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FRAV Document 5 - Annex
An Approach to Defining Codified Rules of the Road

1. Introduction

Scenario-based testing is being discussed extensively in the UNECE VMAD and FRAV groups. One of the open questions in the assurance or verification and validation of Automated Driving Systems (ADSs) remains the definition of the pass or acceptance criteria. An approach to define an acceptance criterion is to **evaluate the scenarios against the "rules of the road"**. FRAV ADS Safety Topics (FRAV-15-08 & FRAV-15-09) mentions that "The ADS should comply with traffic rules", it is challenging to test against this requirement in the absence of "codified rules of the road". Focussing on the interplay between FRAV and VMAD, our proposed approach thus provides necessary guidance to both:

- FRAV activities (from requirements perspective), and,
- VMAD activities (from pass/fail perspective).

Furthermore, there is a need to create a **natural language description** and **machine-readable description** of the codified rules of the road which can be used by:

- Natural language description: Regulators or type approval authorities
- Machine readable: ADS developers, OEMs, Tier-1s etc. for simulation-based testing purposes (for nominal scenarios) and also allowing them to identify gaps and contradictions in the rules

2. Need for an Operational Design Domain approach to Codifying ADS Rules of the Road

Operational design domain (ODD) refers to the operating environment in which vehicles can operate safely. As defined in the BSI PAS 1883 ODD taxonomy, it covers **environmental conditions** such as rainfall**, scenery elements** such as drivable area, and **dynamic elements** such as macroscopic traffic behaviour and designated speed of the subject vehicle. It is crucial for the ADS to ensure that:

- it can operate safely within its ODD
- it will be primarily used within its ODD
- it can monitor whether it is inside/outside its ODD, and consequently react to it.

If one compares the scope of ODD and the content of current "rules of the road for human drivers" (e.g., UK's Highway Code or the Vienna Convention's Rules of the Road), a large overlap of scenery aspects and environmental condition aspects can be observed. It is therefore plausible to follow an ODD based approach and an ODD taxonomy, to model the environmental and scenery aspects of the "rules of the road". In addition to the ODD aspects, another important aspect for the safety assurance of ADSs is the behaviour competencies. Behaviour can be further divided into ego (vehicle under test) behaviours and actor behaviours.

Any rule of the road can be classified into two categories:

- Doing some "behaviour" "somewhere"
- NOT doing some "behaviour" "somewhere"

While doing or not doing some behaviour can be defined as part of ADS's behaviour competencies, "somewhere" could be considered as "operating condition" or part of the ODD definition.

3. ODD and Behaviour competency-based approach to codifying rules of the road

This Annex presents a framework for codifying the rules of the road to govern the behaviour of ADSs. The approach may be used to define *"good behaviour"* to inform validation and verification processes (including for scenario-based testing) for nominal scenarios.

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

Rule of road (for human drivers) = *Operating condition* + *Behaviour competency* + *Assumptions*

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 tend to have a set of implicit "assumptions" which human drivers tend to follow. These assumptions can include weather attributes (rain, snow etc.) or waiting time (at junctions) etc.

Following the process (illustrated in section 4), **a "codified" rule of the road for an automated driving system, will also have three components:**

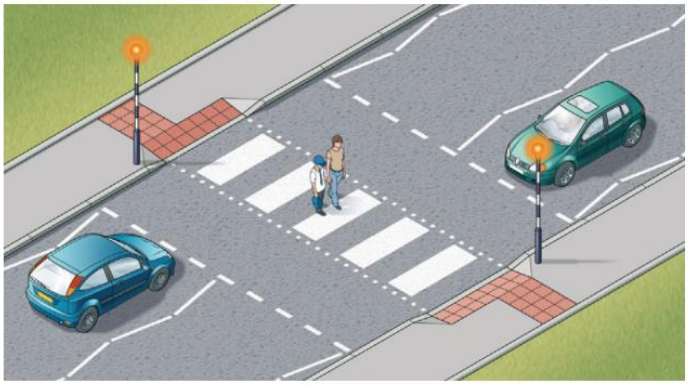
Codified Rule of road = *Operating condition* + *Behaviour competency* + *Driving characteristics (optional)*

The process helps makes the "implicit assumptions" in the rules for human drivers into explicit rules. In other words, **the codified rules of 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".**

Taking an example of the UK road where behaviour (for human drivers) is governed by the Highway Code (HC)[1], the methodology is further explained. UK's Highway Code Rule 195 states (Zebra crossing):

Rule 195: "As you approach a zebra crossing: look out for pedestrians waiting to cross and be ready to slow down or stop to let them cross; you MUST give way when a pedestrian has moved onto a crossing"

[1] UK Highway Code: https://www.gov.uk/guidance/the-highway-code



Rule 19: Zebra crossings have flashing beacons

Figure 1: Example of zebra crossing from UK's Highway Code:
Source: https://www.gov.uk/guidance/the-highway-code/rules-for-pedestrians-1-to-35#rule19

From this rule, one can extract the "operating condition or ODD" variables, as well as the behaviour competencies. ***"Zebra crossing"*** and ***"pedestrian"*** define the ***operating condition***; and ***"slow down or stop"*** defines the ***behaviour competency***. However, the rule doesn't mention how long should the vehicle be stopped. This is an implicit assumption made by the driver. However, for ADSs, such assumptions will need to be specified. We foresee such assumptions potentially being specific to countries, regions, and cultures.

