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Scenario Categories for the Assessment of Automated Vehicles

Version 1.7 from January 21, 2020

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Contents

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1 Introduction

For safety assessment of Automated Vehicles (AVs) to be deployed, a data-driven approach is followed in which scenarios play an essential role [1]. In [1], it is proposed to use selected test cases for the quantitative assessment of an AV through virtual and physical safety validation. Figure 1 provides a schematic overview of the required components to describe the test cases that an AV should be subjected to [2]. Real-world driving data is used to describe the different situations on the road, with the manoeuvres of traffic participants, the typical layout of the road and infrastructure elements, and weather and lighting conditions. Two different abstraction levels can be considered where the first level qualitatively describes the scenarios and the second level quantitatively describes the scenarios using parameters and models. In a similar manner, the AV can be described, such that the relevant test cases can be deduced.

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. To handle a large number of scenarios, this report focuses on the qualitative description of the scenarios. Therefore, the scenarios are categorized into so-called scenario categories, where a scenario category can be regarded as an abstraction of a quantitative scenario. For example, "Lead vehicle braking" is a scenario category referring to the scenarios in which a car in front of the ego vehicle brakes. Tags are used to make a selection out of the large collection of possible scenarios.

The aim of this report is to introduce an appropriate system of tags and to describe different scenario categories that cover a large portion of the possible varieties that are found in real-world traffic. It is the objective to get a fair indication of the safe operation of the AV when deployed in real-world traffic by subjecting the AV to test cases (both in physical tests, e.g., on a test track, and virtual simulations using appropriate AV models) based on all described scenario categories and their varieties.

This report does not provide an overview of required test cases. The test cases, however, will be based on the scenario categories that are presented here. Before selecting and generating test cases, a match needs to be made of the AV's Operational Design Domain (ODD) onto the requirements for deployment of the AV in a certain area. Based on the ODD, test

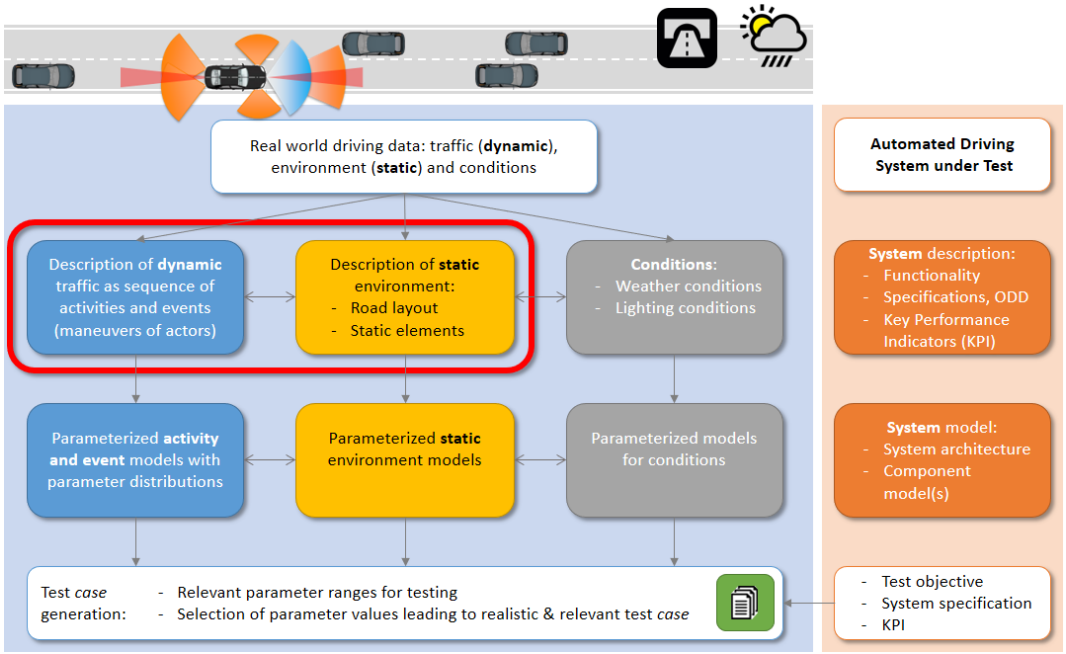

Figure 1: A schematic overview of the required components to describe a scenario, and the relation to AV specifications and test cases, based on [2]. The red box indicates the focus of the current report.

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cases can be selected for the safety assessment of the AV according to [3]. Describing a process for selecting test cases is out of the scope of the current report.

As described in the StreetWise position paper [2], the scenario database is ideally based on naturalistic driving data, in which many thousands of kilometres of data are collected and analysed. This requires a huge effort in deploying multiple data collection vehicles (typically in the order of 100) onto the road, with a sensor set dedicated to the type of study, for the mere benefit of collecting analysis data. In the US and Europe several large data collection activities have been performed in government funded programs, such as SHRP2 [4] and UDRIVE [5] to study the variability in the response of different type of vehicle drivers to every day driving situations including near-critical and critical conditions.

Another structured approach towards providing an overview of scenarios is to study in-depth accident databases, in which data is collected on the specific situations that led to a traffic accident. Particularly well-reported are those cases that resulted in fatalities or severe injuries. Collecting accident reports in different countries over many years provides insight into the large variety of scenarios that resulted in an accident. The results are structured by means of statistical analyses. This report considers literature on accidentology in Singapore, the US and Europe to provide a first overview of scenario categories. A distinction is made in type of road user, road layout, type of manoeuvre, objects interfering with road users, etc. The manoeuvres and traffic situations from accidentology have been used as a starting point in the definition of the scenario categories. Since the scenario database needs to contain not only accident scenarios but generic scenarios that describe all relevant traffic situations, the scenarios were reviewed and completed using an abstraction of all reasonably possible manoeuvres on the road.

This approach has resulted in an overview of 67 scenario categories in an attempt to fully cover the possible scenarios. This overview provides a large variety of realistic and relevant scenarios from which test cases can be generated. The overview, however, is certainly not complete. If and when we may encounter new scenarios during on-road driving, that cannot be attributed to any of the existing scenario categories provided in this document, appropriate new categories can be added to this document. Herewith, this is a living document[1] that will be reviewed regularly for missing scenarios or attributes. Also, when additional information becomes available from vehicles collecting data, the scenario database will be further extended with newly encountered scenarios and their parameters. In this continuous process, the database will grow with time, leading to an increasing number of scenario categories. It is noted that the number of test cases does not necessarily increase with the same rate as the number of scenario categories in the database. The number of test cases is strongly related to the process to generate test cases based on the information in the scenario database. The description of this process is, however, outside the scope of this document.

The used terminology is described and a system of tags is proposed in Section 2. In Section 3, the approach that has led to the set of scenario categories is explained and motivated. The scenario categories are subsequently listed in Section 4. The report is concluded in Section 5.

[1] The most recent version can be found at: http://cetran.sg/publications/.

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2 Terminology

This section describes the different terms used throughout this report to limit the ambiguity regarding the terms used throughout this report. First, the notion of scenario is presented in Section 2.1. Scenario categories refer to the abstraction of scenarios, as explained in Section 2.2. As describe in Section 2.3, the scenario categories will be characterized by a set of tags. Section 2.4 presents the tags that are used to describe the scenario categories defined in Section 4. Finally, we describe the difference between the notion of a scenario and the notion of a test case in Section 2.5.

2.1 Scenario

For the definition of a scenario, the work of Gelder, Paardekooper, Khabbaz Saberi, *et al.* [6] is adopted, as it is more applicable for the context of the assessment of AVs [1]. Before providing the definition of the term *scenario*, a few concepts are introduced.

- *Ego vehicle:* The ego vehicle refers to the perspective from which the world is seen. Usually, the ego vehicle refers to the vehicle that is perceiving the world through its sensors or the vehicle that has to perform a specific task. The ego vehicle is often referred to as the system-under-test or the vehicle-under-test (VUT) – in our case the AV-under-test.
- *Activity:* An activity refers to the behaviour of a particular mode of a system. For example, an activity could be described by the label 'braking' or 'changing lane'.
- *Event:* An event marks the time instant at which a transition of state occurs, such that before and after an event, the state corresponds to two different activities. For example, an event could be described by the label 'initiate braking'.
- *Actor:* An element of a scenario acting on its own behalf. The ego vehicle and other road users are examples of actors in a scenario.
- *Static environment:* The static environment refers to the part of a scenario that does not change during a scenario. This includes geo-spatially stationary elements, such as the infrastructure layout, the road layout and the type of road. Also the presence of buildings near the road side that act as a view-blocking obstruction are considered part of the static environment.
- *Dynamic environment:* As opposed to the static environment, the dynamic environment refers to the part of a scenario that changes during the time frame of a scenario. The dynamic environment is described using activities, the way the state of actors evolve over time. In practice, the dynamic environment mainly consists of the moving actors (other than the ego vehicle) that are relevant to the ego vehicle.

  Note that it might not always be obvious whether a part of a scenario belongs to the static or dynamic environment. For example, the post of a traffic light can be considered as part of the static environment, while the signal of the traffic light can be considered as part of the dynamic environment. Most important, however, is that all parts of the environment that are relevant to the assessment are described in either the static or the dynamic environment.
- *Conditions:* Important for the description of a scenario are also the weather and lighting conditions as these also have an influence on the ego vehicle. For instance, precipitation can have a large influence on sensor performance and vehicle dynamics. Lighting conditions also influence sensor performance. Cameras, for instance, might have difficulty in detecting and classifying objects during night-time in the absence of artificial light. Although one might argue whether light and weather conditions are dynamic or not, it is reasonable to assume that these conditions are in most cases not subject to significant changes during the time frame of a scenario.

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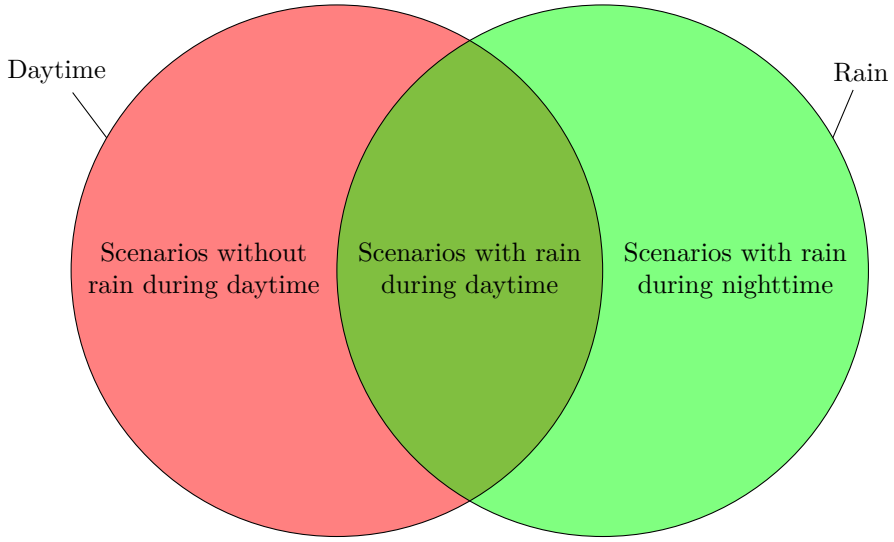

Figure 2: The two circles correspond to the two scenario categories "Daytime" and "Rain", respectively. Scenarios that occur during daytime with rain fall into both scenario categories "Daytime" and "Rain". The new scenario category "Daytime and rain" can be defined as the category that in which all scenarios that occur during daytime with rain fall. The scenario category "Daytime and rain" is falls into the scenario categories "Daytime" and "Rain".

The definition of "Scenario" is taken from [2]:

Definition 2.1 (Scenario)**.** *A scenario is a quantitative description of the ego vehicle, its activities and/or goals, its dynamic environment (consisting of traffic environment and conditions) and its static environment. From the perspective of the ego vehicle, a scenario contains all relevant events.*

Note that this definition is closely related to the definitions of Geyer, Baltzer, Franz, *et al.* [7], Ulbrich, Menzel, Reschka, *et al.* [8], and Elrofai, Worm, and Op den Camp [9]. Definition 2.1 deviates from these existing definitions in the fact that it explicitly states that a scenario is a quantitative description.

2.2 Scenario category

Although a scenario is a quantitative description, there also exists a qualitative description of a scenario. We refer to the qualitative description of a scenario as a *scenario category*. The qualitative description can be regarded as an abstraction of the quantitative scenario.

Scenarios fall into scenario categories. Multiple scenarios can fall into a single scenario category. On the other hand, a scenario may fall into one or multiple scenario categories. As an example, consider all scenarios that occur during daytime. These scenarios fall into the scenario category "Daytime". Similarly, all scenarios with rain fall into the scenario category "Rain", see Figure 2. A scenario that occurs during the night without rain does not fall into any of the previously defined scenario categories. Likewise, a scenario that occurs during daytime with rain falls into both scenario categories "Daytime" and "Rain".

A scenario category can include another scenario category. For example, when we continue our previous example and consider the scenario categories "Daytime" and "Rain", these scenario categories include the scenario category "Daytime and rain".

Several scenario categories are described in Section 4. Firstly, each scenario category contains a human-interpretable description of all its instances. Secondly, it contains so-called tags (see Section 2.3) that characterize the scenario category in a more formal manner. Because the scenario categories are characterized by the tags, two scenario categories are similar if and only if the tags that are associated with the scenario categories are similar.

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2.3 Tags

It is proposed to provide scenarios with applicable tags that describe the scenario in a qualitative manner. The tags of a scenario determines which scenario categories the scenario belongs to. For example, if a scenario occurred during daytime, it will contain the property "tags={Daytime}". As a result, the scenario is automatically recognized as an instance of the scenario category "Daytime" which is characterized by the single tag "Daytime". The use of these tags brings some benefits:

- The scenarios do not need to be directly categorized. This can be a time consuming effort if the number of scenario categories is high.
- If a scenario category that only contains known tags is added to the database of scenario categories, it can be easily seen which scenarios belong to this scenario category by only inspecting the tags of the scenarios.
- It is easy to select scenarios from a scenario database or a scenario library by using tags or a combination of tags.

There is a balance between having generic scenario categories - and thus a high 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 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 [10].

In this report, we propose a first list of tags and trees of tags. With the provided tags, the different scenario categories in Section 4 can be described. It should be noted that the list of tags only provides a first framework. It is expected that additional tags will need to be introduced in due time with the description of more scenarios and scenario categories. In that case it is recommended to define new tags in accordance with the tag trees provided in Section 2.4, aiming to keep the number of tags to the minimum.

2.4 Selection of tags and trees 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.

2.4.1 Tags for the dynamic environment

Carriageway user type A first distinction within a scenario is usually made for the type of carriageway user, see Figure 3. The tree of tags is not considered to be complete, however, the current tags cover the scenarios that are listed in Section 4. For the motorized vehicle a reference is made to the UNECE regulation [11]. In the regulation, a further distinction in vehicle categories is made, however this is not considered important for the purpose of describing scenarios. In this report, a vehicle of category M, N, or L is considered as a *vehicle* unless otherwise indicated. So when the "Carriageway user type" is "Vehicle", it could be, e.g., a passenger car, a large goods vehicle, a bus, or a motorcycle. 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 behaviour they exhibit compared to VRU; their position on the road and their riding dynamics including speed are just two of the striking differences.

Activities As mentioned in Section 2.1, an activity describes the behaviour related to an actor. This includes, but is not limited to, the dynamic driving tasks as mentioned in SAE J3016 [12]. In this report, only the lateral motion control (via steering) and longitudinal motion control (via acceleration and deceleration) are reflected into tags.

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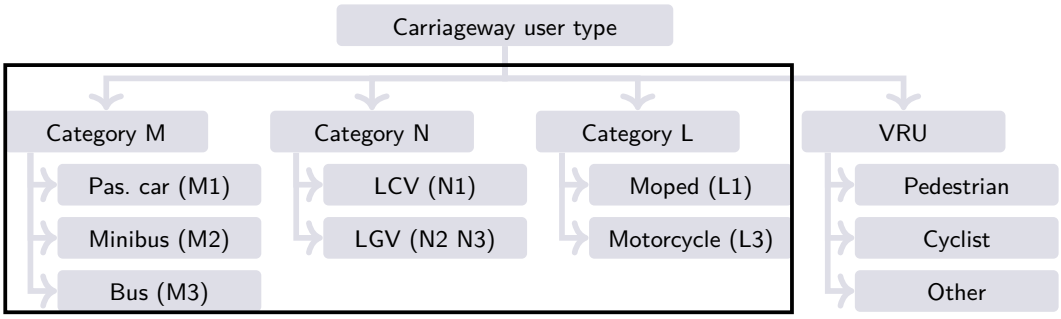

Figure 3: Tags for the type of the carriageway user, with a reference to UNECE vehicle categories [11]. Category M refers to power-driven vehicles having at least four wheels and used for the carriage of passengers. Category N refers to power-driven vehicles having at least four wheels and used for the carriage of goods. Category N consists of the subcategories light commercial vehicle (LCV) and large goods vehicle (LGV). Category L refers to motor vehicles with less than four wheels. A vehicle of category M, N, or L is considered as a *vehicle* in the context of this report as indicated by the black box outline. Note that the list is not complete. For a full reference, see [11].

The lateral and longitudinal activities of the a vehicle are characterized by the tags of Figures 4a and 4b, respectively. 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 (see Figure 4a). Here, it is assumed that "Lateral" refers to the direction perpendicular to the lane the vehicle is driving in (e.g., according to the Road Coordinate System in [13]). 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.

Due to the typical dynamics for pedestrians and cyclists, separate tag trees are provided to characterize their behaviour. Figure 5 shows a single tree for the pedestrian activities. Due to the pedestrian's specific dynamics, no separate lateral and longitudinal activities are distinguished. For the tag "Walking", a distinction is made in walking "Straight", "Turning left", or "Turning right". Furthermore, a pedestrian can almost instantaneously come to a full stop (hence the tag "Stopping") and can be "Standing still". Similar to large deceleration levels for stopping, large acceleration levels can be deployed to start walking.

Figures 6a and 6b show the typical activities for a cyclist. For cyclists, a distinction between lateral and longitudinal activities is made, similar to the distinction for vehicles. In the same way as for pedestrians, a tag for both "Stopping" and "Standing still" is used. As a cyclist can exhibit high deceleration levels, a differentiation is made between a forceful deceleration until standstill (Stopping) and the activity of being at standstill.

Note that other types of actors, such as mono-wheels and powered skateboards, can also have their trees of tags that characterize their behaviour. Because these types of actors are not yet explicitly included into the scenario categories in Section 4, no special tags describing their activities are defined in this report.

Initial state Figure 7 shows tags for the initial state of the potential other road users with respect to the ego vehicle. A distinction is made in the initial direction of orientation of the road user, the initial dynamics, and the initial longitudinal and lateral position. Three tags, i.e., "Same as ego", "Oncoming", and "Crossing", refer to the initial direction of the road user with respect to the initial direction of the ego vehicle. Obviously, the tag "Same as

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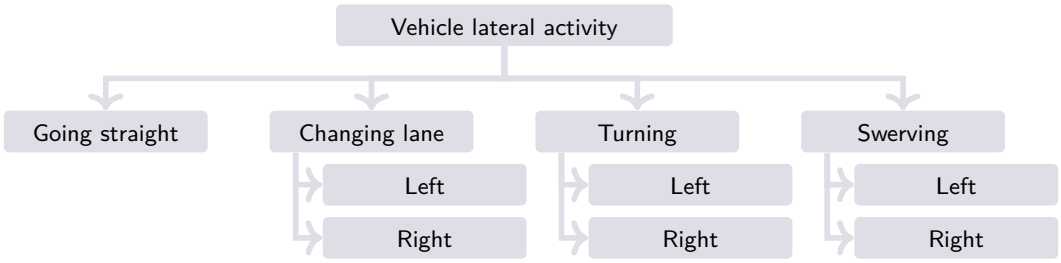
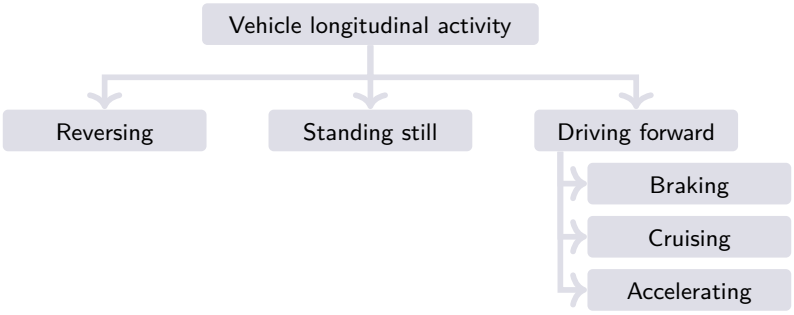


(a)



(b)

Figure 4: Tags for lateral and longitudinal activities of a vehicle. The lateral activity is relative to the lane in which the corresponding vehicle is driving. For example, if the vehicle is driving on a curved road, its lateral activity is "Going straight". As shown in Figure 3, the term vehicle could refer to a car, truck/bus, or powered two wheeler.

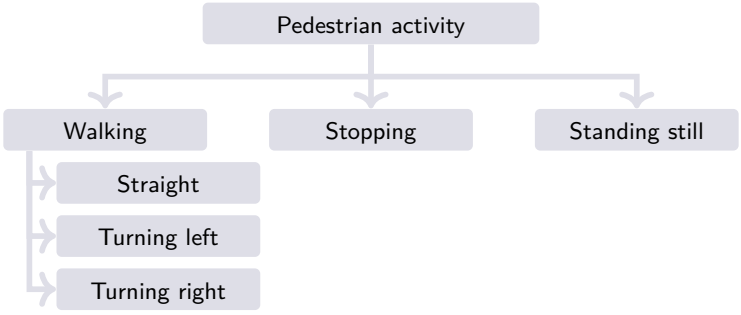


Figure 5: Tags for pedestrian activities.

