1. Introduction

An essential aspect in the development of autonomous vehicles (AVs) is the assessment of quality and performance aspects of the AVs, such as safety, comfort, and efficiency. Among other methods, a scenario-based approach has been proposed. With scenario-based testing, the AV is subjected to a collection of scenarios that represent real-world situations.

The collection of scenarios needs to cover the variety of what an AV can encounter in real traffic. As a result, many different scenarios are considered, that are grouped into so-called scenario categories. We propose a method for defining the scenario categories using a system of tags, where each tag describes a particular characteristic of a scenario category.

There is a balance between having generic scenario categories – and thus a high variety among the scenarios in the scenario category – and having specific scenario categories without much variety among the scenarios in the scenario category. For some systems, one is interested in very specific set of scenarios, while for another system one might be interested in a set of scenarios with a high variety. To accommodate this, tags are structured in trees. The different layers of the trees can be regarded as different abstraction levels.

Next to presenting the method for describing scenario categories using tags, we will illustrate the method by showing applicable trees of tags using concrete examples in the Singapore traffic system. Trees of tags are shown for the vehicle under test, the dynamic environment (e.g., the other road users), the static environment (e.g., the road layout), and the environmental conditions (weather and lighting conditions). Few examples are presented to illustrate the proposed method for defining the scenario categories using tags.

KEY WORDS: autonomous vehicle, assessment, scenarios
2. Terminology

In this section, we first explain what we mean with scenarios and scenario categories. Next, in Section 2.2, we describe why tags are used to define scenario categories. We end this section in Section 2.3 with an explanation of the relation between the scenario categories and test cases for the assessment of AVs.

2.1. What is a scenario category?

We distinguish quantitative scenarios from qualitative scenarios, using the definitions of scenario and scenario category of [11].

Definition 1 (Scenario). A scenario is a quantitative description of the relevant characteristics of the ego vehicle, its activities and/or goals, its static environment, and its dynamic environment. In addition, a scenario contains all events that are relevant to the ego vehicle.

Definition 2 (Scenario category). A scenario category is a qualitative description of the ego vehicle, its activities and/or goals, its static environment, and its dynamic environment.

Introducing the concept of scenario categories brings the following benefits [11]:

- For a human, it is easier to interpret a qualitative description rather than a quantitative description.
- It enables to refer to a group of scenarios that have something in common. Therefore, it enables characterization of the type of scenarios, thus making discussing scenarios much easier.
- It allows for quantifying the completeness of a set of scenarios by separately quantifying the completeness of scenario categories and the completeness of scenarios in each category. This is easier because scenario categories are discrete by nature whereas scenarios are continuous. See [14] for more details.

To describe the relation between a scenario and a scenario category, the verb “to comprise” is used [11]. If a specific scenario category $S$ is an abstraction of a specific scenario $s$, then we say that the specific scenario category $S$ comprises that specific $s$. To describe the relation between two scenario categories, the verb “to include” is used [11]. To further illustrate this, consider Fig. 2 where $a$, $b$, and $c$ represent scenarios and $A$, $B$, and $C$ represent scenario categories. The following principles apply for these relations:

- A given scenario category can comprise multiple scenarios, e.g., in Fig. 2, $B$ comprises $a$ and $b$.
- Multiple scenario categories can comprise a specific scenario, e.g., in Fig. 2 both $A$ and $B$ comprise $b$.
- A scenario category includes another scenario category if it comprises all scenarios that the other scenario category comprises, e.g., in Fig. 2, $B$ includes $A$.

Figure 1. A schematic overview of the required components to describe a scenario, and the relation to AV specifications and test cases, based on [10]. The red box indicates the focus of the current report.

Figure 2. The red and green circles correspond to the scenario categories $B$ and $C$, respectively. The overlap between the two circles corresponds to scenario category $A$. The dots represent scenarios $a$, $b$, and $c$. 
2.2. Why using tags?