Therefore, we DO NOT suggest creating a single set of universal rules of the road, but rather an approach to define rules of the road.

Figure 2 illustrates this process. After following the codification process of defining the "rules of the road", there will be no underlying "assumptions" (see section 4). Furthermore, for all areas or jurisdiction or country, there will be a minimum set of behaviour code rules which will have consistent *"driving characteristics"* – the base or common set of rules of the road (for ADS).

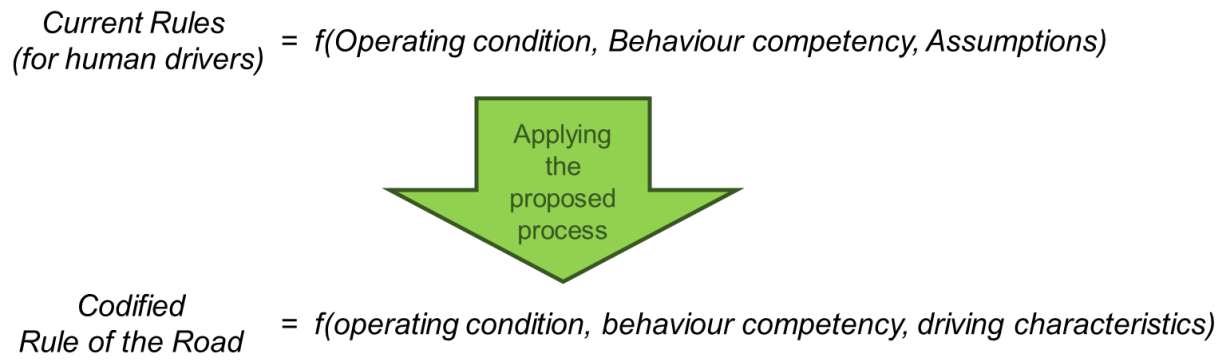


Figure 2: Converting current rules of the road (for human drivers) to codified rules for ADS

4. Codification methodology

The codification methodology is a four-step process:

- **Step 1: Identify terms and construct a vocabulary:** The natural language text of the rule is analysed and words that are associated with the ODD or behaviour of actors in the rule are identified. These terms taken together are used to identify the component of the rule that can be codified

- **Phase 2: Identify ambiguous terms:** Some terms are unclear because they are ambiguous, vague or imprecise and therefore require clarification. In some cases, these terms are codified as is, when a meaning can be inferred, while in others, comments are provided to highlight why the terms are unclear, and how they may be elaborated.

- **Phase 3: Query / Update/ Add ODD and Behaviour terms:** Terms defining predicates (representing facts whose truth may be evaluated) and functions (representing non-Boolean properties – such as ADS attributes, action labels) are identified. The codified rule with consist of these predicates and functions. The outcome of Phase 3 is an intermediate rule that is in its minimal form.

- **Phase 4: Express rule in first order logic:** For each rule of the road, a single codified rule, or a set of rules are written. The predicates and functions identified in Phase 3, together with the structure of constraints from Phase 1 are used to construct the rule(s). The output of Phase 2 provides insights concerning the rule and gaps that exist in its codification. Phase 4 uses the vocabulary to identify which sub-rules are to be converted to First Order Logic and then perform the conversion.

5. Codification Example: Rule 162 (of the UK's Highway Code)

Rule 162 of the UK's Highway Code is used to illustrate the four phases of the codification process. The rule is stated below.

Rule Text
Before overtaking you should make sure *- the road is sufficiently clear ahead* *- road users are not beginning to overtake you* *- there is a suitable gap in front of the road user you plan to overtake.*

The following sections take this rule through each phase, explaining how each component of the codification process works.

5.1. Phase 1: Identify Terms and Construct a Vocabulary

In this phase, terms are identified to generate a vocabulary of predicates. The terms extracted from the ruleset are those relevant to:

- ODD (Scenery, Actor, Environment) & Behaviour
- Rule/Parameter qualifiers: such as '*when', 'limit', 'does not mean',* etc. which affect the meaning of the statement
- Other important terms that need to be reviewed and clarified in Phase 2

Sub-rules that do not contain rules that are actionable for an ADS are not codified.