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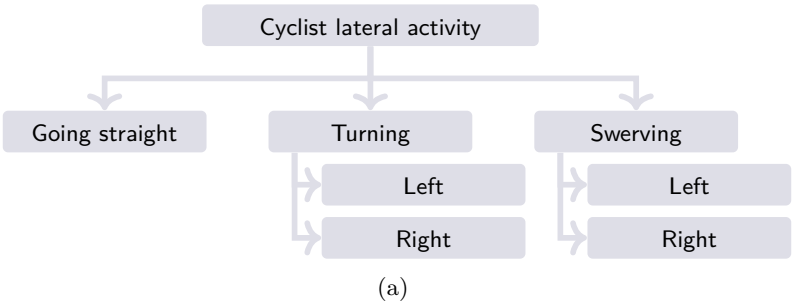

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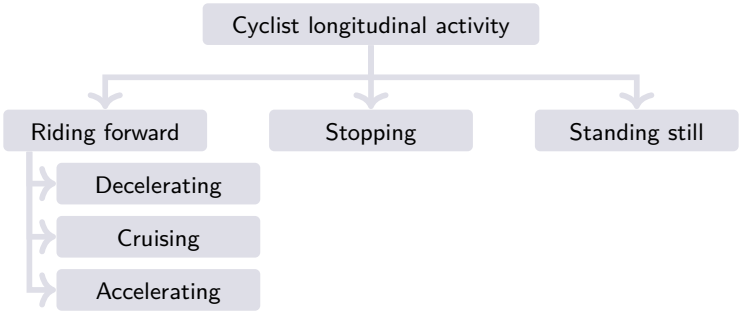

(b)

Figure 6: Tags for cyclist lateral and longitudinal activities.

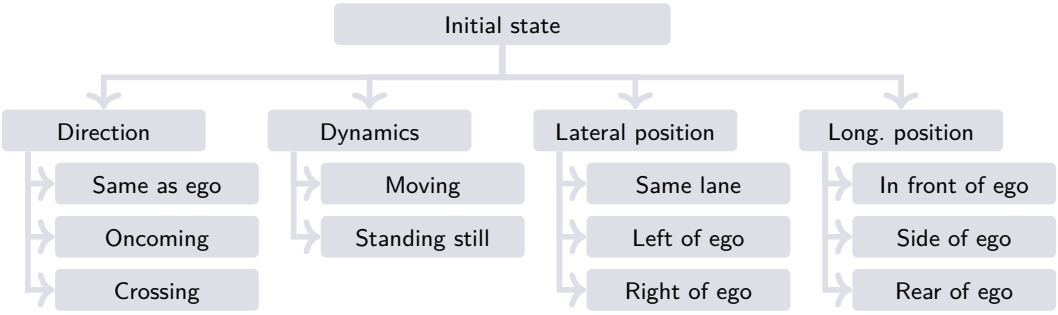

Figure 7: Tags regarding the initial position and movement of road users in a scenario.

ego" refers to road users that are oriented in the same direction as the ego vehicle. The tag "Oncoming" refers to road users that approach the ego vehicle from the opposite direction. For the other road users, the tag "Crossing" is applicable. The tag "Dynamics" refers to the initial dynamics of the road user; the tag distinguishes between initially moving, and stationary, standing still at the start of the scenario. Finally, two tags are used to describe the initial position of the road user with respect to the ego vehicle, in longitudinal and lateral direction.

Note that the relative direction of a road user might change during the course of a scenario. For example, a vehicle that approaches from the left of the ego vehicle will drive in the same direction as the ego vehicle if it turns left while the ego vehicle continues to drive straight and does not change its direction. To avoid ambiguity, the tags, describing the relative position and activities of road users, refer to the initial position and movement of the corresponding road user with respect to the initial position and movement of the ego vehicle. A distinction is made between road users approaching from the left side (nearside in Singapore) and from the right side (farside in Singapore). There are several reasons to make the distinction between a nearside or farside approach:

- Rules for giving way are different for the near- and farside.

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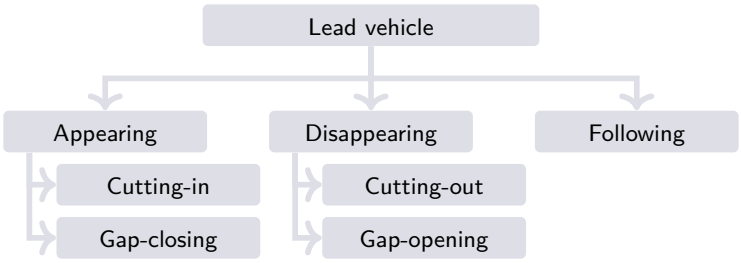

Figure 8: Tags for a lead vehicle, i.e., a vehicle driving in front of ego vehicle, see [6].

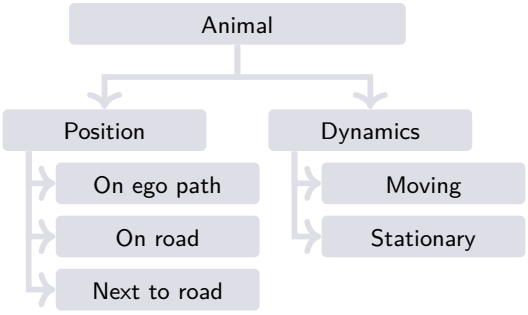

Figure 9: Tags that describe the presence of animals.

- The setup of an AV is possibly not symmetric with respect to the left and right direction. Even when the AV has been designed to be symmetric, it might not behave symmetrically. When the AV correctly responds to a crossing actor from the nearside, it is not guaranteed that it responds equally correctly to a crossing actor from the farside.
- The response time for actors approaching from the nearside and the farside is different, as actors from the farside first usually need to cross at least one lane before interfering with the path of the ego-vehicle.

Lead vehicle Figure 8 contains the tags that are specifically related to a lead vehicle, i.e., a vehicle that is driving directly in front of the ego vehicle. Two different ways of an appearing lead vehicle are considered. The tag "Cutting-in" refers to a vehicle that changes lane such that it ends at the ego vehicle's lane and a "Gap-closing" refers to a vehicle that is already in the ego vehicle's lane and appears in the ego vehicle's field of view. In a similar manner, two different ways of a disappearing lead vehicle are considered, "Cutting-out" and "Gap-opening" respectively. An additional tag "Following" is added to describe the situation that the ego-vehicle is continuously following the lead vehicle for the duration of a scenario.

Note that the tags related to lead vehicle are used to emphasize the role of an actor in a scenario. For example, a vehicle that is initially driving in the same direction as the ego vehicle, in the same lane as the ego vehicle, and in front of the ego vehicle (see Figure 7) is not necessarily a lead vehicle. In other words, the tags that are earlier presented are not sufficient for expressing the role of lead vehicle.

Animals The absence or presence of animals in the scenario can be described using the tags shown in Figure 9.

Example When describing the contribution of an road user to a scenario, the aforementioned tags can be used. We did not, however, explain how one can indicate that multiple tags belong to one actor. To illustrate this, an example is used, see Figure 10. This example describes an actor that performs a cut-in in front of the ego vehicle. First, the road use type is described as vehicle, indicating that this actor can either be a car, truck, bus, or

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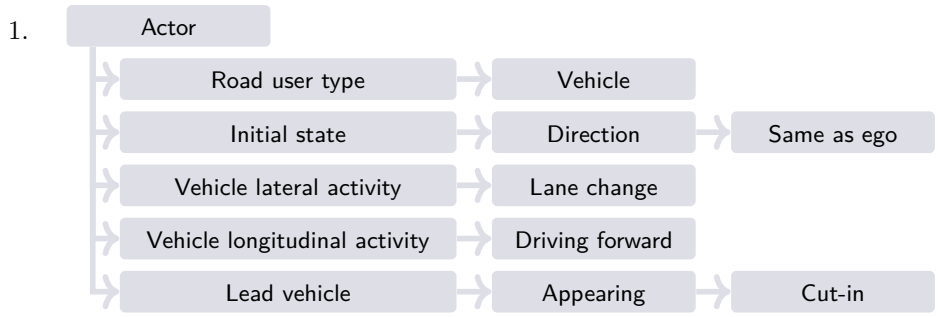

Figure 10: Describing the tags for a vehicle that performs a cut-in in front of the ego vehicle, see also scenario category 9 in Section 4.9.

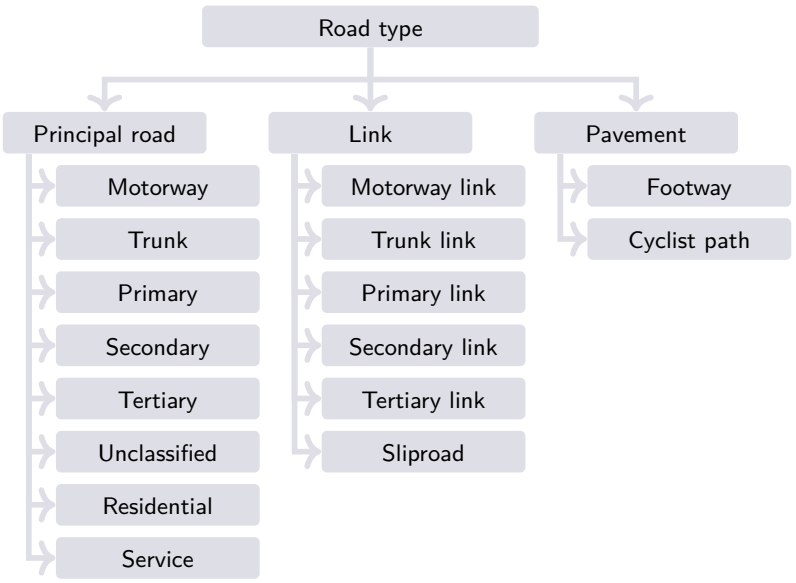

Figure 11: Tags for the type of road, based on the highway tag used for OpenStreetMaps [14].

PTW. Next the initial state is defined. For this particular actor, only the driving direction is defined. Because the initial relative lateral position is not described, the actor can initially be either at the left or right side of the ego vehicle. Similarly, because the initial relative longitudinal position is not described, the actor can initially either be in front of the ego vehicle, next to the ego vehicle, or behind the ego vehicle. The actor is driving forward, but it is not further specified whether the actor is accelerating, cruising, or braking. The actor performs a lane change. Although the direction of the lane change is not specified, it is described that the vehicle appears as a lead vehicle. Therefore, if the actor is initially at the left of the ego vehicle, the lane change is to the right and vice versa.

2.4.2 Tags for the static environment

Road type The tags for the road type on which the ego vehicle is driving are based on the classification that OpenStreetMaps uses [14], see Figure 11. A distinction is made between principal roads and link roads. The link roads refer to roads that are leading to or from the specified road type from or to the specified road type or a lower class road type [14]. Here, a lower class road type refers to all road types listed below the specified road type in Figure 11. For example, the "Trunk link" refers to a road leading to or from a trunk road from or to a road type listed below "Trunk" in Figure 11.

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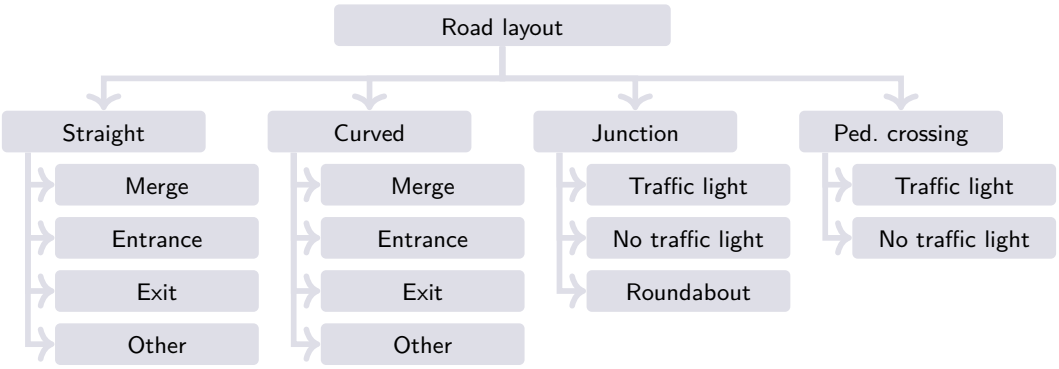

Figure 12: Tags that describe the road layout.

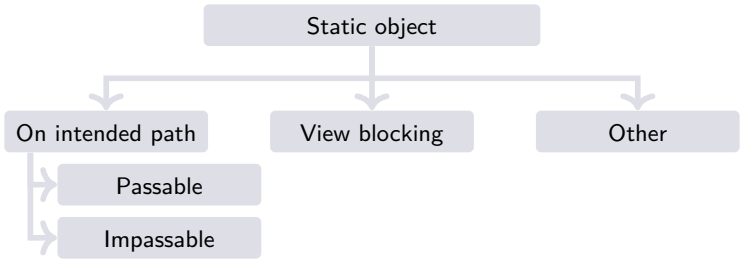

Figure 13: Tags that describe a static object.

Road layout The layout of the road is specified using the tags in Figure 12. Here, four categories are defined. Typically, highway roads will mainly be in the category "Straight". The second subcategory, i.e., "Curved", refers to roads that are highly curved. Typically, the actual speed to safely and comfortably drive these curved roads is lower than the speed limit on the straight section preceding the curved road. For example, a curved road right after a highway exit can often be classified as "Curved". The other two categories refer to junctions, whereas "Pedestrian crossing" refers to intersections where only a footway is intersecting with the road the ego vehicle is driving on, e.g., a zebra crossing. A large roundabout may be regarded as multiple junctions that are close to each other. For smaller roundabouts, it might be better to treat the roundabout as a whole instead of treating it as multiple junctions. In that case, the "Roundabout" tag applies.

Static object The presence of static objects are described using the tags presented in Figure 13. 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 [15]. A further distinction is made between a parked vehicle or another type of object.

Traffic light Figure 14 presents the tags that refers to the traffic light status that is applicable for the ego vehicle. If physically a traffic light is present, but the traffic light is not operating, the tag "N.A." is applicable. Note that it might be possible that multiple tags are applicable for a scenario. For example, if the traffic light is initially green and

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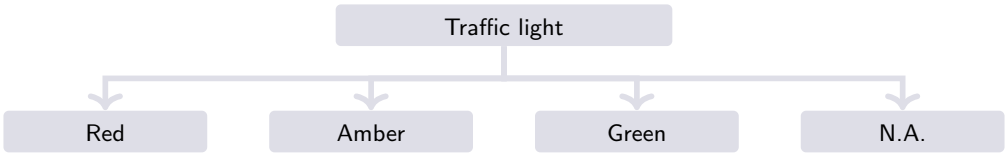

Figure 14: Tags that describe the traffic light status for the ego vehicle.

turns amber during the timespan of the scenario, both the tags "Amber" and "Green" are applicable.

2.4.3 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 15a shows tags describing the weather condition (based on [16]). 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 [17], see Figure 15b. Although it might seem straightforward to use the lux level as a quantitative measure for the lighting condition, in this report 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 [18], 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.

2.5 Test cases

The scenario categories that are presented in this report are meant to cover a large portion of the scenarios that a vehicle can encounter in traffic. These scenario categories can, in turn, be used to define relevant test cases for the assessment of AVs, see, e.g., [1], [9]. It is generally acknowledged that test cases for the safety assessment of AVs should be based on real-world scenarios [9], [19]–[21]. Nevertheless, the terms scenario and test case are often confused; also the combination test scenario is often used in discussions[2]. In this section, the concept of a test case is explained and it is shown what the difference is between scenarios and test cases.

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 Figure 16, this is represented by the fact that the available set of scenarios (red) does not cover all relevant situations in the real world (blue).

[2]We consider a *test scenario* to be similar to *test case*, but we prefer using the term *test case* as to reduce confusion with the term *scenario*.

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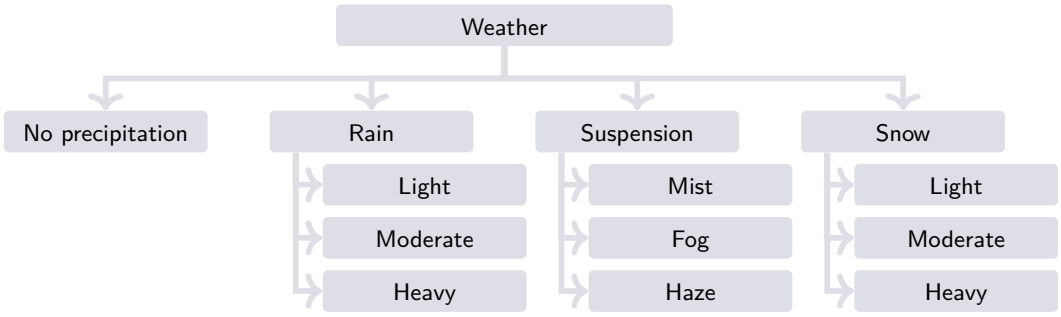
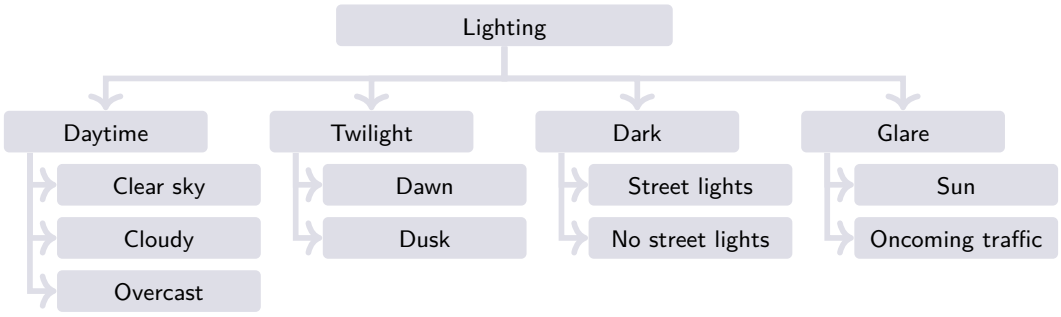


(a)



(b)

Figure 15: Tags for weather condition, based on [16] and lighting conditions, see [17].

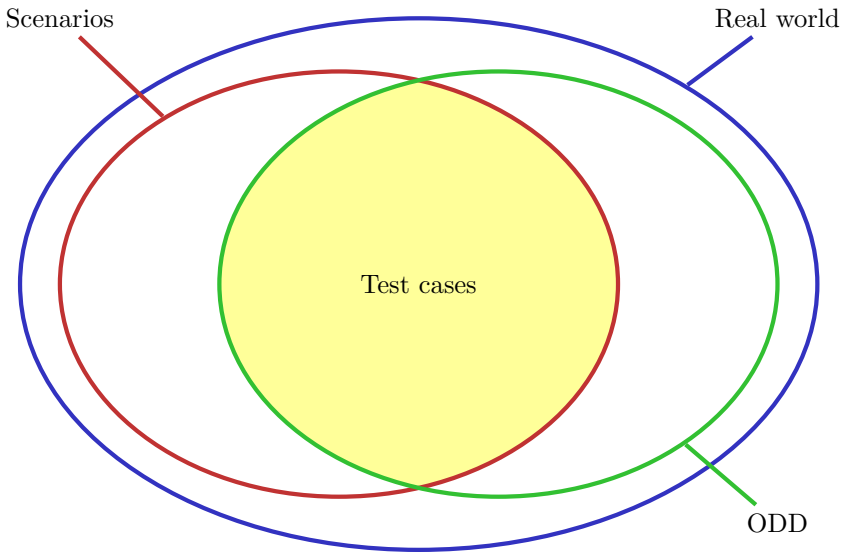


Figure 16: The set of scenarios (red) is a subset of what can happen or can be encountered in the real world (blue). The Operational Design Domain (ODD, green) is also part of the real world (blue), but is not necessarily aligned with the set of scenarios (red). The set of test cases (shaded yellow region) is a subset of the set of scenarios and, ideally, the ODD (green) fully fits within the set of scenarios (red) and there are no test cases that are outside the ODD (green).

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To describe the difference between a scenario and a test case, it is important to know a vehicle's Operational Design Domain (ODD), to determine the set of relevant test cases. SAE automotive standard J3016 [12] defines an ODD as "operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics." 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 Figure 16 by the green set.

The ODD is very likely to differ for different type of vehicles, or even for a different application of a vehicle. Figure 16 considers the ODD of one vehicle type for a given application. Moreover, the figure shows that part of the ODD is covered by the set of scenarios, but possibly we do not have all scenarios identified to cover all of the ODD. A set of scenarios is considered complete in case it covers all relevant ODDs.

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 Figure 16, 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 Figure 16, this would show if the ODD (green) would fully fit within the set of scenarios (red).

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3 Approach

For setting up different scenario categories, several requirements are considered. The first requirement is that the scenario categories should be easy to interpret by a human. Therefore, the scenario categories can be qualitatively described, i.e, using words. Another requirement is that the scenario categories should neither be too generic, nor too specific. If a scenario category is too generic, it can easily lead to misinterpretation, because, in that case, a single scenario category can be interpreted in many different ways. On the other hand, if the scenario categories are very specific, this will lead to large number of scenario categories. This will not only make this document large, it will also lead to scenario categories which are hardly found in real-world traffic. This, in turn, will make it difficult to estimate the variety that exists within a single scenario category.

To come to a first list of scenario categories, different literature sources that describe accident scenarios have been used [22]–[25]. The fact that the listed scenarios led to accidents is a good indication that the scenarios are relevant. The scenario categories are derived from the scenarios mentioned in [22]–[25].

It should be noted, that the scenario categories derived from accident data might be insufficient, because it is possible that AVs have greater difficulty in handling scenarios of a specific scenario category, than human drivers that hardly end up in an accident in these scenarios. In this case, these scenarios will not be represented by accident databases, so using accident databases as only source of information might be insufficient.

