiently incorporates driving situations in order to validate the relevant requirements of this regulation. Sufficient coverage is essential to the overall effectiveness and credibility of these methodologies as a validation approach. Sufficient coverage should be with respect to the ADS feature or ODD. Coverage can be measured across different domains, and metrics can be used to determine sufficiency. **Coverage can be measured both on the test scenarios serving as input to the test, as well as on the behavioural competencies and KPIs demonstrated during testing.**

2.3. Behavioural competencies and scenarios mapping

Once relevant scenarios and behavioural competencies have been identified, it is necessary to link them. The classification in the three broad categories of driving situations an ADS might encounter such as nominal, critical and failure, serves the purpose.

2.3.1. Nominal Situations Competencies

In these situations, ADS competencies can often be derived by applying traffic laws of the country where the ADS is intended to operate, as well as by applying general safe driving principles for situations not addressed adequately by current traffic laws for human drivers. Examples of such competencies may include adherence to legal requirements to maintain a safe distance from vehicles ahead, provide pedestrians the right of way, obey traffic signs and signals, etc. Of course, some nominal competencies (e.g., safe merging, safely proceeding around road hazards) may not be explicitly articulated or mandated by traffic laws. In some instances, traffic laws may provide wide discretion for the driver to determine the safest response to a particular situation (for example, how to respond to adverse weather conditions). As such not all traffic laws are stated with sufficient specificity to provide a clear basis for defining a competency.

Therefore, an **example** approach to codify rules of the road to provide additional specificity ~~was~~ **is introduced in** ~~developed (see Appendix 1~~**paragraph 2.5.2**~~)~~. Additionally, application of models involving safe driving behaviour may be needed in addition to reference to codified rules of the road in developing behavioural competencies for nominal driving situations.

Table 3 provides an example of competencies and scenario mapping for nominal situations.

2.3.2. Critical Situations Competencies

The development of these competencies requires analysis of (1) what constitutes such unreasonable behaviour by ORUs and/or a sudden change of the operating conditions that are not reasonably foreseeable and (2) what constitutes an appropriate ADS response to avoid or mitigate the imminent crash. Additionally, it is also important to identify the occurrence of unplanned emergent behaviours in critical situations.

Analysis of the first type may be based on a variety of methodologies, including **referencing to** ~~e.g. IEEE 2846~~**existing standards** (which offers guidance on what behaviours by other road users are reasonably foreseeable) and other models of reasonable driving behaviour. Analysis of the second factor may be based on various models of acceptable human driving behaviour in crash imminent situations.

Hazard identification methods (e.g. STPA ~~as mentioned in SAE J3187~~) which analyse the system design for functional and operational insufficiencies can help identify the occurrence of emergent behaviour which may lead to critical situations.

Development of behavioural competencies for critical driving situations faces several challenges. No general consensus exists on the appropriate models for the behaviour of ORUs or appropriate responses by the ADS to unreasonable ORU behaviours that make a crash imminent.

Table 4 provides an example of competencies and scenario mapping for critical situations.

Table 3
Example of competencies and scenario mapping in nominal situations

ODD Element	Driving Behaviour	Traffic Rule	ADS Requirements	Behavioural Competency	Test Scenario
Bicycle	Riding in lane		The ADS shall adapt its driving behaviour in line with safety risks	The ADS ensures relative velocity during passing manoeuvre does not exceed [30] km/h	The ADS travels between [30–50]km/h on the centre line of its lane A cyclist travels in the same direction as the ADS between [10–20] km/h, [0.2–1] m away from the lane edge
		Drivers will need to use a minimum passing distance for bicycles of 1.5m in urban areas, and 2m out of town	The ADS shall comply with traffic rules in accordance with application of relevant law within the area of operation.	The ADS shifts in lane to pass by cyclist with 1.5.m lateral distance	
			The ADS shall avoid unreasonable disruption to the flow of traffic in line with safety risks.	The ADS crosses the centre lane marking to ensure the safe passing distance is not violated	
			The ADS shall interact safely with other road users	The ADS activates the turn signal if the centre lane marking is crossed	

