Proposal for an Approach to Defining Rules of the Road

United Kingdom

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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, we propose an approach 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 and also allowing them to identify gaps and contradictions in the rules

The UK would like to make the proposed process (and the outputs) open source with all material openly accessible for all stakeholders. We believe this is essential to enable everyone to be able to perform the process, and enable each stakeholder to have a repository of rules of the road that can be tested at the point of approval.

2. Motivation: 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 element** 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), 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, what is not part of the ODD but is also important for the safety assurance of

Highly Automated Vehicles (HAVs) is the behaviour aspect. 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. Proposal:

We propose an “Operational Design Domain” and “Behaviour competency” based approach to defining the rules of the road. This paper presents a framework for defining the rules of the road to govern the behaviour of ADSs. This approach may be used to define *“good behaviour”* to inform validation and verification processes (including for scenario-based testing).

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 proposed process, **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 proposed process helps makes the “implicit assumptions” in the rules for human drivers into explicit rules. In other words, **the proposed process enables to turn “undefined” attributes in the rules of the road (for human drivers) to “defined” attributes in the codified “rules of the road”.**

Figure 1 illustrates this process. Therefore, after following the proposed process of defining the “rules of the road”, there will be no underlying “assumptions”. 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).

Current Rules (for human drivers) = *f(Operating condition, Behaviour competency, Assumptions)*

Applying the proposed process

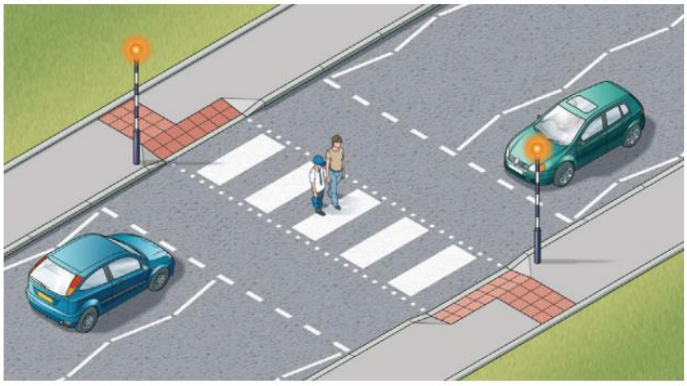
Codified Rule of the Road = *f(operating condition, behaviour competency, driving characteristics)*

Figure 1: Converting current rules of the road (for human drivers) to codified rules for ADS

3.1. Example 1: zebra crossing

Taking an example of the UK road where behaviour (for human drivers) is governed by the Highway Code (HC)[1], we explain the methodology. 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"



Rule 19: Zebra crossings have flashing beacons

Figure 2: 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.

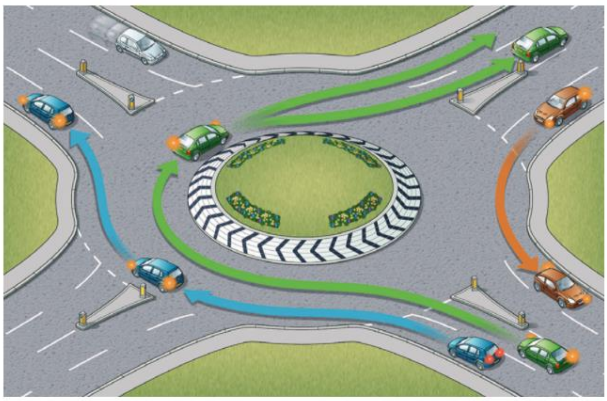
Therefore, we DO NOT suggest creating a single set of universal rules of the road, but rather an approach to define rules of the road.

3.2. Example 2: roundabout

Considering another example from the UK's Highway Code Rule 185, which states:

"When reaching the roundabout you should

- *give priority to traffic approaching from your right, unless directed otherwise by signs, road markings or traffic lights*
- *check whether road markings allow you to enter the roundabout without giving way. If*
- *so, proceed, but still look to the right before joining*
- *watch out for all other road users already on the roundabout; be aware they may not be signalling correctly or at all*
- *look forward before moving off to make sure traffic in front has moved off."*



Rule 185: Follow the correct procedure at roundabouts

Figure 3: UK Highway Code Rule 185

One could identify ODD elements (in blue) and behaviour competency elements (in yellow). After identifying the elements, the next step involves the consolidation and formalisation of the codified rules of the road (for ADS). An example formalisation is given in the Annex.

4. 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 paper) (proposal to harmonise)
- Layer 3: Provides concrete values/rules for the requirements (further FRAV/VMAD discussion) (may not be harmonised)

Our proposal caters to the layer 2 discussion which is currently missing from the FRAV/VMAD discussions.

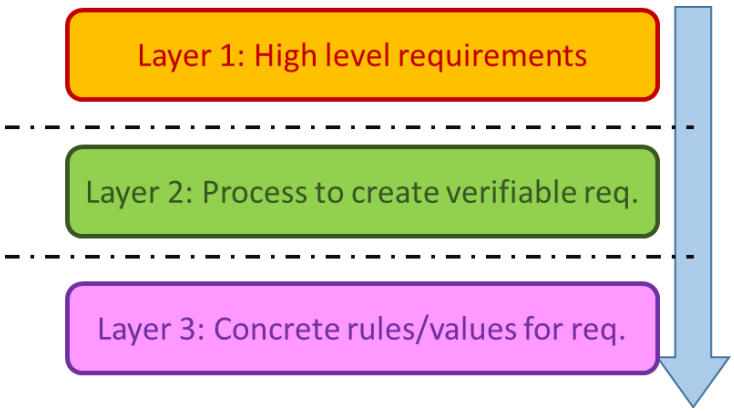


Figure 4: Layers of activities for safety assurance of ADS

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.**

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 our concept for 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 approach.