TNO's expertize is used to make the scenario categories as specific as possible, based on experiences in other projects in which scenario categories and test cases were generated and worked into a safety assessment protocol, e.g., for Euro NCAP [25].

Accident investigation and statistics of (in-depth) accident databases are traditionally used to determine the most common accident scenarios that need to be addressed by current state-of-the-art Advanced Driver Assistance Systems (ADAS). Especially in cases where several accident databases with different level of detail are used for studying cross-border accident scenarios, a translation needs to be made for each database towards a common scenario description [25], [26]. After such translation has been completed, a check is performed whether the identified accident scenarios cover all relevant scenarios. The cumulative coverage of the most important accident scenarios (in share of contribution to the number of casualties) is used to draft ADAS system specifications. A high cumulative coverage of a system translates into a high expected effectiveness and performance. Since ADAS systems are only triggered in imminent safety critical situations, they do typically not cover nearly 100 % of all possible collision variations.

That is different for AVs. To determine the relevant scenarios for AV-systems, in principal 100 % of all possible scenarios need to be covered; an AV is required to respond appropriately to any realistically possible scenario on the road, whether or not it is very common or very rare. Consequently, in our approach, given a certain accident cause, e.g. failing to give way to traffic with right of way at a junction, we start from identifying all possible interaction scenarios at a junction. We consider the manoeuvres an AV (ego vehicle) can follow across the junction in relation to the manoeuvres of a target vehicle at the same junction. The layout of the junction itself does not play a role and is therefore not considered here.

Figure 17 gives an overview of all possible interaction manoeuvres between one ego and one target vehicle coming from different directions of the junction. The colours of the arrow indicate whether there is principally no conflict as paths do not intersect, or there is a possible conflict where either paths intersect (red) or paths coincide from the junction onwards (orange) according to [27]. All these scenarios need to be considered for an AV.

3.1 Combining scenario categories

Most of the scenario categories presented in the next chapter consider at most one actor other than the ego vehicle. When more than one other actor is considered, there are many more interactions possible. In fact, the possibilities grow exponentially with the number of actors involved. Therefore, to keep the document practicable, most scenario categories only

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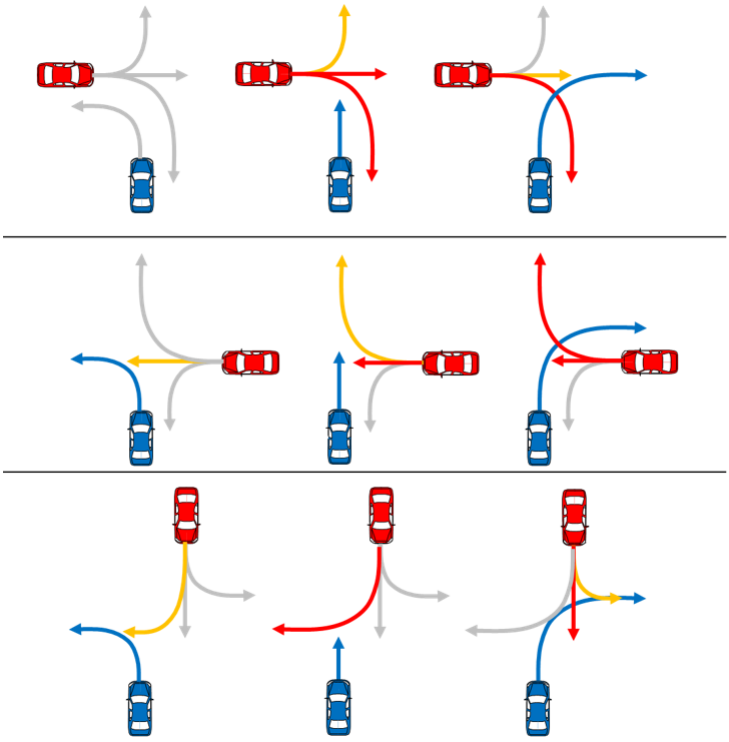

Figure 17: Matrix approach to cover 100 % of all possible interaction scenarios.

consider up to one other actor than the ego vehicle. Instead of presenting a very extensive list of scenario categories with more than two actors, we will illustrate with two example how scenario categories can be combined.

For the first example, consider SC8: Lead vehicle braking and SC10: Ego performing lane change with vehicle behind. In SC8, a vehicle driving in front of the ego vehicle brakes. This might be a reason for the ego vehicle to intend a lane change. In SC10, the ego vehicle intends to perform a lane change while a vehicle is approaching from behind. In Figure 18a, this situation is schematically shown and the corresponding tags are shown in Figure 18b. The tags related to the ego vehicle are the same for SC8 and SC10, so when combining the two scenario categories, these tags remain unchanged. SC8 and SC10 both have one actor and in Figure 18b these actors are both present.

For the first example, consider SC28: Ego vehicle turns right with oncoming vehicle at signalized junction and SC50: Pedestrian at right turn at signalized junction. In SC28, the ego vehicle turns right at a signalized junction while a vehicle is approaching from the opposite direction. Also in SC50, the ego vehicle intends to turn right at a signalized junction. Furthermore, in SC50, a pedestrian is crossing the path of the ego vehicle. In Figure 19a, this situation is schematically shown and the corresponding tags are shown in Figure 19b. The tags related to the ego vehicle and the signalized junction are the same for SC28 and SC50, so when combining the two scenario categories, these tags remain unchanged. Furthermore, Figure 19b contains the tags for the oncoming vehicle in SC28 and the pedestrian in SC50.

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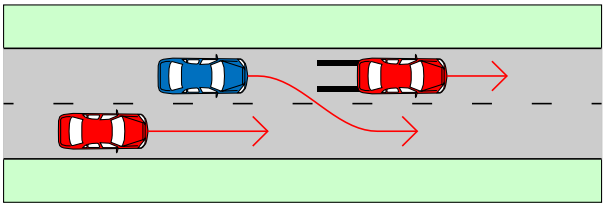

(a) Schematic representation of the combination of SC8 and SC10.

1. Ego
   - Vehicle lateral activity → Changing lane
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Initial state → Long. position → Rear of ego
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward
3. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Initial state → Lateral position → Same lane
   - Initial state → Long. position → In front of ego
   - Lead vehicle → Following
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward → Braking

(b) Tags that resulted from combining SC8 and SC10.

Figure 18: Schematic representation and tags of the combination of SC8: Lead vehicle braking and SC10: Ego performing lane change with vehicle behind.

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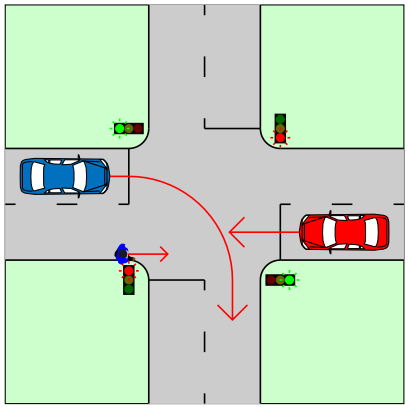

(a) Schematic representation of the combination of SC28 and SC50.

1. Ego
   - Vehicle lateral activity → Turning → Right
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Oncoming
   - Initial state → Lateral position → Right of ego
   - Initial state → Long. position → In front of ego
   - Vehicle lateral activity → Going straight
3. Actor
   - Carriageway user type → VRU → Pedestrian
   - Initial state → Lateral position → Right of ego
   - Pedestrian activity → Walking
4. Road layout → Junction → Traffic light

(b) Tags that resulted from combining SC28 and SC50.

Figure 19: Schematic representation and tags of the combination of SC28: Ego vehicle turns right with oncoming vehicle at signalized junction and SC50: Pedestrian at right turn at signalized junction.

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4 Scenario categories

This section contains the descriptions of the scenario categories. For each scenario category, a schematic representation is given. Table 1 explains the meaning of the different symbols that are used for these schematic representations.

For each scenario category, a set of tags is defined such that all scenarios belonging to this scenario category contain at least all these tags.

Considering all possible combination of tags will result in a virtual infinite number of scenario categories. The following is done to avoid having a huge list of scenario categories:

- Weather conditions are not specified for the scenario categories. Hence, each scenario category is valid independent of the type of weather.
- Similarly, lighting conditions are not specified for the scenario categories. Hence, each scenario category is valid independent of the type of lighting condition.
- For each scenario category, only the objects that the ego vehicle has to interact with are described.

Note that some scenarios of a specific scenario category might be more relevant in certain conditions that are not described by the tags. In this case, this will be noted in the description of the scenario category.

Each scenario category contains a minimal list of parameters that are needed to describe the scenarios of that particular scenario category. There might be additional parameters. For example, if additional vehicles are surrounding the ego vehicle, these trajectories also need to be parametrized. Additionally, the following parameters are implicitly included, unless otherwise specified:

- The road layout that is relevant for the scenario, denoted by θ_{road}.
- The light conditions are described by the parameter vector θ_{light}.
- The weather conditions are desribed with the parameter vector θ_{weather}.
- The friction coefficient between a regular tire and the road, denoted by μ.
- The initial easting position of the ego vehicle, denoted by x_0.
- The initial northing position of the ego vehicle, denoted by y_0.
- The initial speed of the ego vehicle, denoted by v_0.

Remark 4.1. The scenario categories are provided with labels of the form SCXX, where XX is replaced by a number. Note, however, that the order of the scenario categories is not based on the number XX. Instead, the order of the scenario categories is based on some elements of the scenario category. For example, we first list the scenario categories with no other actor than the ego vehicle. Next, we list the scenario categories with one other actor being a vehicle. If a scenario category is added to a newer version of the document, it gets the number XX that equals the number of scenario categories originally present plus one. As a result, the number XX of a scenario category is different than the order of scenario categories. ◊

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Table 1: Explanation of the different symbols used for the schematic representations of the scenario categories.

Image	Description
	Ego vehicle
	Moving vehicle that is part of the dynamic environment
	Vehicle (other than the ego vehicle) that is not moving
	Cyclist that is part of the dynamic environment
	Pedestrian that is part of the dynamic environment
	Impassable static object that is part of the static environment
	Passable static object that is part of the static environment
	Animal that is part of the dynamic environment

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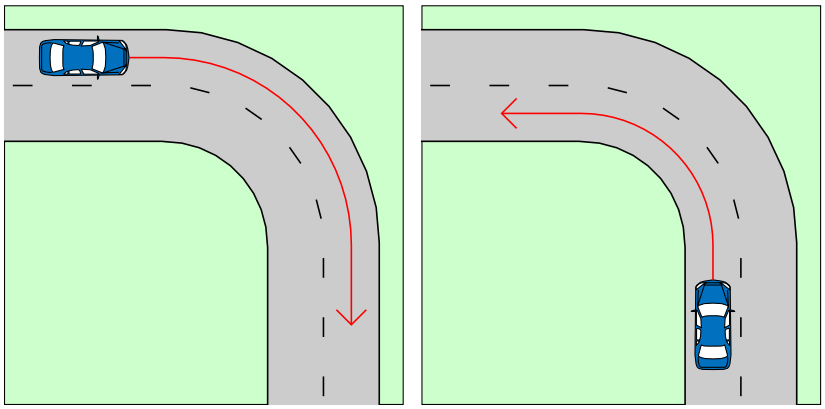
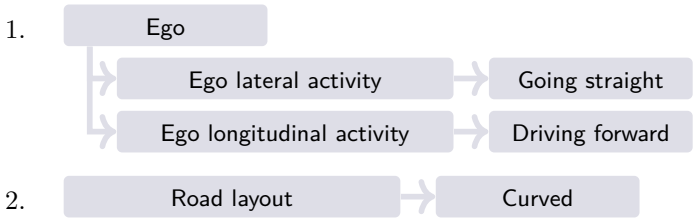
4.1 SC1: Maneuvering a bend



(a) Schematic representation of SC1: Maneuvering a bend.



(b) Tags of SC1: Maneuvering a bend.

Figure 20: Schematic representation and tags of SC1: Maneuvering a bend.

4.1.1 General description

The scenario is schematically shown in Figure 20a. The ego vehicle is driving on a curved road. To safely and comfortably drive the bend in the road, the ego vehicle needs to slow down (usually below the speed limit) on the straight road preceding the curve. The majority of the accidents for this scenario class occur during wet weather conditions and dark lighting conditions [23].

While driving on a straight road mainly requires longitudinal control of the vehicle (with small lateral correction to stay in lane), manoeuvring a bend considers a combination of longitudinal control to determine a vehicle speed appropriate for the bend curvature and lateral control to follow the curve and simultaneously adapting lane position (usually more to the inside of the bend). Generally, a strict distinction is made between accidents due to leaving the road on a straight and accidents due to leaving the road in a curve. Where the first is a failure of lateral control to keep the car on the straight, the latter is usually due to the speed being too high for the bend's curvature. Either the curvature has not been well anticipated for, or the speed has not been adapted sufficiently, e.g. due to late response to the curve.

4.1.2 Formal description

Static environment The static environment consists of a curved road.

Ego vehicle The objective of the ego vehicle is to continue driving on the same lane.

Dynamic environment For this scenario category, no dynamic environment is considered.

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Tags Figure 20b shows the tags that are assigned to this scenario category.

4.1.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 20a are described by at least the parameters mentioned at the beginning of this section on page 19.

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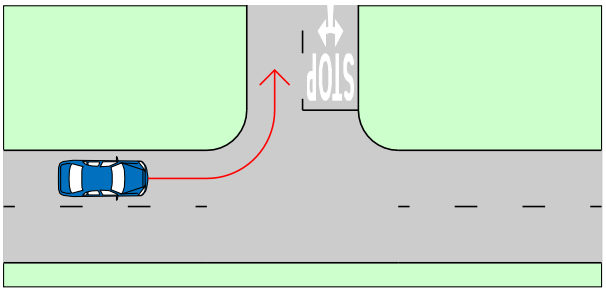
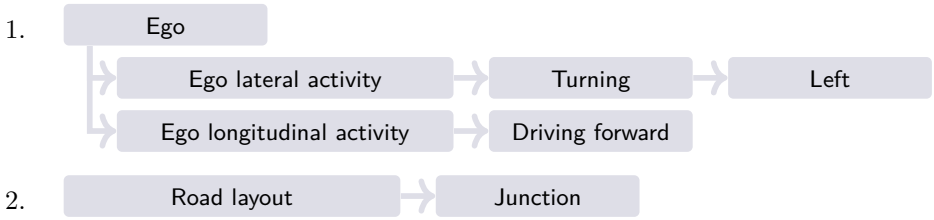
4.2 SC2: Turning left



(a) Schematic representation of SC2: Turning left.



(b) Tags of SC2: Turning left.

Figure 21: Schematic representation and tags of SC2: Turning left.

4.2.1 General description

The scenario is schematically shown in Figure 21a. The ego vehicle is approaching a junction. The objective of the ego vehicle is to turn left at this junction. In order to safely and comfortably make the turn, the ego vehicle needs to slow down (usually below the speed limit). Note that in Figure 21a, the ego vehicle is making a left turn on a 3-way junction. However, the scenario class may contain scenarios at other junctions than 3-way junctions. The majority of the accidents for this scenario class occurs during wet weather conditions and dark lighting conditions.

4.2.2 Formal description

Static environment The static environment consists of a junction.

Ego vehicle The objective of the ego vehicle is to turn left at the junction. To safely and comfortably take the turn, the ego vehicle has to slow down (usually below the speed limit).

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 21b shows the tags that are assigned to this scenario category.

4.2.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 21a are described by at least the parameters mentioned at the beginning of this section on page 19.

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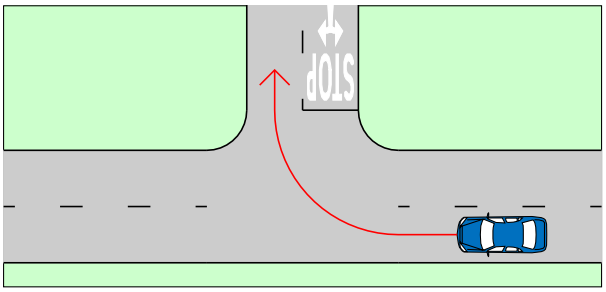
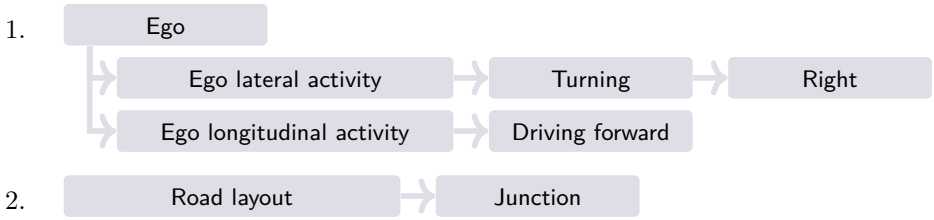
4.3 SC3: Turning right



(a) Schematic representation of SC3: Turning right.



(b) Tags of SC3: Turning right.

Figure 22: Schematic representation and tags of SC3: Turning right.

4.3.1 General description

The scenario is schematically shown in Figure 22a. The ego vehicle is approaching a junction. The objective of the ego vehicle is to turn right at this junction. In order to safely and comfortably make the turn, the ego vehicle needs to slow down (usually below the speed limit). Note that in Figure 22a, the ego vehicle is making a right turn on a 3-way junction. However, the scenario class may contain scenarios at other junctions than 3-way junctions. The majority of the accidents for this scenario class occurs during wet weather conditions and dark lighting conditions.

4.3.2 Formal description

Static environment The static environment consists of a junction.

Ego vehicle The objective of the ego vehicle is to turn right at the junction. To safely and comfortably take the turn, the ego vehicle has to slow down (usually below the speed limit).

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 22b shows the tags that are assigned to this scenario category.

4.3.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 22a are described by at least the parameters mentioned at the beginning of this section on page 19.

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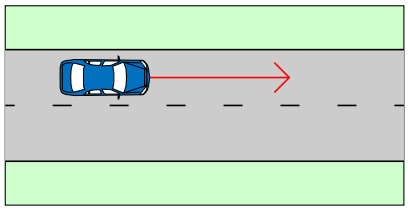
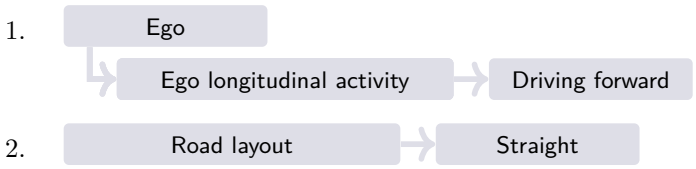
4.4 SC4: Driving straight



(a) Schematic representation of SC4: Driving straight.



(b) Tags of SC4: Driving straight.

Figure 23: Schematic representation and tags of SC4: Driving straight.

4.4.1 General description

The scenario is schematically shown in Figure 23a. The ego vehicle is driving on a straight road. It is assumed that the initial objective of the ego vehicle is to continue driving straight in the same direction. The road, however, might be slippery, for example because of oil on the road or an excess of water. It might, therefore, be possible that the ego vehicle needs to divert its path to avoid the oil or water on the road. The presence of bad, unclear or aged line markings is considered a subclass of this scenario class.

4.4.2 Formal description

Static environment The static environment consists of a straight road. Parts of the road might be slippery, having a lower friction coefficient μ_{low}.

Ego vehicle The initial objective of the ego vehicle is to drive straight.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 23b shows the tags that are assigned to this scenario category.

4.4.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 23a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The friction coefficient between a regular tire and a part of the road which has a lower friction coefficient, denoted by μ_{low}.

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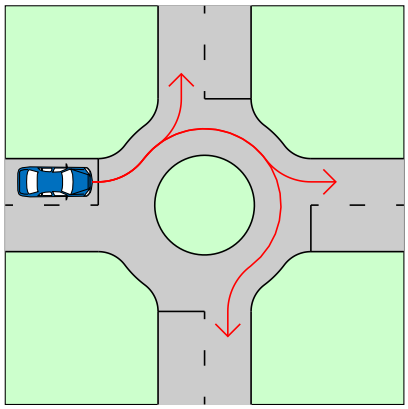
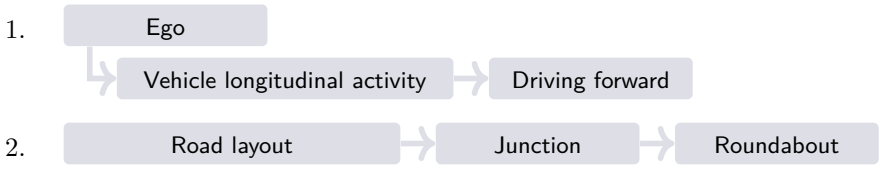
4.5 SC5: Navigating on an empty roundabout



(a) Schematic representation of SC5: Navigating on an empty roundabout.



(b) Tags of SC5: Navigating on an empty roundabout.

Figure 24: Schematic representation and tags of SC5: Navigating on an empty roundabout.

4.5.1 General description

The scenario is schematically shown in Figure 24a. The ego vehicle is approaching a roundabout. There are no other actors at the roundabout. The ego vehicle wants to navigate the roundabout in any of the possible directions. Figure 24a shows a roundabout with a single lane. However, this scenario category also includes roundabouts with multiple lanes.

4.5.2 Formal description

Static environment The static environment consists of a roundabout with one or multiple lanes. The roundabout is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to turn left, go straight or turn right on the roundabout.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 24b shows the tags that are assigned to this scenario category.

4.5.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 24a are described by at least the parameters mentioned at the beginning of this section on page 19.