Table 4
Example of competencies and scenario mapping in critical situations

Losses	Hazards	Unsafe Control Action	Loss scenario	Causal factors	Behavioural Competency	Test Scenario
Collision with object outside the vehicle	ADS does not maintain a safe distance from the lead motor vehicle	Braking demand is not provided	Object in vehicle trajectory is not detected	Undetected/misclassified object; Obscured object; Incorrect sensor fusion result	The ADS is following behind a lead vehicle, with the headway set by the ADS. The lead vehicle decelerates at the max assumed rate depending on the weather conditions	Lead vehicle decelerated to turn [right/left] or travel straight on a [mini /large] roundabout
			Object is not considered to be in the vehicle trajectory	Localisation issues leading to incorrect positioning of ego vehicle or object		Lead vehicle decelerated whilst shifting lane to avoid a [static object/other road user]

[Critical situation behavioural competencies should provide evidence that an ADS needs to be responsive to actions by other road users, which may make a crash unavoidable. ThereforeTherefore, critical scenarios should not be limited to those that are deemed preventable by the ADS. Unsafe behaviours of other road users (e.g., vehicle travelling in the wrong direction, sudden unsignalled lane changes, and exceeding the speed limit) — if reasonably foreseeable within the appropriate ODD — should be included as part of validation testing.]

2.3.3. Failure Situations Competencies

The ADS safety requirements include management of various failure modes. As noted above, failure situations scenarios involve those in which the ADS or another vehicle system experiences a fault or failure that compromises the ADS's ability to perform the DDT, such as sensor or computer failure or a failed propulsion system.

In developing the behavioural competencies appropriate for failure situations, the objective is to describe the ability of the ADS to detect and respond safely to specific types of faults and failures. Depending upon the nature and extent of the fault or failure, the responses can include identifying a minor fault for immediate repair after trip completion, responding to a significant fault with restrictions (such as limp-home mode) for the remainder of the trip, or responding to major failures by achieving a mitigated risk condition. Communication of the fault or failure condition to vehicle users may also be a desirable ADS behavioural competency.

Table 5 provides an example of competencies and scenario mapping for failure situations.

2.4. Assumptions

Concrete performance requirements depend on the specific situations the ADS encounters, on a reference behaviour that is deemed appropriate for a human driver or a technical system, and on assumptions (e.g., cut-in speed values, reaction times, …) about the behaviour of the vehicle and other road users. Assumptions concerning the actions of other road users may need to account for cultural differences in driving styles in different geolocations, making it impracticable to harmonise these assumptions across different domains. Therefore, evidence should be provided to support the assumptions made. Existing standards e.g. IEEE 2846-2022 provide a set of assumptions to be considered by ADS safety-related models for an initial set of driving situations. Additionally, several other tools including data collection campaigns performed during the development phase, real-world accident analysis and realistic driving behaviour evaluations, constraint randomisation, Bayesian optimisation besides others can be used to inform values for such assumptions.

2.5. Performance Evaluation

As previously highlighted, nominal situations are considered reasonably foreseeable for a given ODD and therefore it is expected that the ADS would be capable of handling them without any resulting collision.

Table 5
Example of competencies and scenario mapping in failure situation

Failure Type	Failure Mode	Potential Cause	Behavioural Competency	ADS Requirements	Test Scenario	Pass/Fail Criteria
Perception	Fail to identify ODD boundary	Failure to detect ODD attribute e.g. heavy rain/fog	Safely stop in lane of travel	The ADS shall recognise the conditions and boundaries of the ODD of its feature(s)	The ADS operates beyond the predicted ODD	The ADS detects the ODD conditions are not met and issues a minimal risk manoeuvre
				In response to a fault, the ADS shall either execute a fallback response and prohibit activation of the impacted feature(s) if the fault prevents the ADS from performing the DDT in accordance with the requirements of **paragraph 4**~~5~~.1.**/6.1.**, or adapt its performance of the DDT in accordance with the severity of the fault provided the resulting performance complies with the requirements of ~~section~~ **paragraph 4**~~5~~.1.**/6.1.**		The minimum risk manoeuvre should not cause the vehicle to decelerate greater than [4]m/s2

On the other hand, **in** failure situations **the aim is** ~~are performed~~ to assess the ADS ability to recognise faults/failures in the system and safely react to such cases.