Example: Rule 162 (Phase 1: Identify Terms)

The rule is re-stated below highlighting important terms.

Before <u>overtaking</u> you should **make sure**

- the **<u>road</u>** is sufficiently **<u>clear ahead</u>**
- **<u>road users</u>** are **not beginning** to **<u>overtake</u>** **<u>you</u>**
- there is a **<u>suitable gap</u>** **in <u>front</u> of the <u>road user</u> you plan to <u>overtake</u>**.

Terms that are ODD and behaviour related are in bold and underline, while other terms that are relevant to giving the rule meaning are in bold.

5.2. Phase 2: Identify Ambiguous Terms

Using domain specific concepts, each minimal statement is fleshed out to clarify any underspecified (unquantified) terms, ambiguous or abstract terms. For instance, if a broad statement is made requiring further qualification, such as, "unsafe road layouts or junctions", it must be identified that a further qualification is necessary and what this may look like. In this case, it is important to specify which road layouts or junctions are unsafe. This may be done using relative terms – for instance, with respect to the ODD of the vehicle; or in absolute terms – enumerating a list of unsafe road layouts and junctions. This should however not be confused with a rule that expresses a general requirement, where the absence of specification of an ODD concept makes the rule applicable to all instances of that concept. For instance, if road type or weather condition is not qualified in the rule's text, then the rule is applicable to all roads and weather conditions. It is only the vague components of a rule that must be fleshed out to make the rule complete from the perspective of an ADS.

Example: Rule 162 (Phase 2: Identify Fuzzy Terms)

This phase involves the identification of the terms that are unclear and that need to be clarified. These are the terms that make the rule ambiguous or underspecified and hence need to be investigated and resolved.

From the example above, the terms that remain underspecified are as follows:

Term	Specification Required
Clear ahead	How is clear ahead defined? *Stopping distance* may be used to define this.
Suitable gap	What is a suitable gap? Twice the *stopping distance* may be a good definition to consider.
Overtaking is an action that is applicable to vehicles that are ahead of the ego	This is an assumption that is understood by a human reader.

5.3. Phase 3: Identify Predicates and Functions

In this phase, each rule is reduced to its minimal form by identifying predicates and functions that form the core facts of the rule. These are the terms that provide meaning to the rule. Once terms are identified, it is important to establish which terms are synonyms or antonyms. For terms that are synonymous, a single term is chosen to be used in place of all terms that are equivalent in meaning to it. In this manner a normalized vocabulary may be constructed.

This exercise focuses on the key aspects of the rule of the road and eliminates the unimportant phrases or terms that cannot be actioned as part of this process.

Example: Rule 162 (Phase 3: Identify Predicates and Functions)

The non-highlighted terms are removed and only terms that are important to the meaning of the rule are kept.

Before <u>overtaking</u> make sure

- **<u>road</u> <u>clear ahead</u>**
- **<u>road users</u> not beginning <u>overtake</u> <u>you</u>**
- **<u>suitable gap</u> in <u>front</u> of the <u>road user</u> you plan to <u>overtake</u>**.

The terms identified are converted into predicates. For Rule 162, we construct the following predicates:

Predicate	Description
isEgo(x)	x is the Ego
isAhead(x,y)	x is ahead of y
isOtherRoadUser(x)	x is a non-Ego object
isClearAhead(x)	x is clear ahead
isOvertaking(x,y)	x is overtaking y
hasSuitableGapAhead(x)	There is a suitable gap ahead of x
canOvertake(x,y)	x can overtake y
isOnRoadLane(x,y)	x is on road-lane y

5.4. Phase 4: Express Rule in First Order Logic

Each rule is then expressed using the normalized vocabulary in first-order logic. The normalized vocabulary is a collection of predicates and predicate parameters, representing concepts in the rule of the road, that are re-used across the codified ruleset.

Phase 4: Express Rule in First-Order Logic

Rule 162 is a rule that identified whether an overtake manoeuvre can be performed. If the conditions of the rule are true, then an overtake manoeuvre can be acted upon, otherwise it must be abandoned. Further, this rule implicitly also identifies which actor the ego can overtake.

For ease of understanding, the rule may be broken down into four logical statements, that are logically related, with the relationship being stated as the last rule. The predicates that were produced as an outcome of Phase 1 are used to construct the logic specification for the rule.

The parameters for the rules: the ego vehicle (x), the lane (y), other actor (w), and actor being overtaken (z).