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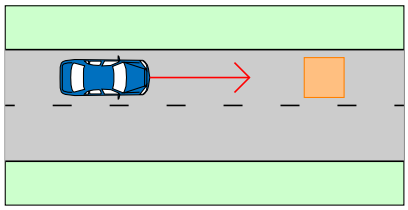
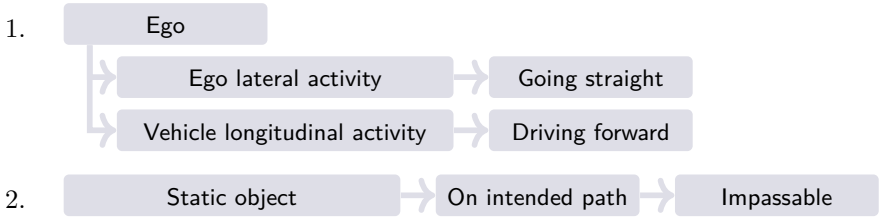
4.6 SC6: Impassable object on intended path



(a) Schematic representation of SC6: Impassable object on intended path.



(b) Tags of SC6: Impassable object on intended path.

Figure 25: Schematic representation and tags of SC6: Impassable object on intended path.

4.6.1 General description

The scenario is schematically shown in Figure 25a. The ego vehicle is driving on a road with an object on the intended path of the ego vehicle that is impassable. The initial objective of the ego vehicle is to continue driving straight. Because of the impassable object, the ego vehicle needs to avoid the object. In this example, the ego vehicle might change lane to avoid the object. There are no other vehicles specified. If indeed there is no other vehicle present, the ego vehicle might swerve around the object. If, however, an oncoming vehicle is approaching from the other lane, this vehicle has priority over the passing manoeuvre of the ego vehicle. Scenario class 21 considers an impassable object on the intended path of the ego vehicle together with an oncoming vehicle.

4.6.2 Formal description

Static environment The static environment consists of a road with an impassable object that is located on the road. The object is described by the parameter vector θ_{object}. The parameter vector contains the position of the object and might contain, amongst others, its size.

Ego vehicle The initial objective of the ego vehicle is to continue driving.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 25b shows the tags that are assigned to this scenario category.

4.6.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 25a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The static object is described with the parameter vector θ_{object}.

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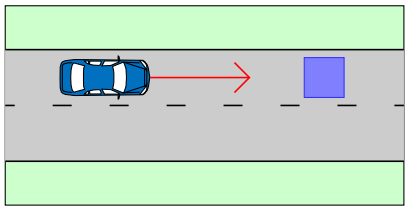
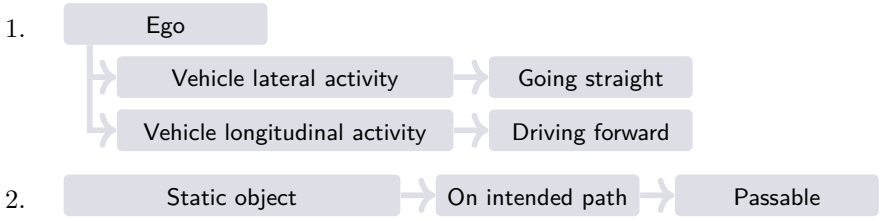
4.7 SC7: Passable object on intended path



(a) Schematic representation of SC7: Passable object on intended path.



(b) Tags of SC7: Passable object on intended path.

Figure 26: Schematic representation and tags of SC7: Passable object on intended path.

4.7.1 General description

The scenario is schematically shown in Figure 26a. The ego vehicle is driving on a road with an object on the intended path of the ego vehicle that is passable, e.g., a manhole lid or a small branch. The initial objective of the ego vehicle is to continue driving straight. Because of the passable object, the ego vehicle might identify the object as impassable (false-positive). There are no other vehicles specified. In case there is indeed no other vehicle present, the ego vehicle might swerve around the object, although it also could have driven over it. If, however, an oncoming vehicle is approaching from the other lane, manoeuvring around the object is subject to priority rules. Similarly, if a vehicle is closely following the ego vehicle, a heavy braking action of the ego vehicle might be undesired.

4.7.2 Formal description

Static environment The static environment consists of a road with an impassable object that is located on the road. The object is described by the parameter vector θ_{object}. The parameter vector contains the position of the object and might contain, amongst others, its size.

Ego vehicle The initial objective of the ego vehicle is to continue driving.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 26b shows the tags that are assigned to this scenario category.

4.7.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 26a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The static object is described with the parameter vector θ_{object}.

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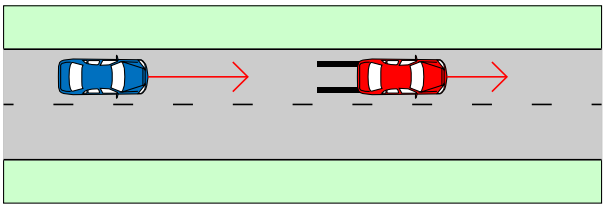
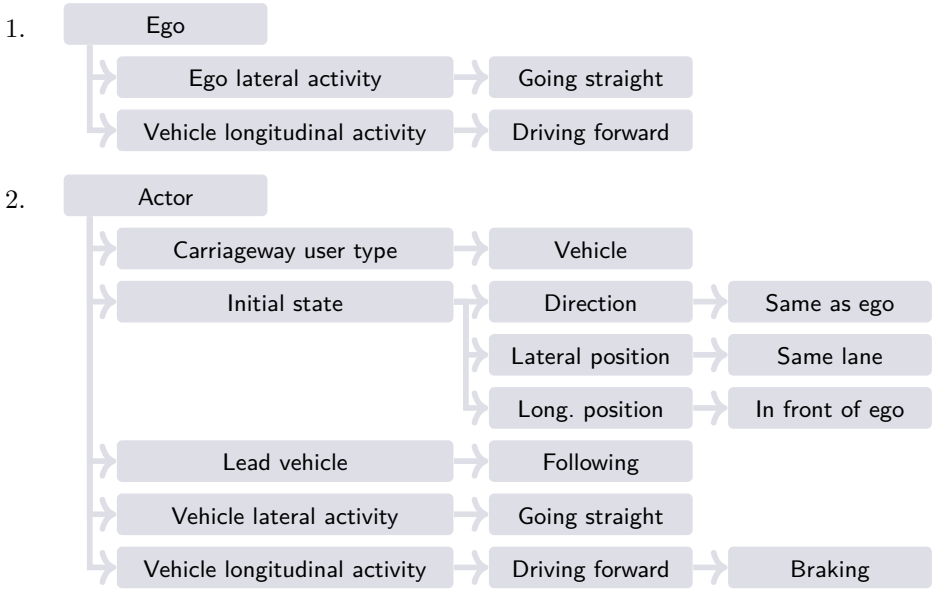
4.8 SC8: Lead vehicle braking



(a) Schematic representation of SC8: Lead vehicle braking.



(b) Tags of SC8: Lead vehicle braking.

Figure 27: Schematic representation and tags of SC8: Lead vehicle braking.

4.8.1 General description

The scenario is schematically shown in Figure 27a. The ego vehicle is following another vehicle. The other vehicle is referred to as the lead vehicle. The lead vehicle brakes, such that the ego vehicle has to adapt its speed in order to stay at a safe distance from the lead vehicle.

4.8.2 Formal description

Static environment The static environment consists of a single road.

Ego vehicle The objective of the ego vehicle is to drive behind the lead vehicle and keep a safe distance.

Dynamic environment The dynamic environment consists of a vehicle driving in front of the ego vehicle. This vehicle reduces its speed. The position of the lead vehicle is described by a parametrized function $x_{\text{lead}}(t, \theta_{\text{lead}})$, where t denotes the time and θ_{lead} denotes the parameter vector. Note that $x_{\text{lead}}(\cdot)$ has an easting and a northing component.

Tags Figure 27b shows the tags that are assigned to this scenario category.

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4.8.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 27a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the lead vehicle, denoted by the parametrized function $x_{\text{lead}}(t, \theta_{\text{lead}})$, where t denotes the time and θ_{lead} denotes the parameter vector.

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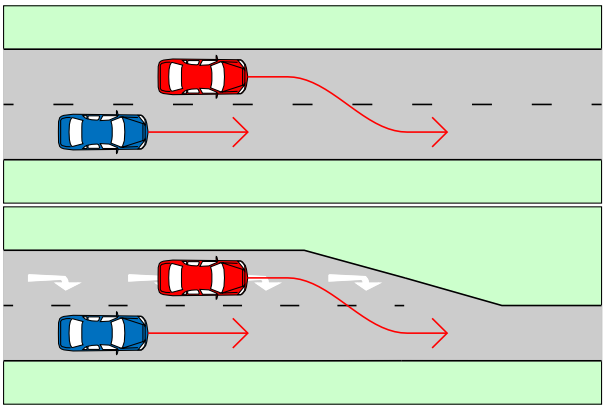
4.9 SC9: Cut-in in front of the ego vehicle



(a) Schematic representation of SC9: Cut-in in front of the ego vehicle.

1. Ego
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Lead vehicle → Appearing → Cutting-in
   - Vehicle lateral activity → Changing lane
   - Vehicle longitudinal activity → Driving forward

(b) Tags of SC9: Cut-in in front of the ego vehicle.

Figure 28: Schematic representation and tags of SC9: Cut-in in front of the ego vehicle.

4.9.1 General description

The scenario is schematically shown in Figure 28a. Another vehicle is driving in the same direction as the ego vehicle in an adjacent lane. The other vehicle makes a lane change, such that is becomes the lead vehicle from the ego vehicle's perspective. The reason for the other vehicle to perform the lane change is principally not important to the scenario. As shown in Figure 28a, the reason for the other vehicle to change lane is for instance that the lane of the other vehicle is merged with the ego vehicle lane.

4.9.2 Formal description

Static environment The static environment consists of a road with at least two lanes at the starting location of the ego vehicle.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of another vehicle that starts at a lane adjacent to the ego vehicle lane. The other vehicle performs a lane change towards

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the ego vehicle lane. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 28b shows the tags that are assigned to this scenario category.

4.9.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 28a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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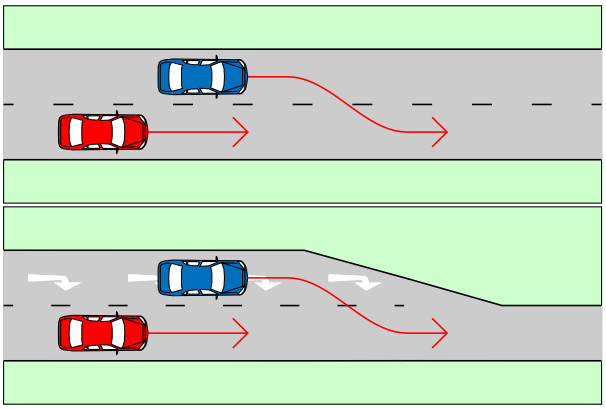
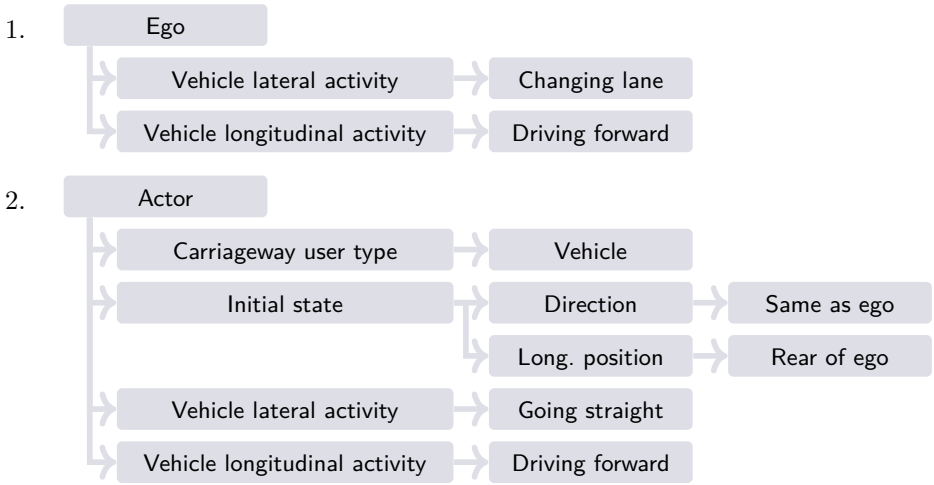
4.10 SC10: Ego performing lane change with vehicle behind



(a) Schematic representation of SC10: Ego performing lane change with vehicle behind.



(b) Tags of SC10: Ego performing lane change with vehicle behind.

Figure 29: Schematic representation and tags of SC10: Ego performing lane change with vehicle behind.

4.10.1 General description

The scenario is schematically shown in Figure 29a. Another vehicle is driving in the same direction as the ego vehicle, in a lane adjacent to the ego vehicle lane. The ego vehicle intends to perform a lane change towards the lane in which the other vehicle is driving. The reason for the ego vehicle to perform a lane change is principally not important for the scenario. It might for example be because the ego vehicle lane is merged with the lane the other vehicle is driving in (Figure 29a). Because of the other vehicle, it might be that the ego vehicle postpones the lane change until the other vehicle has passed the ego vehicle.

4.10.2 Formal description

Static environment The static environment consists of a road with at least two lanes at the starting location of the ego vehicle.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction on the other lane.

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Dynamic environment The dynamic environment consists of another vehicle that drives in a lane adjacent to the ego vehicle lane. The other vehicle stays in its lane. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 29b shows the tags that are assigned to this scenario category.

4.10.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 29a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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4.11 SC11: Ego merging into an occupied lane

4.11.1 General description

The scenario is schematically shown in Figure 30a. The lane adjacent to the ego vehicle lane is occupied by slow driving vehicles. The ego vehicle intends to perform a lane change towards the lane in which the other vehicles are driving. The reason for the ego vehicle to perform a lane change is principally not important for the scenario. It might for example be because the ego vehicle lane blocked, e.g., because of road works.

4.11.2 Formal description

Static environment The static environment consists of a road with at least two lanes at the starting location of the ego vehicle.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction on the other lane.

Dynamic environment The dynamic environment consists of other vehicles that drive in a lane adjacent to the ego vehicle lane, in the same direction as the ego vehicle. The other vehicles stay in their lane. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 30b shows the tags that are assigned to this scenario category.

4.11.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 30a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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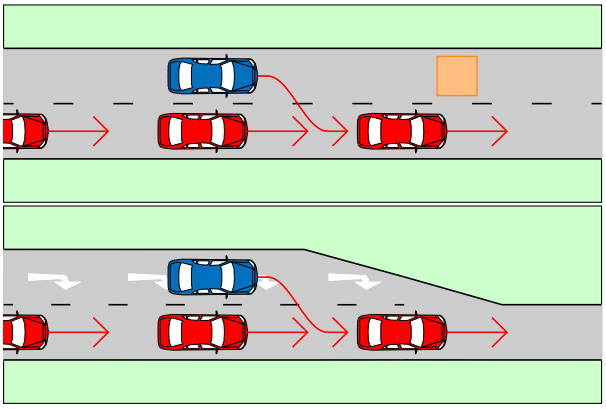

(a) Schematic representation of SC11: Ego merging into an occupied lane.

1. Ego
   - Vehicle lateral activity → Changing lane
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Initial state → Long. position → In front of ego
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward
3. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Initial state → Long. position → Side of ego
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward
4. Actor
   - Carriageway user type → Vehicle
   - Initial state → Direction → Same as ego
   - Initial state → Long. position → Rear of ego
   - Vehicle lateral activity → Going straight
   - Vehicle longitudinal activity → Driving forward

(b) Tags of SC11: Ego merging into an occupied lane.

Figure 30: Schematic representation and tags of SC11: Ego merging into an occupied lane.

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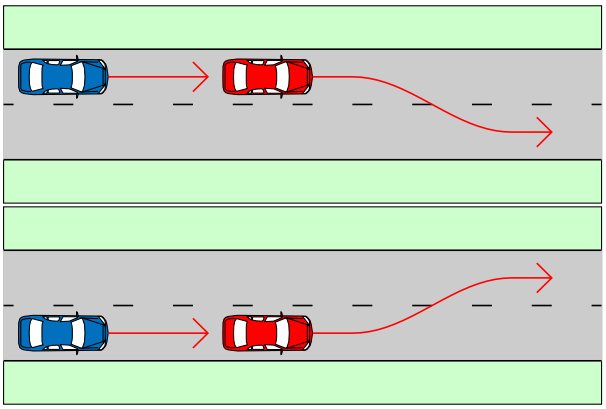
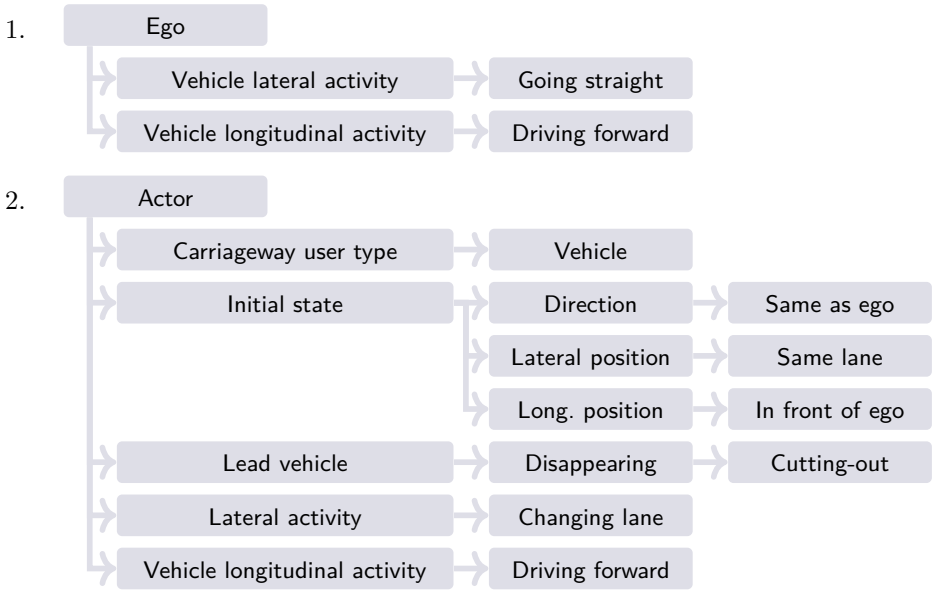
4.12 SC12: Cut-out in front of the ego vehicle



(a) Schematic representation of SC12: Cut-out in front of the ego vehicle.



(b) Tags of SC12: Cut-out in front of the ego vehicle.

Figure 31: Schematic representation and tags of SC12: Cut-out in front of the ego vehicle.

4.12.1 General description

The scenario is schematically shown in Figure 31a. Another vehicle is driving in the same direction as the ego vehicle in front of the ego vehicle such that it is the lead vehicle from the ego vehicle's perspective. The other vehicle makes a lane change, such that it will no longer be the ego vehicle's lead vehicle.

4.12.2 Formal description

Static environment The static environment consists of a road with at least two lanes.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of another vehicle that starts in front of the ego vehicle in the ego vehicle lane. The other vehicle performs a lane change

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towards an adjacent lane. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 31b shows the tags that are assigned to this scenario category.

4.12.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 31a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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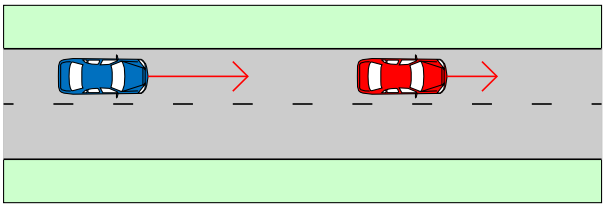
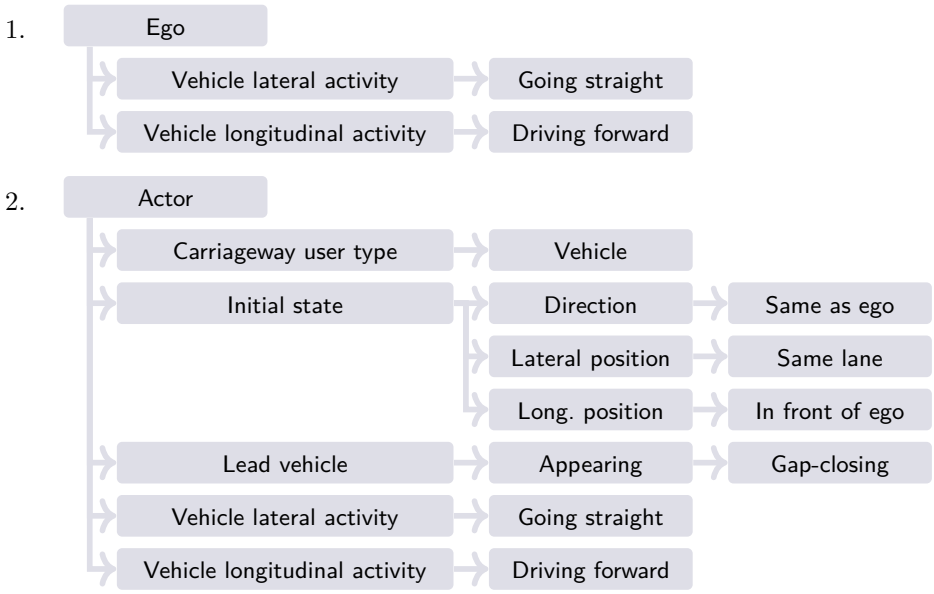
4.13 SC13: Ego vehicle approaching slower lead vehicle



(a) Schematic representation of SC13: Ego vehicle approaching slower lead vehicle.



(b) Tags of SC13: Ego vehicle approaching slower lead vehicle.

Figure 32: Schematic representation and tags of SC13: Ego vehicle approaching slower lead vehicle.

4.13.1 General description

The scenario is schematically shown in Figure 32a. Another vehicle is driving in front of the ego vehicle at a slower speed. As a result, the other vehicle appears in the ego vehicle's field of view. The ego vehicle might brake to avoid a collision. Another possibility for the ego vehicle is to perform a lane change if this is possible. The reason for the other vehicle to drive slower is, e.g., due to a traffic jam ahead.