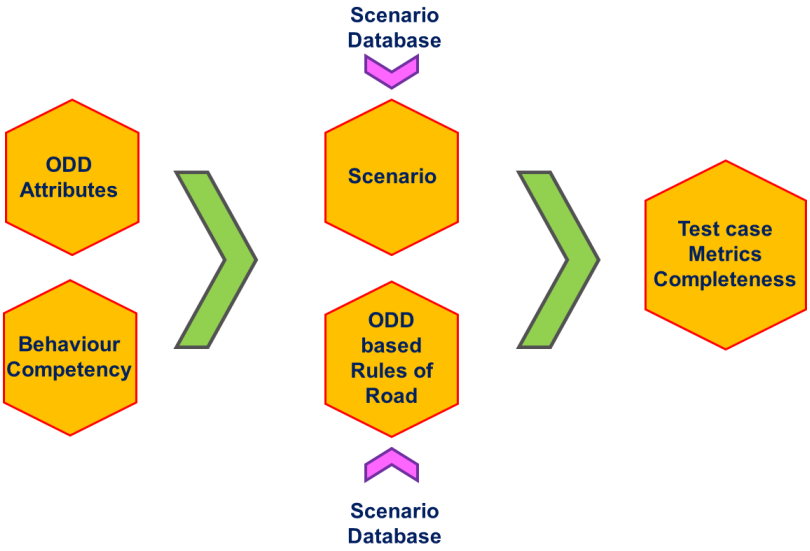


Figure 5: Using ODD based Rules of the Road as part of the Safety Assurance Process

Advantages of using this approach:

- The approach provides a comprehensive approach to define “rules of the road”, providing a common language to describe them, which is essential from a harmonization purpose.
- **It is important to highlight that the rules themselves may differ from country to country (depending on ODD, culture etc.), but the approach for creating the rules and the language for them can be harmonized.**
- The proposed approach provides a guidance on the interplay between the work scope of FRAV and VMAD:
    - The approach can be used by FRAV (for deriving functional requirements from rules of the road based on the ODD description and behaviour competency).
    - Also, the approach can be used by VMAD to define the pass/fail criteria for a scenario by matching it rules of the road to the ODD tags/attributes of the ODD associated with a scenario
- Furthermore, by **underpinning the approach for generating “rules of the road” with ODD**, the **approach is scalable for selecting any set of rules for any ODD**, making it easy to identify which rules of the road apply to which ODD.
- The machine-readable version of the “rules of the road” can allow developers to identify gaps and contradictions in the defined set of rules.
- Using an ontological approach for the “rules of the road” definition, the entire process can be automated using reasoners and other ontological features. Thus, reducing the level of manual effort.

Bibliography:

1. UK Highway Code: https://www.gov.uk/guidance/the-highway-code
2. NHTSA - A Framework for Automated Driving System Testable Cases and Scenarios: https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/13882-automateddrivingsystems_092618_v1a_tag.pdf
3. Waymo’s Safety Report (see behaviour competencies): https://storage.googleapis.com/waymo-uploads/files/documents/safety/2021-03-waymo-safety-report.pdf
4. CETRAN - Scenario Categories for the Assessment of Automated Vehicles : https://cetran.sg/wp-content/uploads/2020/01/REP200121_Scenario_Categories_v1.7.pdf

Annex: Examples

UK Highway Code Rule 165:

"You MUST NOT overtake

- *if you would have to cross or straddle double white lines with a solid line nearest to you (but see Rule 129)*
- *if you would have to enter an area designed to divide traffic, if it is surrounded by a solid white line*
- *the nearest vehicle to a pedestrian crossing, especially when it has stopped to let pedestrians cross*
- *if you would have to enter a lane reserved for buses, trams or cycles during its hours of operation*
- *after a 'No Overtaking' sign and until you pass a sign cancelling the restriction."*

The first segment of Rule 165 states that, *"You MUST NOT overtake after a 'No Overtaking' sign and until you pass a sign cancelling the restriction"*. The rule may be codified as a combination of **operating conditions** and **behaviour competencies** as follows:

isViolatingRule165_1 ⇔ (**noOvertakingSign**(?s1) ∧ **cancellationSign**(?s2) ∧ **car**(?c1) ∧ **isRearOf**(?s1, ?c1) ∧ **isFrontOf**(?s2, ?c1) ∧ **trafficLane**(?l1) ∧ **isOn**(?s1, ?l1) ∧ **isOn**(?s2, ?l1) ∧ **isOn**(?c1, ?l1) ∧ **overtake**(?m) ∧ **intendTo**(?y, ?m))

The rule is expressed using predicates describing the objects, actors, and the relationships between them, that together constitute a violation of the first segment of Rule 165. The rule describes a violation. Here a car, c1, a single instance of the class car, translated as – "*The car*", participates in the violation. It is in a traffic lane on which there are two signs, and it intends on performing an overtake manoeuvre. The logical statement about the car must however be interpreted as a violation of Rule 165. In English a translation would read as follows: "*Rule 165 is violated by a car when it is on a lane ahead of a no overtaking sign and behind a cancellation sign and intends on performing an overtake manoeuvre."*