For the purpose of defining performance criteria in critical situations, those where others are at fault, behaving unforeseeably, and the collision might potentially not be prevented**, they** have to be analysed further. In these situations, different considerations can be made.

2.5.1. Evaluation of target evidence and residual risk

As testing by the manufacturer is an ongoing process, the outcome of the testing is constantly evaluated. The goal of the evaluation is to assess if sufficient evidence to support the claims of the safety case is achieved, and if an assessment of an acceptable residual risk can be developed. This evaluation is **a** major input to the decision of **whether the** acceptance criteria are met, or if more scenarios and tests are required. If more are required, then additional effort is invested (by using all method shown above) ~~in~~ **to** increas**e**~~ing~~ the ODD and scenario coverage, until the goals of the acceptance criteria is met.

Another way to look at it is represented by the goal-based methods. ~~[While many of the knowledge-based method are looking at existing data and knowledge, a different method is goal-based.~~ As the acceptance criteria are defined, they are actually setting the goals that should be demonstrated by testing and coverage and used as evidence for safety claims. Starting from these goals, and looking at the existing status of the evidence, gaps in testing and coverage can be identifie**d**~~s~~, and mapped back to missing scenarios that should be used for testing.

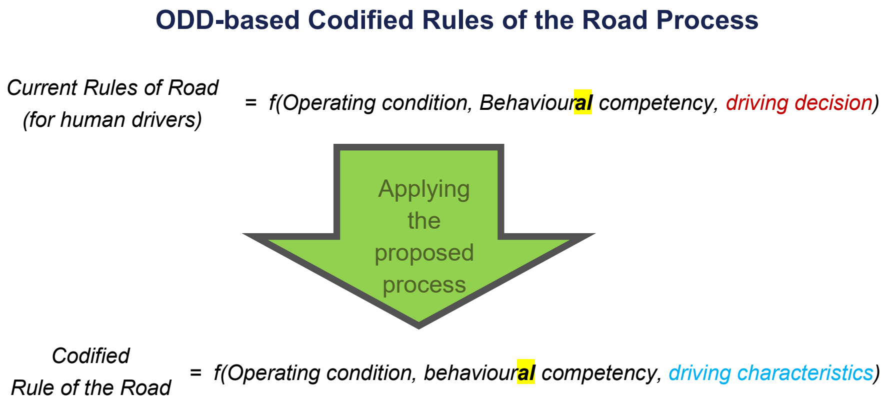
2.5.2. Application of Rules of **the** Road

An approach to define an acceptance criterion related to nominal driving situations is to evaluate the ADS performance against the rules of the road. Furthermore, ADS safety requirements state that, "The ADS shall comply with traffic rules in accordance with application of relevant law within the area of operation."

~~It is challenging to test against this requirement in the absence of codified rules of the road.~~

One possible approach is the codification of the "rules of the road". Figure 3 illustrates the use of rules of the road as pass/fail criteria for individual scenarios. The following approach for codification of Rules of the Road can be used to link individual rules with corresponding scenarios using ODD and behaviour labels.

Figure 3
Rules of the Road to define pass/fail criteria



Current rules of the road (for human drivers) have three components:

Operating conditions include both ODD aspects and vehicle states (e.g., system failures, hardware failures etc.). Every set of traffic laws or behaviour rules (for human drivers) defined in any country are based on an understanding of the expected behaviours of human drivers. As a result, they do not explicitly define all aspects of the expected driving behaviour but can be argued to include "implicit assumptions" based on this understanding.

Following the process, a "codified" rule of the road for an automated driving system will also have three components:

Codified rule = Operating condition + behavioural competency + driving decisions

The process of codification helps identify where "implicit assumptions" about driving behaviour are present in the rules for human drivers. The codified rules of the road help to turn "undefined" attributes in the rules of the road (for human drivers) to "defined" attributes in the codified "rules of the road".