4.13.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of a lead vehicle driving in front of the ego vehicle. The lead vehicle is driving slower than the ego vehicle and, as a result, it appears in the ego vehicle's field of view. The position of the lead vehicle is described by a parametrized function $x_{\text{lead}}(t, \theta_{\text{lead}})$, where t denotes the time and θ_{lead} denotes the parameter vector. Note that $x_{\text{lead}}(\cdot)$ has an easting and a northing component.

Tags Figure 32b shows the tags that are assigned to this scenario category.

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4.13.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 32a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the lead vehicle, denoted by the parametrized function $x_{\text{lead}}(t, \theta_{\text{lead}})$, where t denotes the time and θ_{lead} denotes the parameter vector.

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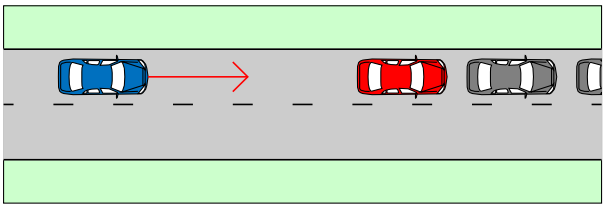
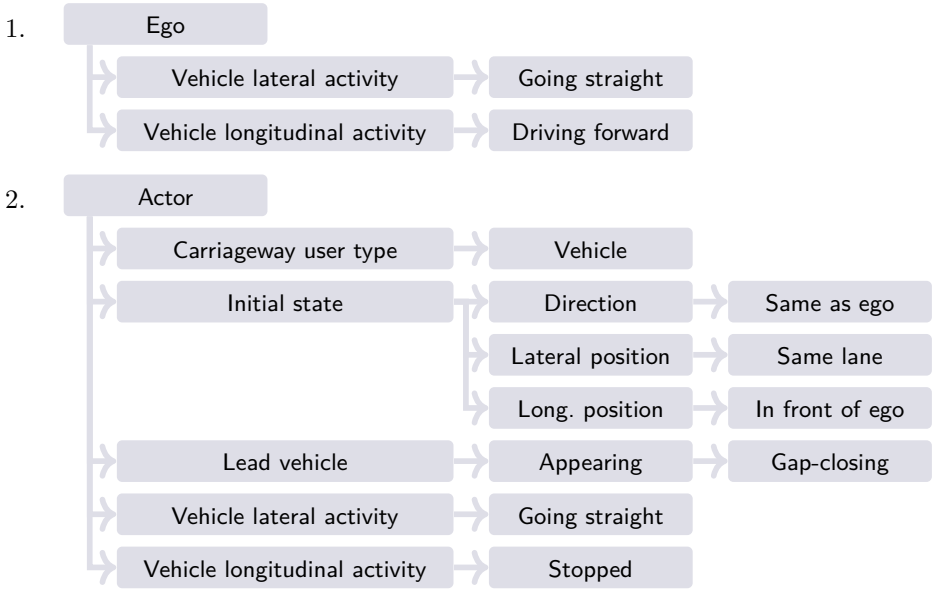
4.14 SC14: Ego vehicle approaching stopped lead vehicle



(a) Schematic representation of SC14: Ego vehicle approaching stopped lead vehicle.



(b) Tags of SC14: Ego vehicle approaching stopped lead vehicle.

Figure 33: Schematic representation and tags of SC14: Ego vehicle approaching stopped lead vehicle.

4.14.1 General description

The scenario is schematically shown in Figure 33a. The ego vehicle is approaching another vehicle that has stopped driving. The reason for the other vehicle to come to a full stop is, e.g., because of a traffic light. The objective of the ego vehicle is to continue driving in the same direction. However, to avoid the stopped vehicle, the ego vehicle has to stop or change its direction.

4.14.2 Formal description

Static environment A stopped vehicle is in front of the ego vehicle. The easting and northing position of the stopped vehicle is described by the vector x_{object}.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 33b shows the tags that are assigned to this scenario category.

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4.14.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 33a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The easting and northing position of the stopped vehicle, denoted by x_{object}.

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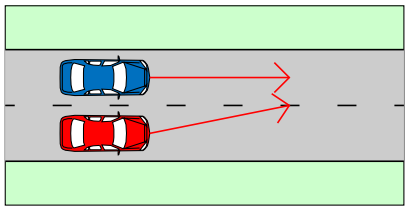
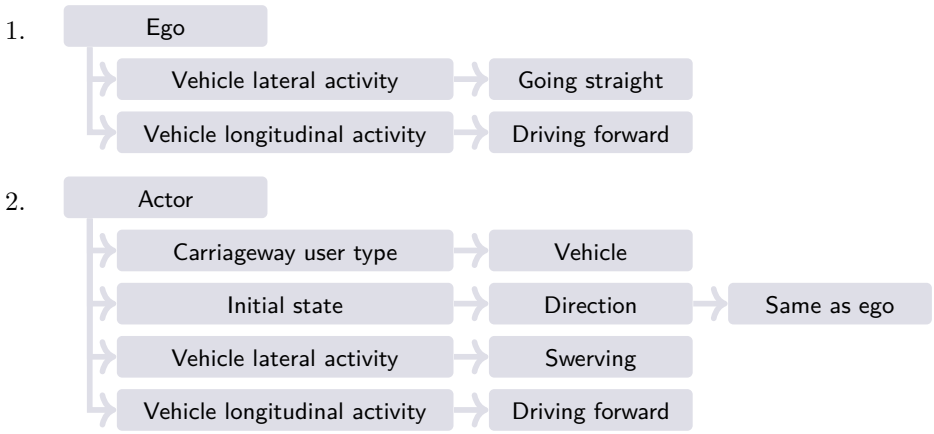
4.15 SC15: Vehicle swerving towards ego vehicle



(a) Schematic representation of SC15: Vehicle swerving towards ego vehicle.



(b) Tags of SC15: Vehicle swerving towards ego vehicle.

Figure 34: Schematic representation and tags of SC15: Vehicle swerving towards ego vehicle.

4.15.1 General description

The scenario is schematically shown in Figure 34a. Another vehicle is driving in the same direction as the ego vehicle in an adjacent lane. The other vehicle swerves towards the ego vehicle's lane. The reason for the other vehicle to swerve is principally not important for the scenario. For example, there could be an object, e.g., a parked vehicle, that is (partially) on the lane of the other vehicle. Most of the accidents that resulted from scenarios of this scenario class happen at high speed roads, e.g., highway roads.

4.15.2 Formal description

Static environment The static environment consists of a road with at least two lanes.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of another vehicle that starts at a lane adjacent to the ego vehicle lane. The other vehicle swerves towards the ego vehicle lane. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 34b shows the tags that are assigned to this scenario category.

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4.15.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 34a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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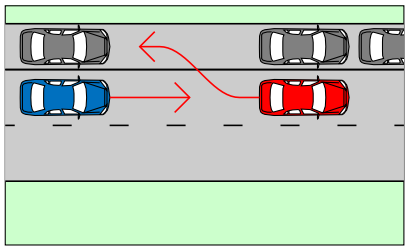
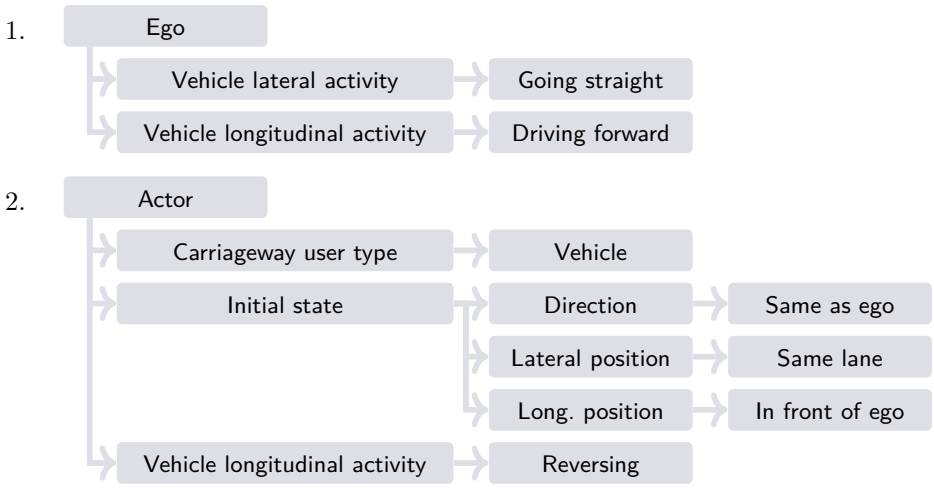
4.16 SC16: Vehicle backing up into ego vehicle



(a) Schematic representation of SC16: Vehicle backing up into ego vehicle.



(b) Tags of SC16: Vehicle backing up into ego vehicle.

Figure 35: Schematic representation and tags of SC16: Vehicle backing up into ego vehicle.

4.16.1 General description

The scenario is schematically shown in Figure 35a. Another vehicle is driving in reverse. This could be, for example as shown in Figure 35a, because the vehicle is being parked. It might be the case that the ego vehicle has to respond to the reversing vehicle, for example by diverting its path or by using the horn to warn the other vehicle of its presence.

4.16.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of a target vehicle that is reversing. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 35b shows the tags that are assigned to this scenario category.

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4.16.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 35a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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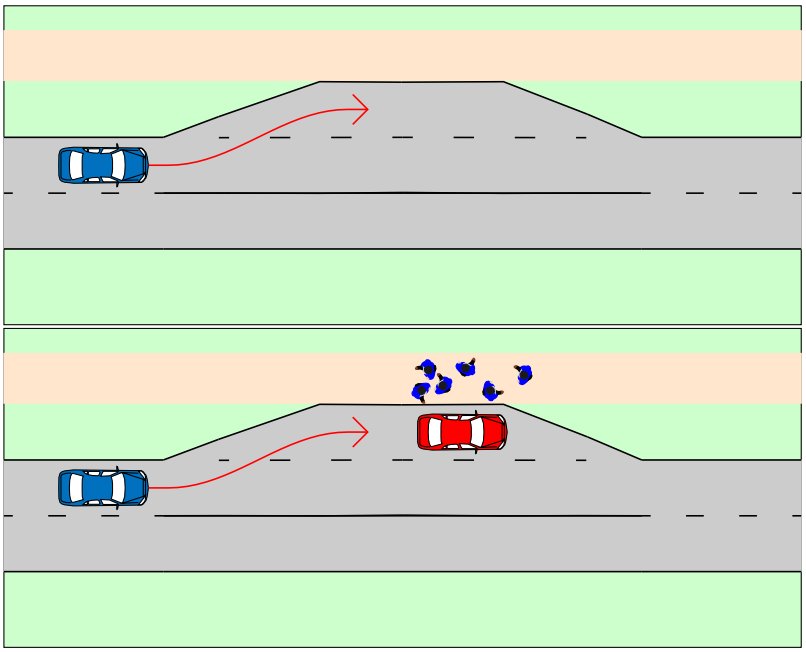
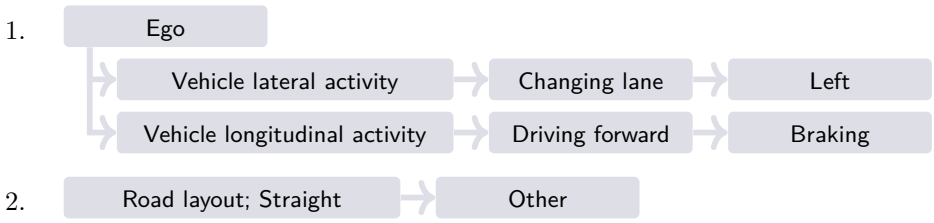
4.17 SC17: Stopping at a bus bay



(a) Schematic representation of SC17: Stopping at a bus bay.



(b) Tags of SC17: Stopping at a bus bay.

Figure 36: Schematic representation and tags of SC17: Stopping at a bus bay.

4.17.1 General description

The scenario is schematically shown in Figure 36a. The ego vehicle is approaching a bus bay. The goal of the ego vehicle is to park at the bus bay. This generally requires a high precision as the vehicle is supposed to park close to the edge of the road. As shown in Figure 36a, the bus bay might be empty, bus there might be multiple pedestrians waiting along the bus bay and there might be another vehicle at the bus bay.

4.17.2 Formal description

Static environment The static environment consists of a single road with a bus bay.

Ego vehicle The objective of the ego vehicle is to drive park at the bus bay. To do that, the ego vehicle has to change lane and brake to come to a standstill.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 36b shows the tags that are assigned to this scenario category.

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4.17.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 36a are described by at least the parameters mentioned at the beginning of this section on page 19.

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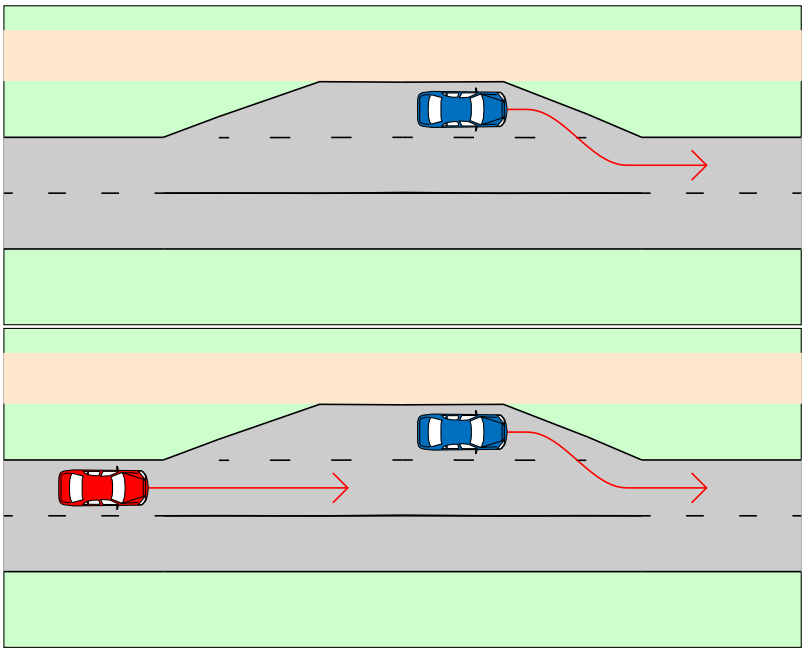
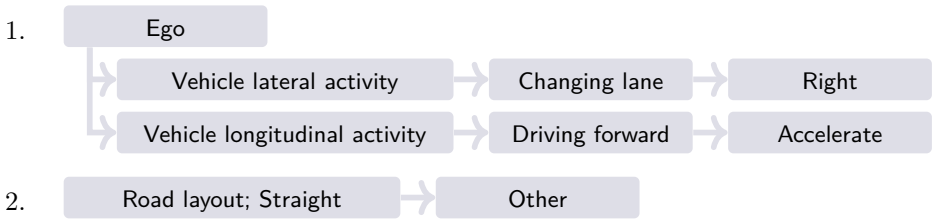
4.18 SC18: Leaving a bus bay



(a) Schematic representation of SC18: Leaving a bus bay.



(b) Tags of SC18: Leaving a bus bay.

Figure 37: Schematic representation and tags of SC18: Leaving a bus bay.

4.18.1 General description

The scenario is schematically shown in Figure 37a. The ego vehicle is initially stationary at a bus bay. The goal of the ego vehicle is to leave the bus bay. In case traffic is approaching from behind, the ego vehicle might need to wait. Depending on the local traffic regulations, the ego vehicle might have priority.

4.18.2 Formal description

Static environment The static environment consists of a single road with a bus bay.

Ego vehicle The objective of the ego vehicle is to leave the bus bay. To do that, the ego vehicle has to change lane and accelerate.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 37b shows the tags that are assigned to this scenario category.

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4.18.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 37a are described by at least the parameters mentioned at the beginning of this section on page 19.

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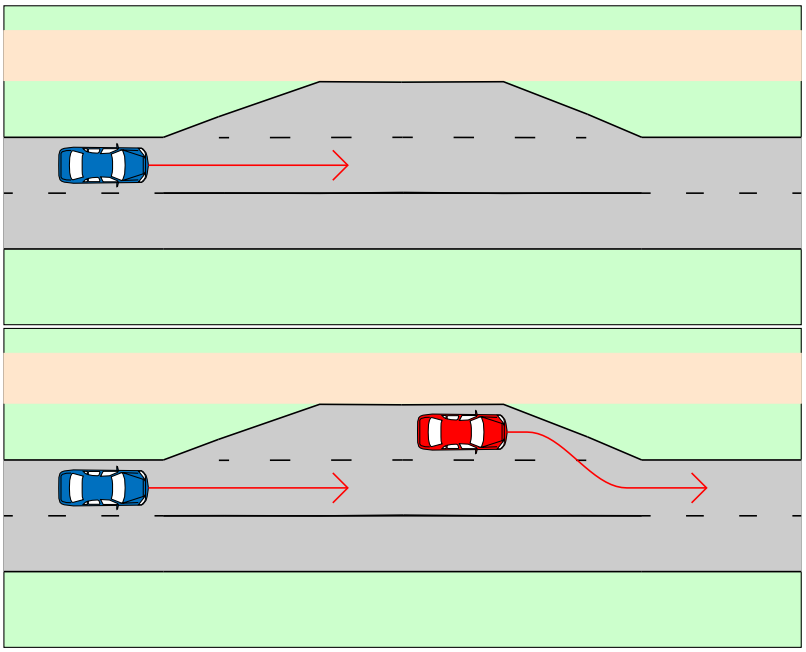
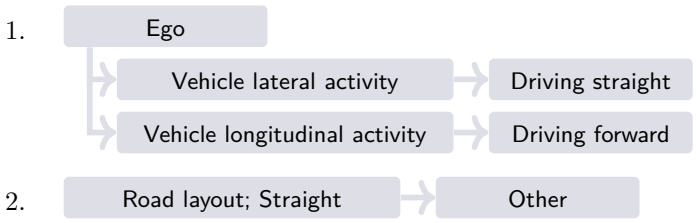
4.19 SC19: Driving along a bus bay



(a) Schematic representation of SC19: Driving along a bus bay.



(b) Tags of SC19: Driving along a bus bay.

Figure 38: Schematic representation and tags of SC19: Driving along a bus bay.

4.19.1 General description

The scenario is schematically shown in Figure 38a. The ego vehicle passes a bus bay. The goal of the ego vehicle is to continue driving. There might be another vehicle at the bus bay intending to leave the bus bay. Depending on the local traffic regulations, this ego vehicle might need to give way to the vehicle leaving the bus bay.

4.19.2 Formal description

Static environment The static environment consists of a single road with a bus bay.

Ego vehicle The objective of the ego vehicle is to continue driving.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 38b shows the tags that are assigned to this scenario category.

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4.19.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 38a are described by at least the parameters mentioned at the beginning of this section on page 19.

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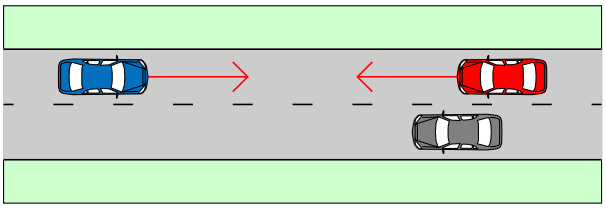
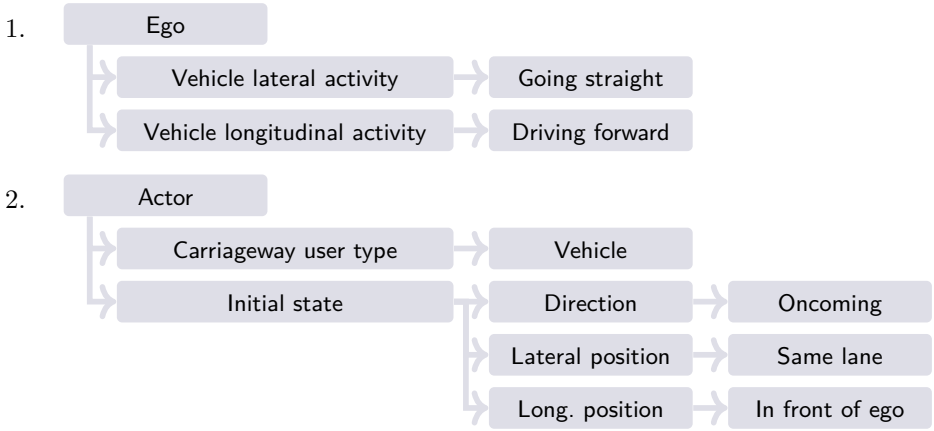
4.20 SC20: Oncoming vehicle



(a) Schematic representation of SC20: Oncoming vehicle.



(b) Tags of SC20: Oncoming vehicle.

Figure 39: Schematic representation and tags of SC20: Oncoming vehicle.

4.20.1 General description

The scenario is schematically shown in Figure 39a. The ego vehicle is driving straight while another vehicle drives in opposite direction in the same lane. The reason for the other vehicle to drive in the opposite direction in the same lane is principally not important for the scenario. As shown in Figure 39a, the other vehicle might be overtaking a parked vehicle.

4.20.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of a target vehicle that drives in the opposite direction in the ego vehicle lane. The position of the target vehicle is described by a parametrized function $x_\mathrm{t}(t, \theta_\mathrm{t})$, where t denotes the time and θ_t denotes the parameter vector. Note that $x_\mathrm{t}(\cdot)$ has an easting and a northing component.

Tags Figure 39b shows the tags that are assigned to this scenario category.