The rules are as follows:

*Rule (**a**):*	**isEgo**(*x*)	x is the ego
*Rule (**b**):*	**isOnRoadLane**(*x,y*) ∧ **isClearAhead**(y)	x is on road-lane y and y is clear ahead
*Rule (**c**):*	**isOtherRoadUser**(*w*) ∧ **isOvertaking**(*w,x*)	w is overtaking x
*Rule (**d**):*	**isAhead**(z,*x*) ∧ **hasSuitableGapAhead**(*z*)	suitable gap in front of the road user you plan to overtake.
The Rule	(**a**) ∧ (**b**) ∧ (¬**c**) ∧ (**d**) → **canOvertake**(*x,z*)	

The symbol "¬" when used as a prefix to a logic sentence (such as "c" which denotes Rule (c)) indicates the negation of the logic sentence. In this context, in English, the rule may be read as: If "a" is true, and "b" is true, and "c" is false, and "d" is true, then x can overtake z. The truth asserted is hierarchically asserted within the sub-rules.

6. Using Rules of the road in wider safety assurance process

For safety assurance, we see FRAV and VMAD activities at three levels of abstraction (see Figure 4):

- Layer 1: Provides the high-level safety requirements (FRAV-15-08/09) (harmonised)
- Layer 2: Proves a process for converting high-level safety requirements to verifiable requirements (this Annex) (proposal to harmonise)

- Layer 3: Provides concrete values/rules for the requirements (further FRAV/VMAD discussion) (may not be harmonised)

This Annex caters to the layer 2 discussion which is currently missing from the FRAV/VMAD

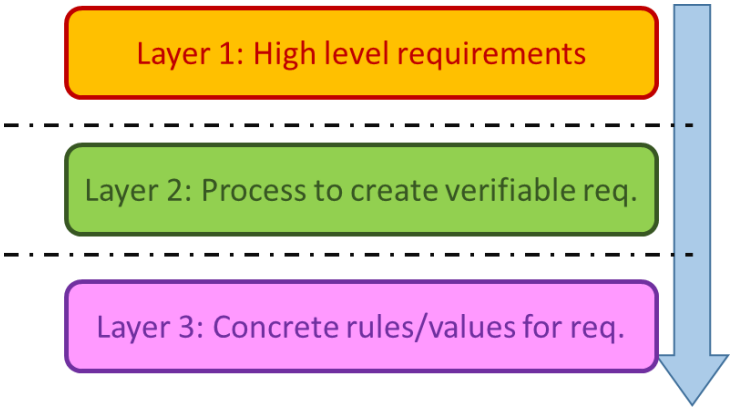


Figure 3: Layers of activities for safety assurance of ADS

discussions.

Furthermore, Figure 5 illustrates the usages of codified rules of the road as an oracle for scenario-based testing activities – scenario generation and evaluation, provide guidance for ADS manoeuvre control under various situations, etc.

Considering every scenario in scenario-based testing approach can be associated with ODD and behaviour tags or labels, **using this approach it is possible to map every scenario to a corresponding rule(s) of the road** using the corresponding ODD & behaviour labels**.**

The first step in safety assurance for an ADS may be identifying the ODD and behaviour competencies of the ADS. This is also fundamental to scenario generation. One may use the identified ODD and behaviour competencies to identify scenarios from a **scenario catalogue (VMAD SG1)**.

As illustrated in this Annex, the codified “rules of the road” is also a function of the identified ODD and behaviour competencies, allowing the test engineer to map each scenario to a corresponding rule (and a corresponding functional requirement – FRAV-15-08/09). These

rules can then serve as the “oracles” or pass criteria during the scenario-based testing for nominal scenarios.

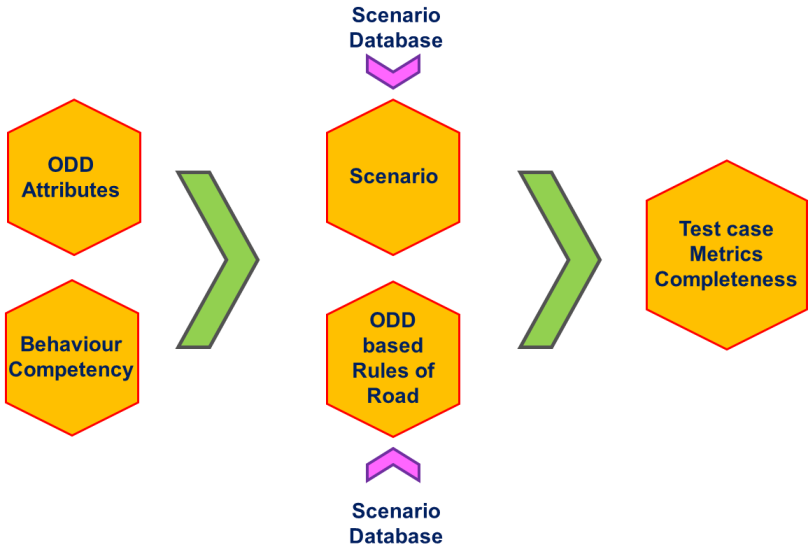


Figure 4: Using ODD based Rules of the Road as part of the Safety Assurance Process

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