Tags are often used when providing extra information on a piece of data [15]. A tag is a keyword or a term that helps describing an item. For example, items in a database can contain some tags that enable users to quickly obtain several items that share a certain characteristic described by a tag [16]. Applications are very broad, e.g., from classification of audio data [17] capturing musical characteristics from songs [18] to tagging of Wikipedia pages [19]. The use of these tags brings several benefits:

- The tags of a scenario can be helpful in determining which scenario categories do and do not comprise the scenario [20].
- It is easy to select scenarios from a scenario database or a scenario library by using tags or a combination of tags.
- As opposed to the proposed categorization of scenarios in [21] [22] [23] [24] [25], scenario categories do not need to be mutually exclusive.

There is a balance between having generic scenario categories — and thus a wide variety among the scenarios belonging to the scenario category — and having specific scenario categories without much variety among the scenarios in the scenario category. For some systems, one may be interested in very specific set of scenarios, while for another system one might be interested in a set of scenarios with a high variety. To accommodate this, tags can be structured in hierarchical trees [25]. The different layers of the trees can be regarded as different abstraction levels [26].

2.3. Test cases

Scenario categories can be used to define relevant test cases for the assessment of AVs, see, e.g., [27] [28]. It is generally acknowledged that test cases for the safety assessment of AVs should be based on real-world scenarios [4] [29] [30]. Nevertheless, the terms scenario and test case are often confused; also the combination test scenario is often used in discussion [1].

We use the term scenario for a description of a situation that can happen or has happened in the real world. In other words, scenarios are used to describe any type of situation that a vehicle in operation can encounter during its lifetime. The set of scenarios described by the scenario categories will not fully cover all possible situations that can occur in reality. In Fig. 3 this is represented by the fact that the available set of scenarios (red) does not cover all relevant situations in the real world (blue).

To describe the difference between a scenario and a test case, it is important to know a vehicle’s Operational Design Domain (ODD) [1] to determine the set of relevant test cases. The ODD depends on the application of an AV and usually is the result of the design of the AV in relation to the requirements of the application. An ODD covers a dedicated and limited area of the real world as indicated in Fig. 3 by the green set.

Once the ODD is known, and we have scenarios that cover (part of) the ODD, test cases can be generated. The set of test cases is considered to be a subset of scenarios, as not all scenarios are relevant for each type of vehicle or each type of application. However, test cases are always generated from scenarios; we therefore assume that no test case is generated in areas not covered by the set of scenarios. It is unnecessary to provide test cases outside the ODD, as the system is not expected to respond outside the ODD. The set of test cases in Fig. 3 is denoted by the yellow shaded area. It is represented by the intersection of the set of scenarios and the ODD. In the ideal case, the scenario set is complete and encompasses the ODD. In Fig. 3 this would show if the ODD (green) would fully fit within the set of scenarios (red).

3. Selection of tags

The definition of tags and trees of tags will be presented subsequently for the dynamic environment, for the static environment, and finally for the conditions.

3.1. Tags for the dynamic environment

To describe the dynamic environment, the activities of the different actors are described. First, we consider different type of actors in Section 3.1.1. Next, in Section 3.1.2, tags are provided to describe the activities of the actors. In Section 3.1.3, tags are presented that describe the initial state of an actor in a scenario. Some special tags are applicable for vehicle driving in front of the ego vehicle, see Section 3.1.4.

3.1.1. Carriageway user type

A first distinction within a scenario is usually made for the type of carriageway user, see Fig. 3. The tree of tags is not considered to be complete, however, the current tags cover the most common type of carriageway users. For the motorized vehicle a reference is made to the UNECE regulation [31]. In the regulation, a further distinction in vehicle categories is made. The more general tag "vehicle" applies if a vehicle could be either of category M, N, or L. For the category of Vulnerable Road Users (VRU), the European convention is used, with the exception that powered two wheelers, such as a motorcycle, are explicitly considered a vehicle and not a VRU. The reason to use the separate category L, i.e., motor vehicles with less than four wheels, is the large difference in behavior they exhibit compared to VRU; their position on the road and their riding dynamics including speed are just two of the striking differences.