4.20.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 39a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

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- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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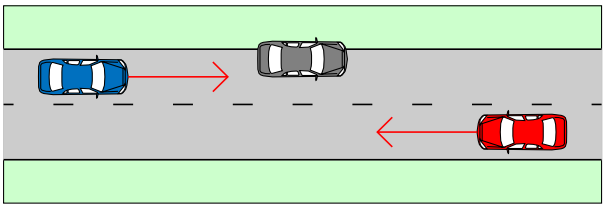
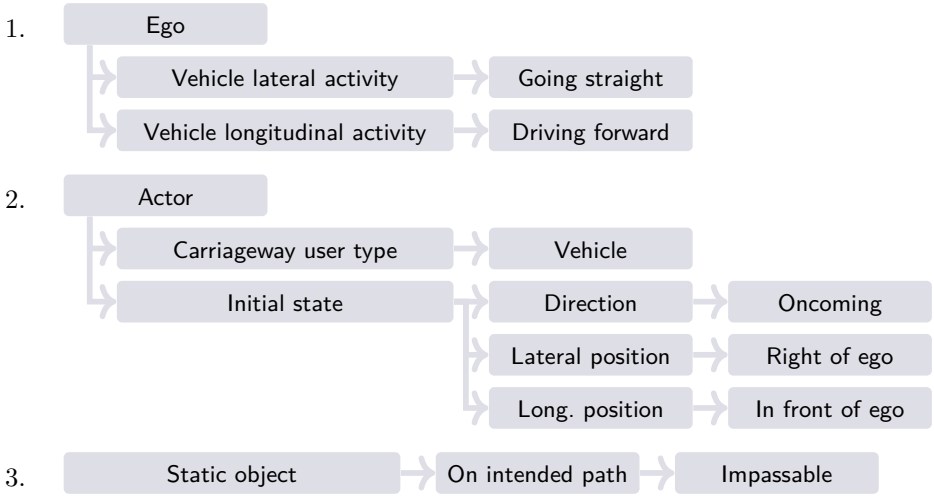
4.21 SC21: Object on road with oncoming traffic



(a) Schematic representation of SC21: Object on road with oncoming traffic.



(b) Tags of SC21: Object on road with oncoming traffic.

Figure 40: Schematic representation and tags of SC21: Object on road with oncoming traffic.

4.21.1 General description

The scenario is schematically shown in Figure 40a. The ego vehicle is driving while approaching an object on the road, e.g., a parked vehicle. At the same time, a vehicle is approaching in opposite direction. To objective of the ego vehicle is to continue driving straight. To do this, the ego vehicle has to pass the object. Depending on the position of the object, the ego vehicle might need to wait until the oncoming vehicle has passed the ego vehicle. Note that this scenario is a subclass of scenario class 6. Scenario class 6 only specified the object on the road.

4.21.2 Formal description

Static environment An object is located on the road. The easting and northing position of the object is described by the vector x_{object}.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of an oncoming vehicle. The position of the target vehicle is described by a parametrized function $x_{\text{t}}(t, \theta_{\text{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\text{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 40b shows the tags that are assigned to this scenario category.

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4.21.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 40a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The easting and northing position of the object, denoted by x_{object}.
- The position of the target vehicle, denoted by the parametrized function $x_{\text{t}}(t, \theta_{\text{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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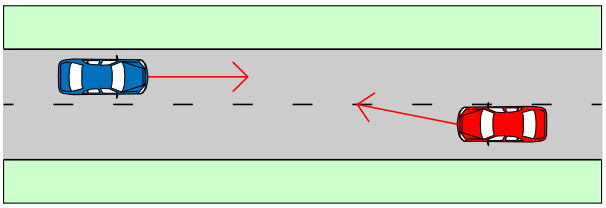
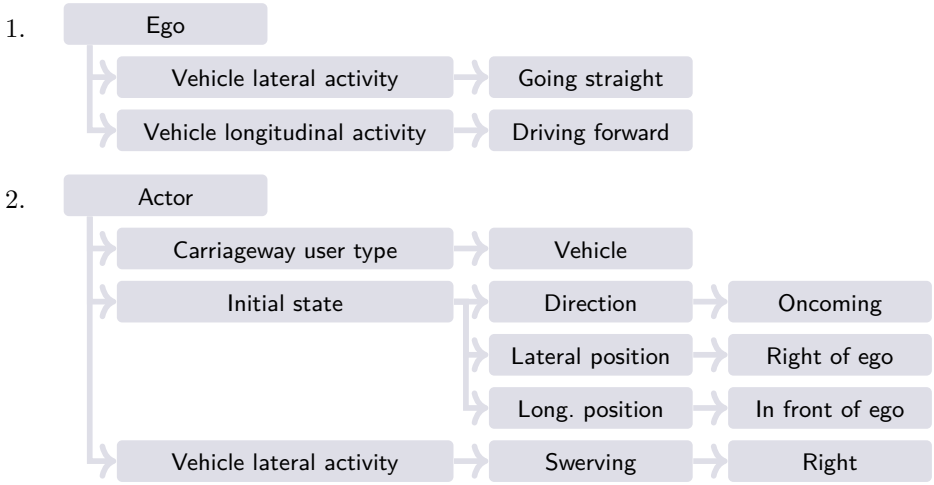
4.22 SC22: Oncoming vehicle swerving into ego vehicle's lane



(a) Schematic representation of SC22: Oncoming vehicle swerving into ego vehicle's lane.



(b) Tags of SC22: Oncoming vehicle swerving into ego vehicle's lane.

Figure 41: Schematic representation and tags of SC22: Oncoming vehicle swerving into ego vehicle's lane.

4.22.1 General description

The scenario is schematically shown in Figure 41a. The ego vehicle is driving straight while another vehicle drives in opposite direction on a lane next to the ego vehicle lane. The other vehicle starts to swerve towards the lane of the ego vehicle. The reason for the other vehicle to swerve is principally not important for the scenario. An object can be (partially) on the road which the vehicle needs to evade. Most scenarios of this scenario class that led to accidents are at curved roads [23]. The objective of the ego vehicle is to continue driving in the same direction. To prevent a collision, however, the ego vehicle might need to brake or to change its direction.

4.22.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving in the same direction.

Dynamic environment The dynamic environment consists of an oncoming target vehicle that swerves towards the lane of the ego vehicle. The position of the target vehicle is described by a parametrized function $x_\mathrm{t}(t, \theta_\mathrm{t})$, where t denotes the time and θ_t denotes the parameter vector. Note that $x_\mathrm{t}(\cdot)$ has an easting and a northing component.

Tags Figure 41b shows the tags that are assigned to this scenario category.

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4.22.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 41a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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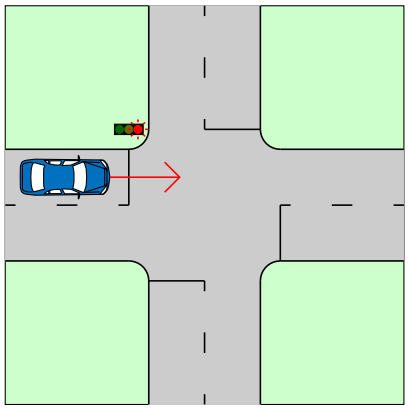
4.23 SC23: Ego vehicle approaching red traffic light



(a) Schematic representation of SC23: Ego vehicle approaching red traffic light.

1. Road layout → Junction → Traffic light
2. Traffic light → Red

(b) Tags of SC23: Ego vehicle approaching red traffic light.

Figure 42: Schematic representation and tags of SC23: Ego vehicle approaching red traffic light.

4.23.1 General description

The scenario is schematically shown in Figure 42a. The ego vehicle is approaching a junction that is equipped with traffic light signals. The traffic signal for the ego vehicle is red. The objective of the ego vehicle is to cross the junction, but because the traffic signal is red, the ego vehicle is expected to stop.

4.23.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to cross the junction.

Dynamic environment The dynamic environment consists of the traffic lights at the junction. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 42b shows the tags that are assigned to this scenario category.

4.23.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 42a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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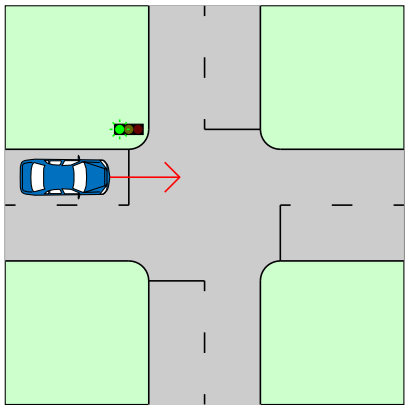
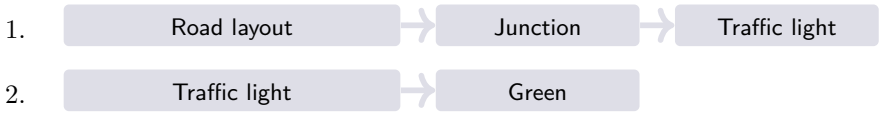
4.24 SC24: Ego vehicle approaching green traffic light



(a) Schematic representation of SC24: Ego vehicle approaching green traffic light.



(b) Tags of SC24: Ego vehicle approaching green traffic light.

Figure 43: Schematic representation and tags of SC24: Ego vehicle approaching green traffic light.

4.24.1 General description

The scenario is schematically shown in Figure 43a. The ego vehicle is approaching a junction that is equipped with traffic light signals. The traffic signal for the ego vehicle is green or turns green. The objective of the ego vehicle is to cross the junction, into any direction. For example, the ego vehicle can have the intention to turn right.

4.24.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to cross the junction.

Dynamic environment The dynamic environment consist of the traffic lights at the junction. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 43b shows the tags that are assigned to this scenario category.

4.24.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 43a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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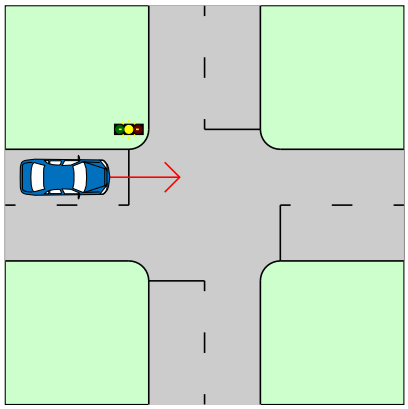
4.25 SC25: Ego vehicle approaching amber traffic light



(a) Schematic representation of SC25: Ego vehicle approaching amber traffic light.

1. Road layout → Junction → Traffic light
2. Traffic light → Amber

(b) Tags of SC25: Ego vehicle approaching amber traffic light.

Figure 44: Schematic representation and tags of SC25: Ego vehicle approaching amber traffic light.

4.25.1 General description

The scenario is schematically shown in Figure 44a. The ego vehicle is approaching a junction that is equipped with traffic light signals. The traffic signal for the ego vehicle is amber or turns amber. The objective of the ego vehicle is to cross the junction. Depending on the speed of the ego vehicle and the distance of the ego vehicle to the traffic lights, the ego vehicle is expected to either cross the junction or stop before the traffic lights.
The response to a traffic light turning amber requires understanding of the complete cycle of the traffic light to determine the meaning of the amber signal. Flashing amber has a completely different meaning than the amber light turning on while the green light turns off; where the first indicates that the traffic light is off and local priority rules apply, the second asks to anticipate a stop whenever this is reasonable considered the distance of the ego vehicle to the stop line.

4.25.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to cross the junction.

Dynamic environment The dynamic environment consist of the traffic lights at the junction. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 44b shows the tags that are assigned to this scenario category.

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4.25.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 44a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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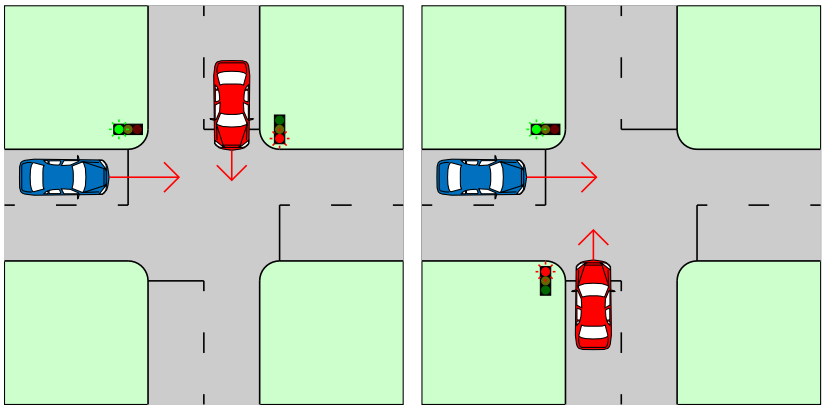
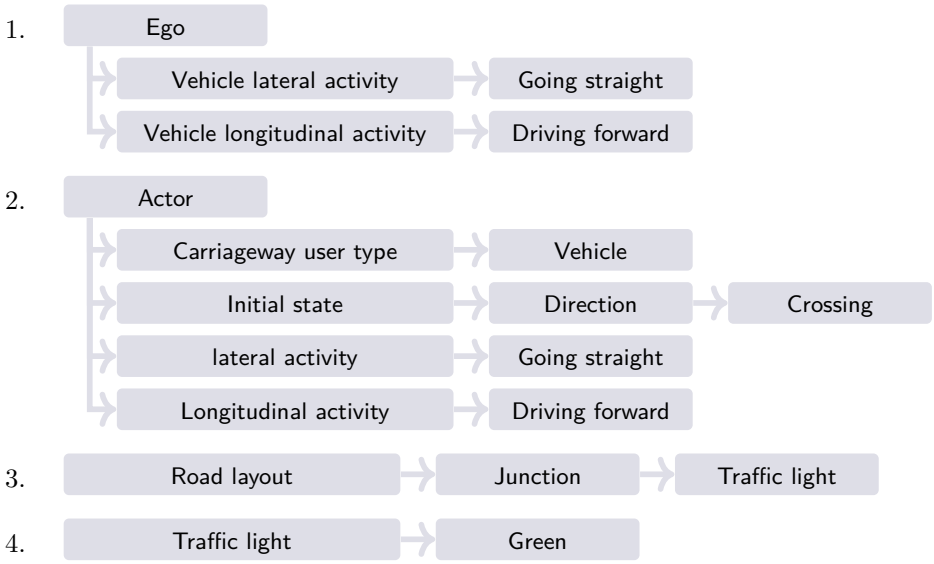
4.26 SC26: Vehicle running red traffic light



(a) Schematic representation of SC26: Vehicle running red traffic light.



(b) Tags of SC26: Vehicle running red traffic light.

Figure 45: Schematic representation and tags of SC26: Vehicle running red traffic light.

4.26.1 General description

The scenario is schematically shown in Figure 45a. The ego vehicle is approaching a junction that is equipped with traffic light signals. The traffic signal for the ego vehicle is green. Another vehicle is also approaching the junction and its trajectory intersects that of the ego vehicle. The traffic signal for the other vehicle is red. However, the vehicle is running through the red light. As a result, the ego vehicle might need to respond appropriately to avoid a collision.

4.26.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to cross the junction.

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Dynamic environment The dynamic environment consists of a target vehicle and traffic lights. The target vehicle crosses the junction, such that its trajectory intersects with the trajectory of the ego vehicle. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 45b shows the tags that are assigned to this scenario category.

4.26.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 45a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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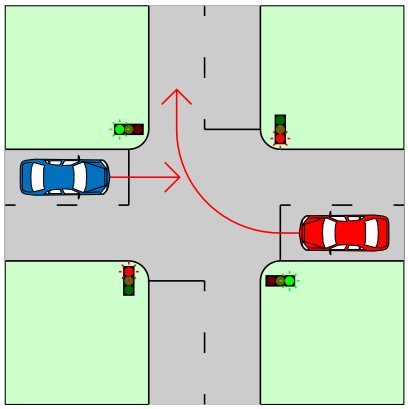
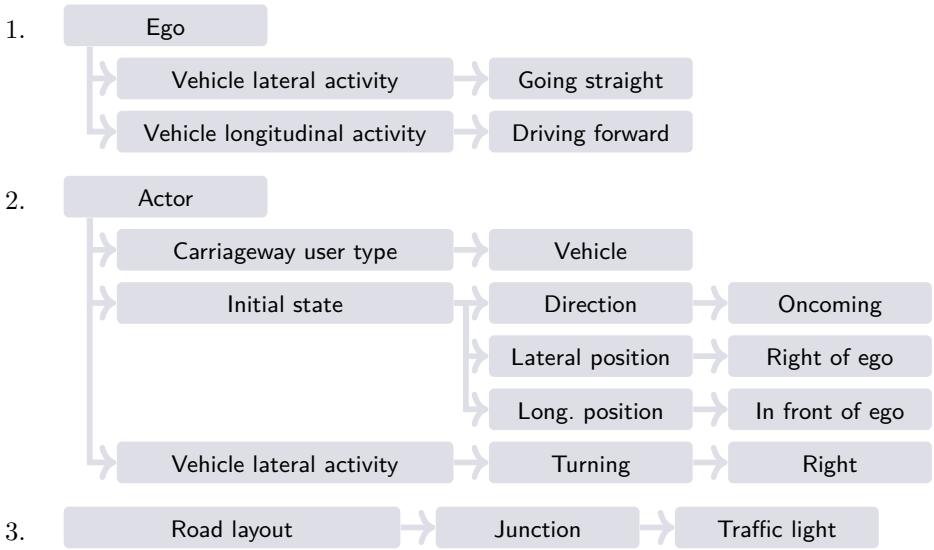
4.27 SC27: Oncoming vehicle turns right at signalized junction



(a) Schematic representation of SC27: Oncoming vehicle turns right at signalized junction.



(b) Tags of SC27: Oncoming vehicle turns right at signalized junction.

Figure 46: Schematic representation and tags of SC27: Oncoming vehicle turns right at signalized junction.

4.27.1 General description

The scenario is schematically shown in Figure 46a. 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. The other vehicle has to give way to the ego vehicle.

4.27.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

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Dynamic environment The dynamic environment consists of an oncoming target vehicle and traffic lights. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 46b shows the tags that are assigned to this scenario category.

4.27.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 46a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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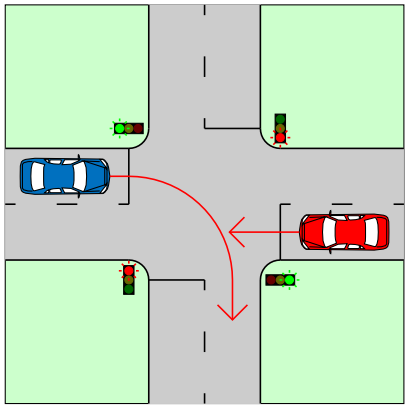
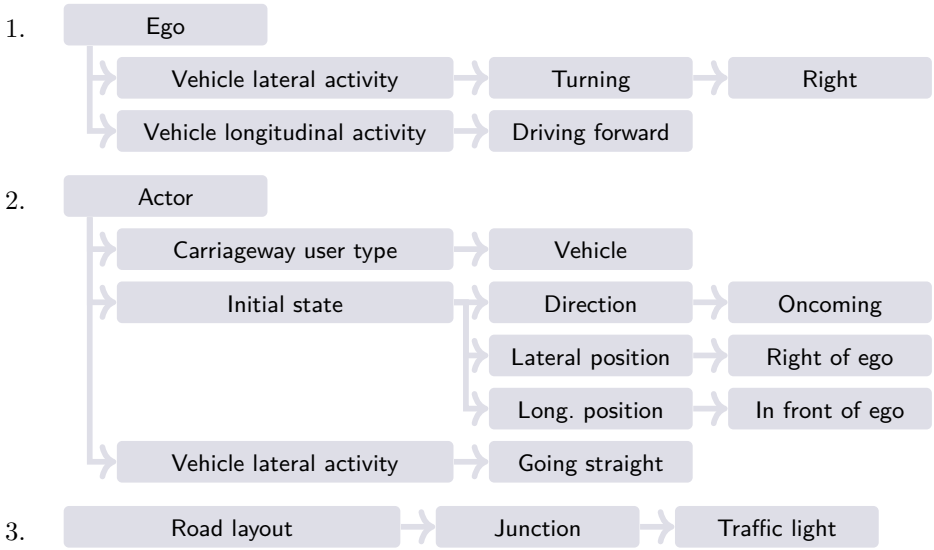
4.28 SC28: Ego vehicle turns right with oncoming vehicle at signalized junction



(a) Schematic representation of SC28: Ego vehicle turns right with oncoming vehicle at signalized junction.



(b) Tags of SC28: Ego vehicle turns right with oncoming vehicle at signalized junction.

Figure 47: Schematic representation and tags of SC28: Ego vehicle turns right with oncoming vehicle at signalized junction.

4.28.1 General description

The scenario is schematically shown in Figure 47a. The ego vehicle is approaching a junction that is equipped with traffic light signals. The ego vehicle turns right at the junction. Another vehicle is approaching the junction from the opposite direction. The other vehicle goes straight at the junction, such that the trajectories of the other vehicle and the ego vehicle intersect. The ego vehicle has to give right of way to the other vehicle.

4.28.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to right at the junction.

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Dynamic environment The dynamic environment consists of an oncoming target vehicle and traffic lights. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 47b shows the tags that are assigned to this scenario category.

4.28.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 47a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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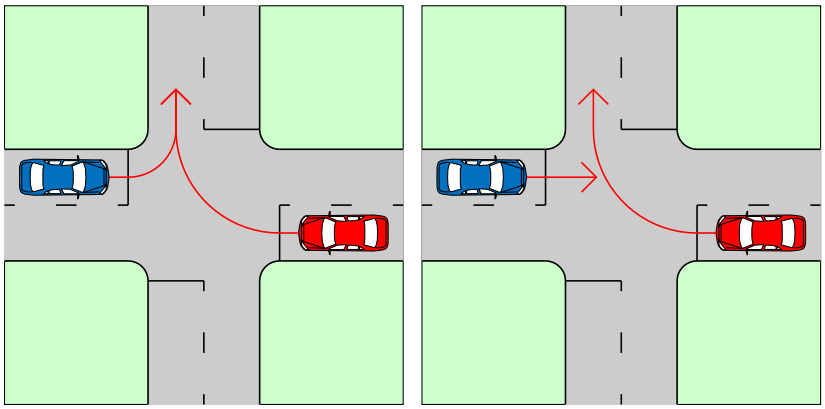
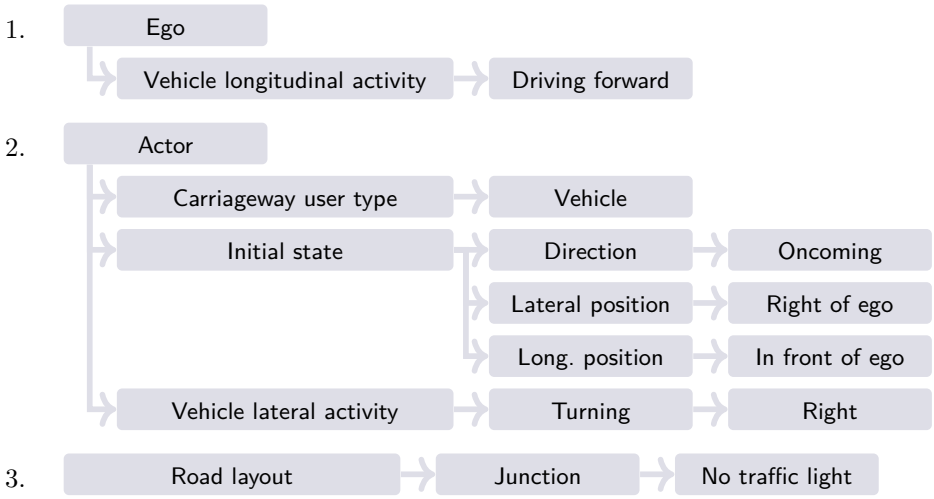
4.29 SC29: Oncoming vehicle turns right at non-signalized junction



(a) Schematic representation of SC29: Oncoming vehicle turns right at non-signalized junction.



(b) Tags of SC29: Oncoming vehicle turns right at non-signalized junction.

Figure 48: Schematic representation and tags of SC29: Oncoming vehicle turns right at non-signalized junction.

4.29.1 General description

The scenario is schematically shown in Figure 48a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. It intended direction of the ego vehicle is not specified. 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 might intersect. Note that the scenario class overlaps with scenario class 30, because scenarios of this scenario class in which the ego vehicle's intention is to turn right also belong to scenario class 30.

4.29.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left, turn right, or go straight at the junction.

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Dynamic environment The dynamic environment consists of an oncoming target vehicle that turns right at the junction. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 48b shows the tags that are assigned to this scenario category.

4.29.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 48a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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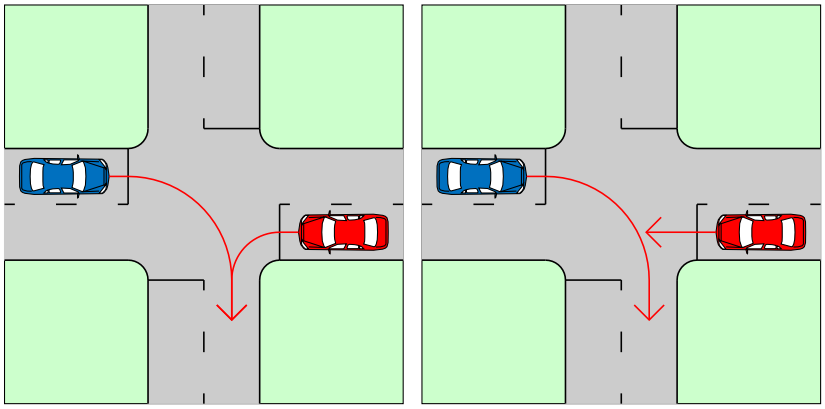
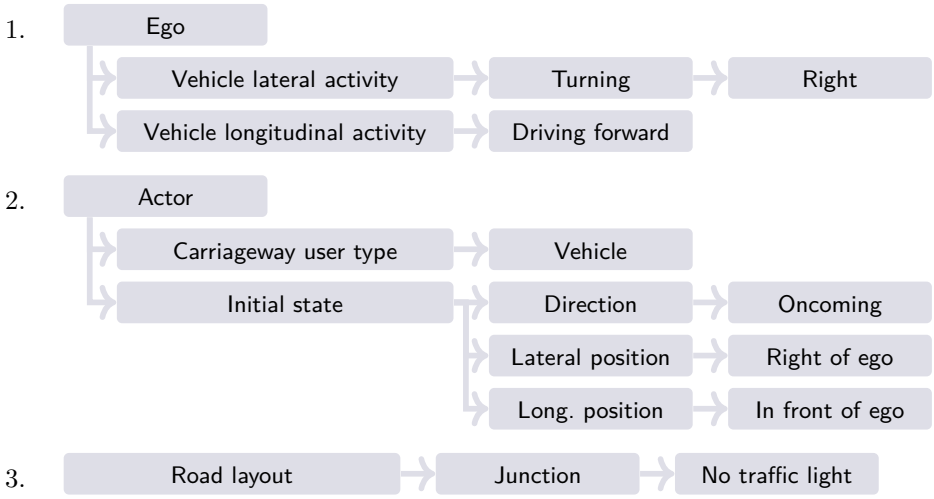
4.30 SC30: Ego vehicle turns right with oncoming vehicle at non-signalized junction



(a) Schematic representation of SC30: Ego vehicle turns right with oncoming vehicle at non-signalized junction.



(b) Tags of SC30: Ego vehicle turns right with oncoming vehicle at non-signalized junction.

Figure 49: Schematic representation and tags of SC30: Ego vehicle turns right with oncoming vehicle at non-signalized junction.

4.30.1 General description

The scenario is schematically shown in Figure 49a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The ego vehicle intends to turn right at the junction. Another vehicle is approaching the junction from the opposite direction. The direction that the other vehicle goes to is not specified, i.e., the vehicle could turn left or right or the vehicle could go straight at the junction. It is possible that the trajectories of the other vehicle and the ego vehicle intersect. Especially the scenario, with a motorcycle as oncoming vehicle going straight, is known to be notorious for having a large share of motorcyclist fatalities. Note that the scenario class overlaps with scenario class 29, because scenarios of this scenario class in which the oncoming vehicle turns right also belong to scenario class 29.

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4.30.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go right at the junction.

Dynamic environment The dynamic environment consists of an oncoming target vehicle that turns left, turns right, or goes straight at the junction. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 49b shows the tags that are assigned to this scenario category.

4.30.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 49a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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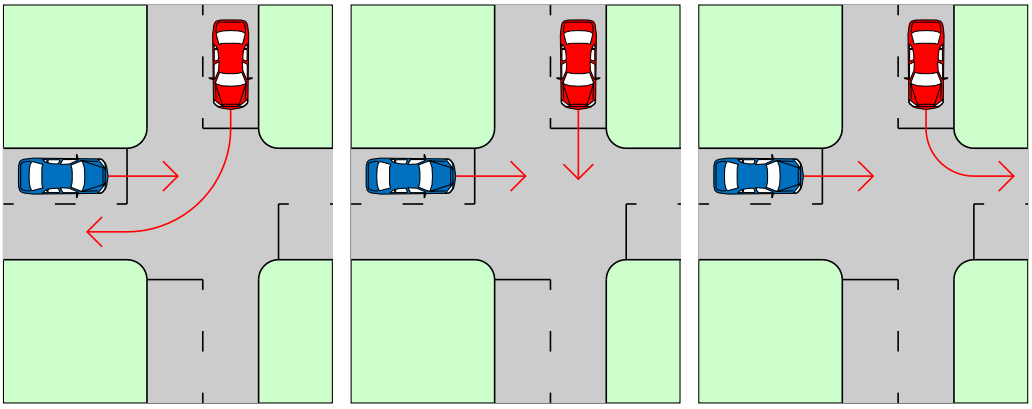
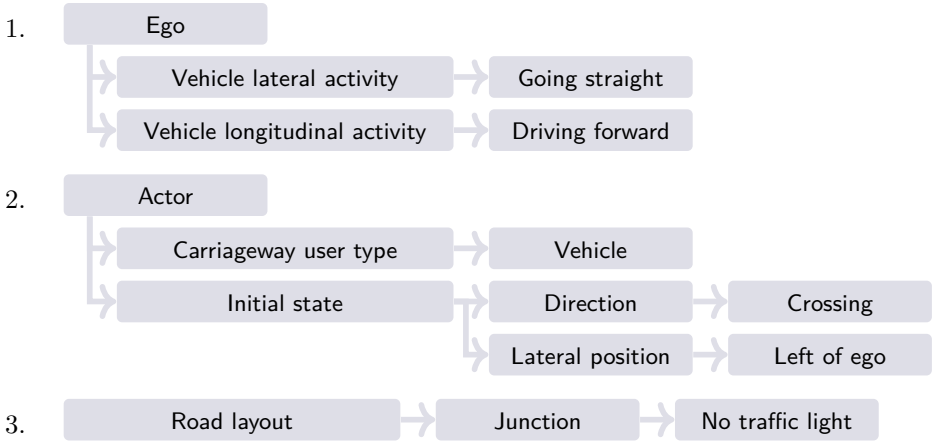
4.31 SC31: Ego straight with vehicle from left at non-signalized junction



(a) Schematic representation of SC31: Ego straight with vehicle from left at non-signalized junction.



(b) Tags of SC31: Ego straight with vehicle from left at non-signalized junction.

Figure 50: Schematic representation and tags of SC31: Ego straight with vehicle from left at non-signalized junction.

4.31.1 General description

The scenario is schematically shown in Figure 50a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The objective of the ego vehicle is to go straight at the junction. Another vehicle is approaching the junction from the left side of the ego vehicle. The direction of the other vehicle is not further specified. In any case, the trajectories of the ego vehicle and the other vehicle intersect. It depends on the traffic signs whether the ego vehicle or the other vehicle has the right of way. If there are no traffic signs, the other vehicle has to give right of way, according to the traffic rules in Singapore [28, p. 61]. The other vehicle might fail to give way to the ego vehicle. The ego vehicle needs to respond appropriately to cross the junction and avoid a collision.

4.31.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

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Dynamic environment The dynamic environment consists of a target vehicle that approaches the crossing from the left side of the ego vehicle. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 50b shows the tags that are assigned to this scenario category.

4.31.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 50a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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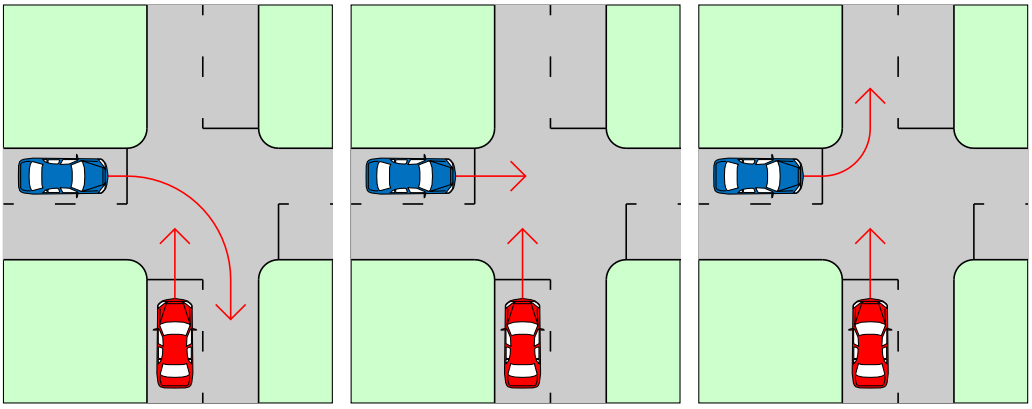
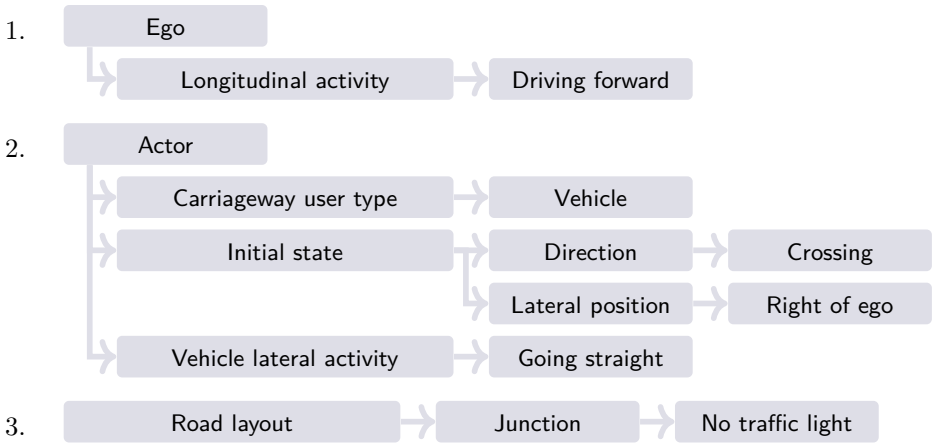
4.32 SC32: Vehicle straight with ego from left at non-signalized junction



(a) Schematic representation of SC32: Vehicle straight with ego from left at non-signalized junction.



(b) Tags of SC32: Vehicle straight with ego from left at non-signalized junction.

Figure 51: Schematic representation and tags of SC32: Vehicle straight with ego from left at non-signalized junction.

4.32.1 General description

The scenario is schematically shown in Figure 51a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. Another vehicle is also approaching the junction and its trajectory intersects the ego vehicle's trajectory. The other vehicle is approaching the junction from the right side of the ego vehicle and this vehicle goes straight at the junction. The objective of the ego vehicle is not further specified. It depends on the traffic signs whether the ego vehicle or the other vehicle has the right of way. If there are no traffic signs, the ego vehicle has to give right of way, according to the traffic rules in Singapore [28, p. 61]. In case the other vehicle has right of way, the ego vehicle is expected to stop or to slow down to give way to the other vehicle.

4.32.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

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Ego vehicle The objective of the ego vehicle is to go either left, straight, or right at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that approaches the junction from the right side of the ego vehicle. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 51b shows the tags that are assigned to this scenario category.

4.32.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 51a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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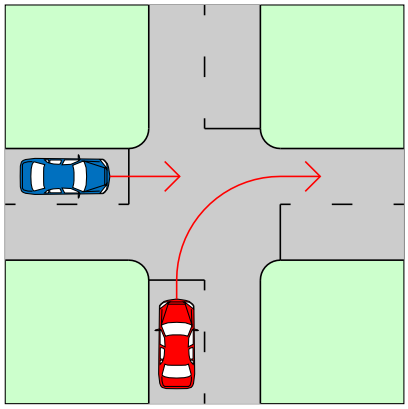
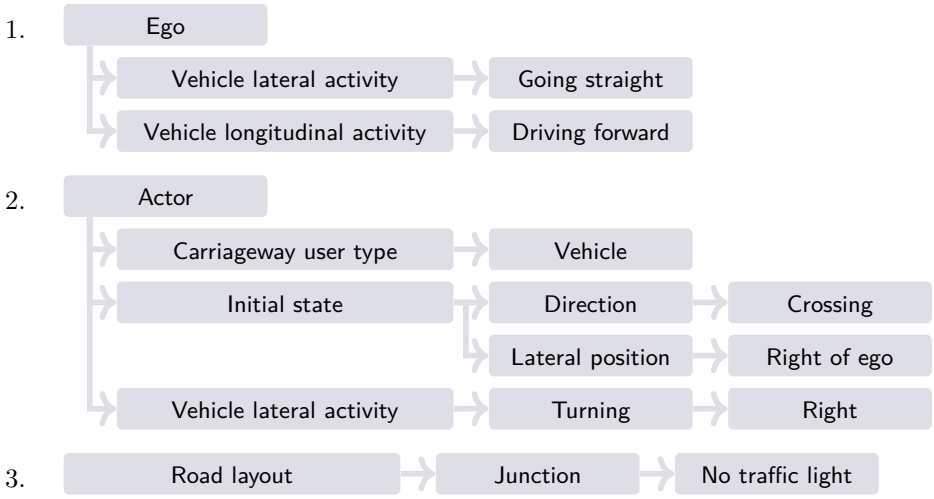
4.33 SC33: Vehicle turns right and ends up in same direction as ego vehicle at non-signalized junction



(a) Schematic representation of SC33: Vehicle turns right and ends up in same direction as ego vehicle at non-signalized junction.



(b) Tags of SC33: Vehicle turns right and ends up in same direction as ego vehicle at non-signalized junction.

Figure 52: Schematic representation and tags of SC33: Vehicle turns right and ends up in same direction as ego vehicle at non-signalized junction.

4.33.1 General description

The scenario is schematically shown in Figure 52a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The ego vehicle intends to go straight at the junction. Another vehicle is approaching the junction from the right side of the ego vehicle. The other vehicle turns right at the junction, such that it ends up in the same direction as the ego vehicle. It depends on the traffic signs whether the ego vehicle or the other vehicle has the right of way. If there are no traffic signs, the other vehicle has to give right of way, according to the traffic rules in Singapore [28, p. 61].

4.33.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

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Ego vehicle The objective of the ego vehicle is to go straight at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that turns right at the junction. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 52b shows the tags that are assigned to this scenario category.

4.33.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 52a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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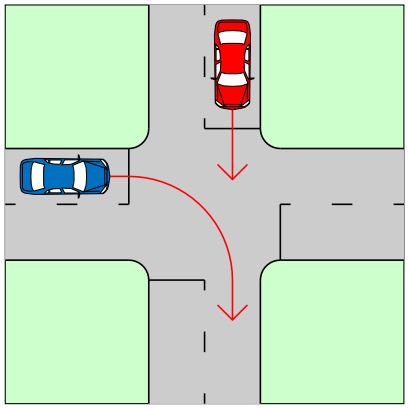
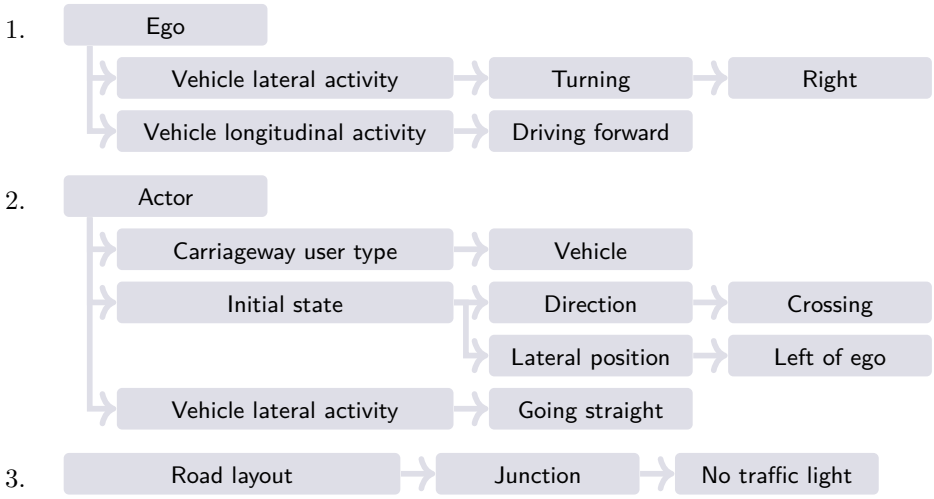
4.34 SC34: Ego vehicle turns right and ends up in same direction as other vehicle at non-signalized junction



(a) Schematic representation of SC34: Ego vehicle turns right and ends up in same direction as other vehicle at non-signalized junction.



(b) Tags of SC34: Ego vehicle turns right and ends up in same direction as other vehicle at non-signalized junction.

Figure 53: Schematic representation and tags of SC34: Ego vehicle turns right and ends up in same direction as other vehicle at non-signalized junction.

4.34.1 General description

The scenario is schematically shown in Figure 53a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The ego vehicle intends to turn right at the junction. Another vehicle is approaching the junction from the left side of the ego vehicle. The other vehicle goes straight at the junction, such that it ends up in the same direction as the ego vehicle. It depends on the traffic signs whether the ego vehicle or the other vehicle has the right of way. If there are no traffic signs, the ego vehicle has to give way, according to the traffic rules in Singapore [28, p. 61].

4.34.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

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Ego vehicle The objective of the ego vehicle is to turn right at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that goes straight at the junction. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 53b shows the tags that are assigned to this scenario category.

4.34.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 53a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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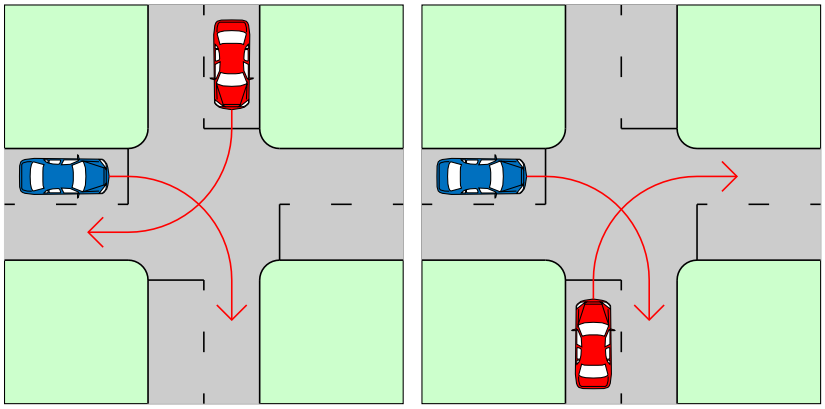
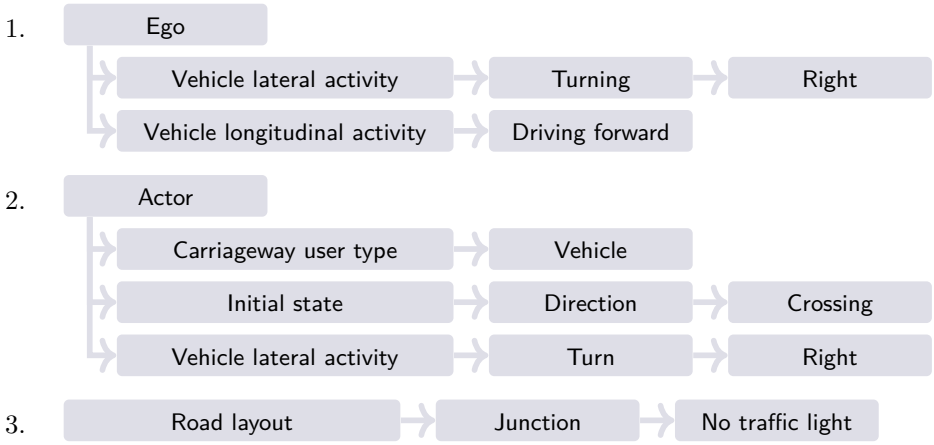
4.35 SC35: Ego and crossing vehicle turn right at non-signalized junction



(a) Schematic representation of SC35: Ego and crossing vehicle turn right at non-signalized junction.