3.1.2. Activities

An activity describes the behavior related to an actor. This includes, but is not limited to, the dynamic driving tasks as mentioned in SAE J3016 [12]. In this paper, only the lateral motion control (via steering) and longitudinal motion control (via acceleration and deceleration) are reflected into tags.

Figure 3. The relation between the real world, the ODD, the scenarios, and test cases.
The lateral and longitudinal activities of the a vehicle are characterized by the tags of Fig. [5]. The tags may also refer to the objective of the ego vehicle in case no activities are defined. For example, a test case in which the ego vehicle’s objective is to make a left turn, the tags “Turning” and “Left” are applicable.

Four different types of activities are identified regarding the lateral movement. Here, it is assumed that “Lateral” refers to the direction perpendicular to the lane the vehicle is driving in. Therefore, if the vehicle is driving on a curved road while staying more or less in its lane (lane following), the tag “Going straight” is applicable. When the vehicle changes lane to an adjacent lane, the tag “Changing lane” is applicable. The tag “Turning” is applicable when the vehicle turns at a junction. The tag “Swerving” is applicable when the vehicle significantly changes lateral position without performing a complete lane change. For example, when the vehicle overtakes a cyclist that is riding at one side of the lane, the vehicle might swerve to the other side of the lane.

Three different types of activities are identified regarding the longitudinal movement. A distinction is made between driving forward, reversing, and standing still. Regarding driving forward, a further distinction is made with respect to the acceleration.

Due to the typical dynamics for pedestrians and cyclists, separate tag trees are envisioned to characterize their behavior. However, for the sake of brevity, the actual trees are omitted here. We refer the interested reader to [32] where we also present these tag trees.

### 3.1.3. State or initial state

Figure 6 shows tags for the state or the initial state of the potential other road users with respect to the ego vehicle. A distinction is made in the direction of orientation of the road user, the dynamics, and the longitudinal and lateral position. Three tags, i.e., “Same as ego”, “Oncoming”, and “Crossing”, refer to the direction of the road user with respect to the direction of the ego vehicle. The tag “Dynamics” distinguishes between moving and standing still. Finally, two tags are used to describe the position of the actor with respect to the ego vehicle, in longitudinal and lateral direction.

### 3.1.4. Lead vehicle

Figure 7 contains the tags that are used to mark specific actors as either being a leading vehicle or not.

### 3.2. Tags for the static environment

In this paper, we consider for the static environment the road type (Section 3.2.1), the road layout (Section 3.2.2), static objects (Section 3.2.3), and a traffic light (Section 3.2.4).

#### 3.2.1. Road type

The tags for the road type on which the ego vehicle is driving are based on the classification that OpenStreetMaps uses [33]. We omit
3.2.3. Static object

The presence of static objects are described using the tags presented in Fig. 8. A distinction is made between objects that are on the intended path of the ego vehicle and objects that are not on the intended path but are still of importance as they might be blocking the view of the ego vehicle. When a static object is on the intended path of the ego vehicle, the object might be passable - when it is possible to drive over it, or impassable - when the ego vehicle can only avoid undesired interaction with the object by steering around it.

Strictly speaking, every object that is in the field of view of the ego vehicle is blocking part of the ego vehicle’s view. For practical reasons, however, an object is classified as “View blocking” if the object is significantly blocking parts where it is likely that a traffic participant is present. For example, a building that partially blocks the view of a road is classified as “View blocking”. For examples of view-blocking objects, see [36]. A further distinction is made between a parked vehicle or another type of object.

3.2.4. Traffic light

For a traffic light, we consider the tags “Red”, “Amber”, “Green”, and “N.A.”. The last tag is applicable in case the traffic light is not operating. Note that it might be possible that multiple tags are applicable for a scenario. For example, if the traffic light is initially green and turns amber during the timespan of the scenario, both the tags “Amber” and “Green” are applicable.

3.3. Tags for the conditions

Separate tags are specified to describe weather and lighting conditions. Weather and lighting conditions are possibly important in the specification of the operational design domain (ODD) of an AV. It might be indicated by an AV developer that the ODD does not include heavy rain or dark night conditions in the absence of street lights. Figure 10 shows tags describing the weather condition (based on [33]). Tags need to be as specific and quantifiable as possible. Consequently, definitions according to meteorology are followed.

Tags for different lighting conditions are based on [34], see Fig. 10. Although it might seem straightforward to use the lux level as a quantitative measure for the lighting condition, in this paper, we choose to use a qualitative description, relating the light level to the time of day and the possible presence of artificial lighting. In a study into the influence of ambient lighting conditions on the detection of pedestrians by Automated Emergency Braking systems [37], it appeared that lux levels show large variations on the public road. The light conditions were measured at a typical junction equipped with street lights during night time. Variations with a factor of 100 to 1000 easily occur due to changes in position underneath a street light. Also the presence of other ambient lighting sources has a large influence. As it is not possible to indicate an average lux level, we use a qualitative description of the light level. During daytime, there is a strong relation between the weather condition and the available light in a scenario. These weather conditions have been included in the tag tree for lighting. Glare, a bright and strong light that shines directly onto the ego-vehicle’s camera, is another important lighting...
condition influencing an AV’s performance. Glare can be caused by the sun shine while driving to the West just before sunset (or to the East just after sunrise), or by cars in on-coming traffic using high beam headlights. A branch on glare has been added to the lighting tree.

4. Examples of scenario categories

In this section, three different ways are presented to use the tags, presented in Section 3, for defining scenario categories. To illustrate this, we present three scenario categories.

The first way to define a scenario category using tags is to list the tags that are applicable. To avoid ambiguity, first the top-level tag is mentioned and, next, the lower-level tags that apply. To illustrate this, see the scenario category “driving on a straight road” that is schematically shown in Fig. 11.

It might be that the way to list the tags as shown in Fig. 12 is too limited. For example, if multiple vehicles are involved, it might be useful to describe the activities of these vehicles separately. To accommodate this, a selection of tags of a scenario category may be grouped in order to indicate that these tags apply to the same actor. This is illustrated with the example shown in Fig. 13:

For more examples, we refer the reader to [32].
scenario category “oncoming vehicle turns right signalized junction”. The ego vehicle is approaching a junction that is equipped with traffic light signals. The ego vehicle intends to go straight at the crossing. Another vehicle is approaching the junction from the opposite direction. The other vehicle intends to turn right at the junction, such that the trajectories of the other vehicle and the ego vehicle intersect. Note that right-hand traffic is assumed. In Fig. 14, the corresponding tags are shown. The first part refers to the ego vehicle that intends to drive straight in forward direction. The second part refers to the other vehicle that turns right. The third part refers describes that the scenario happens at a signalized junction.

A third way to define a scenario category using tags is presented in case the order in which the tags apply matters. To illustrate this, consider the scenario category “cut in at merging lanes” that is schematically shown in Fig. 15. Another vehicle is driving in the same direction as the ego vehicle in an adjacent lane. The other vehicle makes a lane change because the lanes are merging. In Fig. 16, the corresponding tags are shown. Most notably, the tag for the “lead vehicle” changes from “no leader” to “leader. Note that the direction of the lane change is not described. This could mean that the vehicle could either change lane to the left or to the right. In any case, this actor becomes the lead vehicle, as described my the tag “lead vehicle”.

5. Conclusions

The performance assessment of AVs is essential for the legal and public acceptance of AVs as well as for technology development of AVs. Scenarios are crucial for the assessment. We proposed a system of tags to group these scenarios into so-called scenario categories. Because the tags are structured in trees, it is possible to define both generic scenario categories and more specific scenario categories.

We have also discussed the relation between scenarios and test cases. For the definition of test cases for the assessment of an AV, it is important to consider the AV’s ODD. Currently, there is no unambiguous method known to the authors for the definition of an ODD. A promising method to describe the ODD is using scenario categories. Defining the scenario categories belonging to the AV’s ODD according to the proposed method using the system of tags will reduce — if not remove – any ambiguity regarding the AV’s ODD.

We aimed to provide an extensive list of tags. However, depend-
ing on the application, the list of tags might not be extensive enough. Therefore, we will release subsequent versions of the report in which more tags might be added.

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