(b) Tags of SC35: Ego and crossing vehicle turn right at non-signalized junction.

Figure 54: Schematic representation and tags of SC35: Ego and crossing vehicle turn right at non-signalized junction.

4.35.1 General description

The scenario is schematically shown in Figure 54a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The ego vehicle intends to turn right at the junction. Another vehicle is approaching the junction from the left or right side of the ego vehicle. The other vehicle also turns right at the junction, such that the trajectories of the ego vehicle and the other vehicle intersect. It depends on the traffic signs whether the ego vehicle or the other vehicle has the right of way. If there are no traffic signs, the ego vehicle has to give way in case the other vehicle approaches the junction from the right of the ego vehicle, according to the traffic rules in Singapore [28, p. 61]. As a result of the same rule, the other vehicle has to give way to the ego vehicle in case the other vehicle approaches the junction from the left of the ego vehicle, unless otherwise stated by the traffic signs.

4.35.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

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Ego vehicle The objective of the ego vehicle is to turn right at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that turns right at the junction. The position of the target vehicle is described by a parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 54b shows the tags that are assigned to this scenario category.

4.35.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 54a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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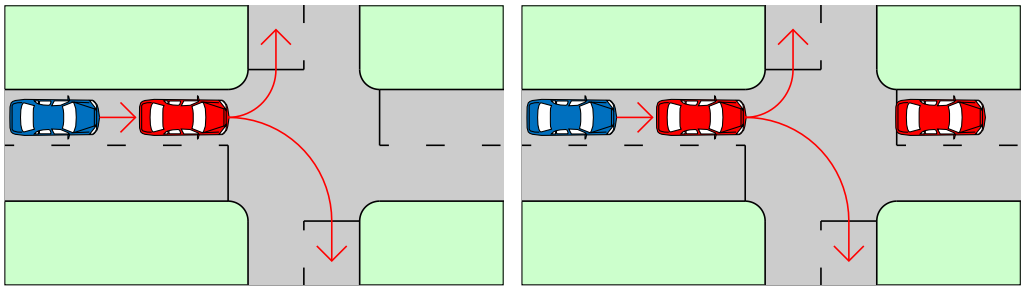
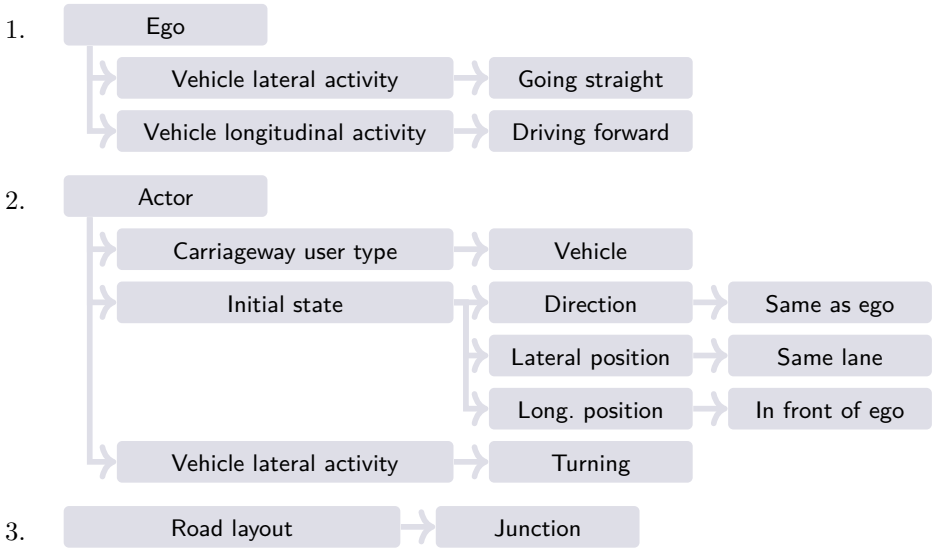
4.36 SC65: Turning lead vehicle



(a) Schematic representation of SC65: Turning lead vehicle.



(b) Tags of SC65: Turning lead vehicle.

Figure 55: Schematic representation and tags of SC65: Turning lead vehicle.

4.36.1 General description

The scenario is schematically shown in Figure 55a. The ego vehicle is approaching a junction while following its lead vehicle. The ego vehicle intends to go straight at the junction while the preceding vehicle turns left or right at the junction. As a result, the preceding vehicle will not be the lead vehicle after it turned. The preceding vehicle might brake to comfortably turn. It is possible that there will be a new lead vehicle after the preceding vehicle turned, e.g., see the second illustration in Figure 55a. If this new lead vehicle drives slower than the ego vehicle or is even at standstill, such as in Figure 55a, the ego vehicle might need to brake before its preceding vehicle turns.

4.36.2 Formal description

Static environment The static environment consists of a junction. The junction is possibly equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that turns at the junction. The position of the target vehicle is described by a parametrized function

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$x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component. In case the junction is equipped with traffic lights, the status of the traffic light signals is described by a parametrized function $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 55b shows the tags that are assigned to this scenario category.

4.36.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 55a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.
- The status of the traffic light signals, in case the junction is equipped with traffic lights, which is a parametrized function over time, denoted by $s_{\mathrm{TL}}(t, \theta_{\mathrm{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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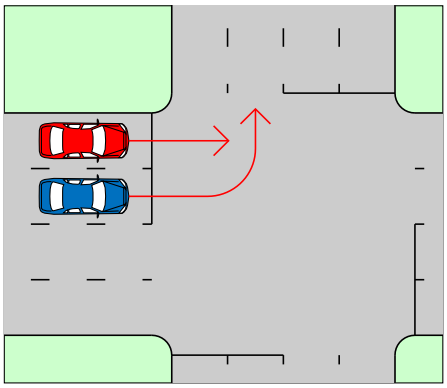
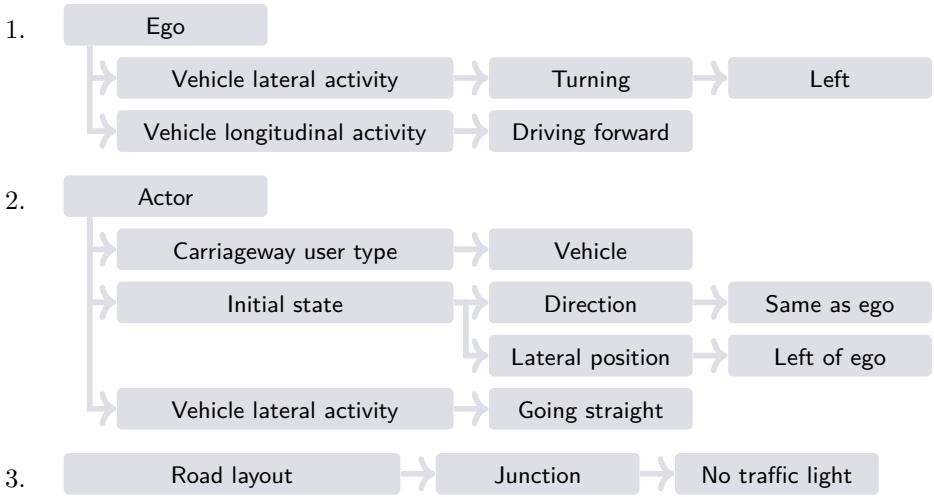
4.37 SC36: Undertaking at left turn at non-signalized junction



(a) Schematic representation of SC36: Undertaking at left turn at non-signalized junction.



(b) Tags of SC36: Undertaking at left turn at non-signalized junction.

Figure 56: Schematic representation and tags of SC36: Undertaking at left turn at non-signalized junction.

4.37.1 General description

The scenario is schematically shown in Figure 56a. The ego vehicle is approaching a junction that is not equipped with traffic light signals. The ego vehicle intends to turn left at the junction. Another vehicle is driving in the same direction in the left lane next to the ego vehicle. Because the other vehicle goes straight at the junction, the trajectories of the other vehicle and the ego vehicle intersect. Although the vehicle type of the other vehicle is not further specified, in practice this is often a motorbike.

4.37.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

Dynamic environment The dynamic environment consists of a target vehicle that goes straight at the junction. The position of the target vehicle is described by a parametrized

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function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector. Note that $x_{\mathrm{t}}(\cdot)$ has an easting and a northing component.

Tags Figure 56b shows the tags that are assigned to this scenario category.

4.37.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 56a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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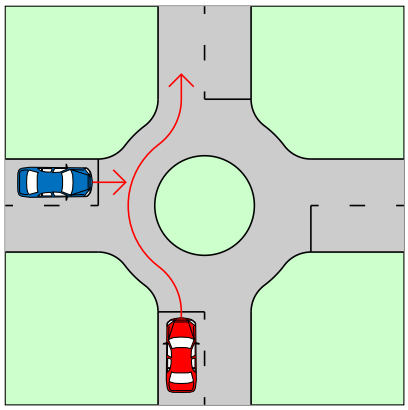
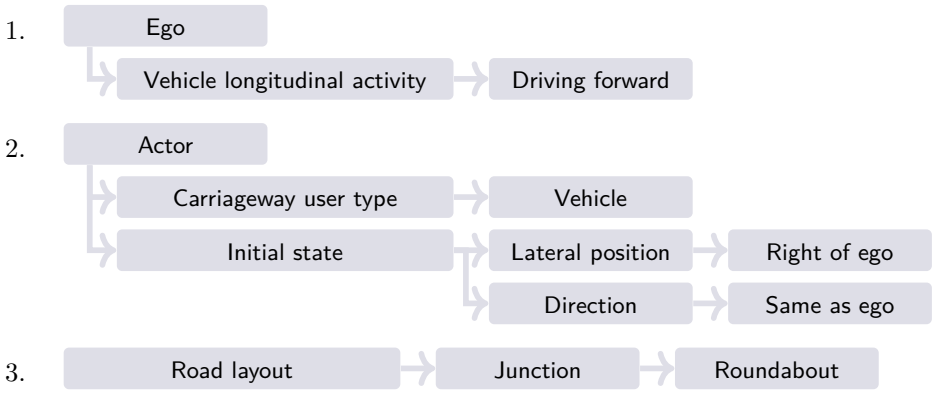
4.38 SC37: Entering a roundabout with another vehicle



(a) Schematic representation of SC37: Entering a roundabout with another vehicle.



(b) Tags of SC37: Entering a roundabout with another vehicle.

Figure 57: Schematic representation and tags of SC37: Entering a roundabout with another vehicle.

4.38.1 General description

The scenario is schematically shown in Figure 57a. The ego vehicle is approaching a roundabout. There is another vehicle on the roundabout or another vehicle is approaching the roundabout from another direction. In any case, because the junction is a roundabout, the other vehicle approaches the ego vehicle from the right. It might be the case that the ego vehicle needs to give priority to the other vehicle. Figure 57a shows a roundabout with a single lane. However, this scenario category also includes roundabouts with multiple lanes.

4.38.2 Formal description

Static environment The static environment consists of a roundabout with one or multiple lanes. The roundabout is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to turn left, go straight or turn right on the roundabout.

Dynamic environment The dynamic environment consists of a target vehicle that also approaches the roundabout or that is already at the roundabout. The position of the target vehicle is described by a parametrized function $x_\mathrm{t}(t, \theta_\mathrm{t})$, where t denotes the time and θ_t denotes the parameter vector. Note that $x_\mathrm{t}(\cdot)$ has an easting and a northing component.

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Tags Figure 57b shows the tags that are assigned to this scenario category.

4.38.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 57a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the target vehicle, denoted by the parametrized function $x_{\mathrm{t}}(t, \theta_{\mathrm{t}})$, where t denotes the time and θ_{t} denotes the parameter vector.

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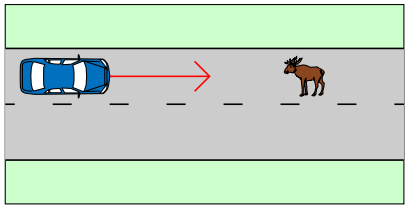
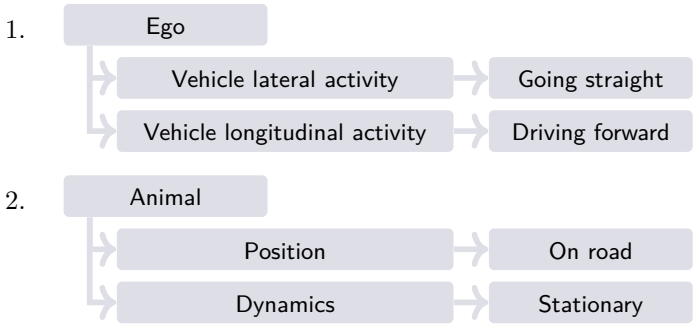
4.39 SC38: Animal on the road



(a) Schematic representation of SC38: Animal on the road.



(b) Tags of SC38: Animal on the road.

Figure 58: Schematic representation and tags of SC38: Animal on the road.

4.39.1 General description

The scenario is schematically shown in Figure 58a. The ego vehicle is driving on a road with an animal on the ego vehicle's path, on the road, or next to the road. Although the objective of the ego vehicle is to continue driving straight, the ego vehicle is expected to slow down while passing the animal.

4.39.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consists of an animal on the road. The position of the animal is described by a parametrized function $x_{\mathrm{a}}(t, \theta_{\mathrm{a}})$, where t denotes the time and θ_{a} denotes the parameter vector. Note that $x_{\mathrm{a}}(\cdot)$ has an easting and a northing component.

Tags Figure 58b shows the tags that are assigned to this scenario category.

4.39.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 58a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the animal, denoted by the parametrized function $x_{\mathrm{a}}(t, \theta_{\mathrm{a}})$, where t denotes the time and θ_{a} denotes the parameter vector.

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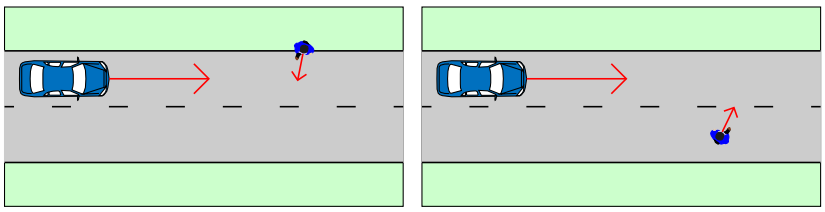
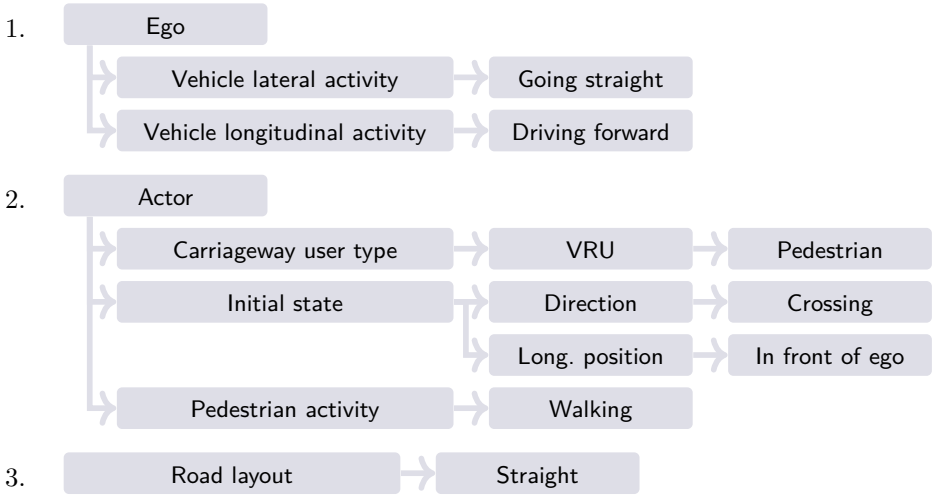
4.40 SC39: Jaywalking



(a) Schematic representation of SC39: Jaywalking.



(b) Tags of SC39: Jaywalking.

Figure 59: Schematic representation and tags of SC39: Jaywalking.

4.40.1 General description

The scenario is schematically shown in Figure 59a. The ego vehicle is driving on a road with a jaywalker. Although the jaywalker is not allowed to cross the road, the ego vehicle is expected to behave appropriately to avoid critical situations.

4.40.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consist of a pedestrian that crosses the road. The pedestrian crosses the road unlawfully or without regard for approaching traffic. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

Tags Figure 59b shows the tags that are assigned to this scenario category.

4.40.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 59a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

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- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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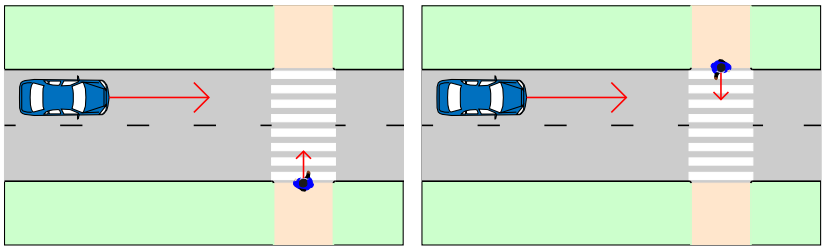
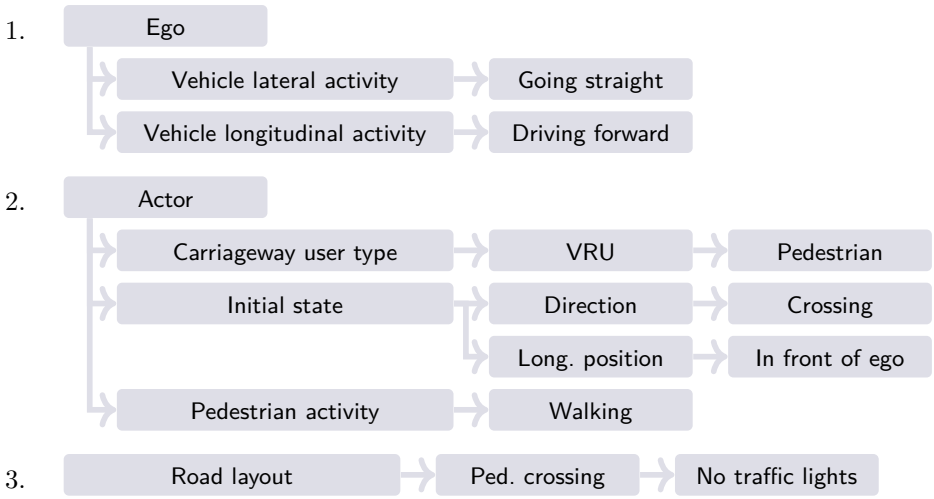
4.41 SC40: Pedestrian crossing at zebra crossing



(a) Schematic representation of SC40: Pedestrian crossing at zebra crossing.



(b) Tags of SC40: Pedestrian crossing at zebra crossing.

Figure 60: Schematic representation and tags of SC40: Pedestrian crossing at zebra crossing.

4.41.1 General description

The scenario is schematically shown in Figure 60a. The ego vehicle is approaching a zebra crossing that is not equipped with traffic light signals. At the same time, a pedestrian is crossing the road using the zebra crossing. The ego vehicle has to give right of way to the pedestrian. The ego vehicle might need to adopt its speed to stay at a safe distance from the pedestrian.

4.41.2 Formal description

Static environment The static environment consists of a road and a footway. The footway, i.e., a road dedicated for pedestrians, cyclists, and personal mobility devices, crosses the road. The crossing is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to drive straight.

Dynamic environment The dynamic environment consists of the pedestrian that crosses the road. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

Tags Figure 60b shows the tags that are assigned to this scenario category.

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4.41.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 60a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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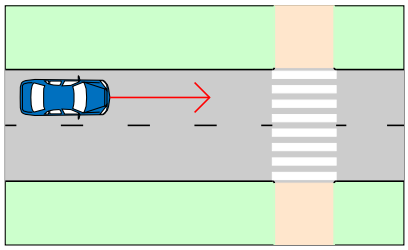
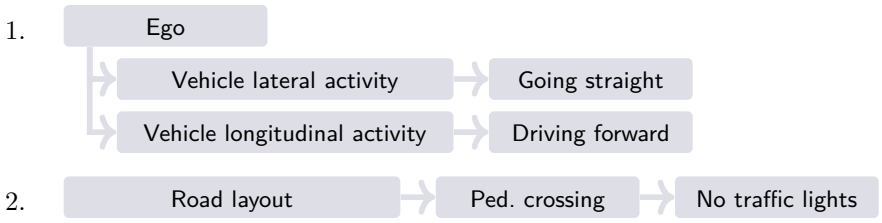
4.42 SC41: Zebra crossing



(a) Schematic representation of SC41: Zebra crossing.



(b) Tags of SC41: Zebra crossing.

Figure 61: Schematic representation and tags of SC41: Zebra crossing.

4.42.1 General description

The scenario is schematically shown in Figure 61a. The ego vehicle is approaching a zebra crossing that is not equipped with traffic light signals. There is no pedestrian specified. If there is no pedestrian, the ego vehicle is expected to continue driving. This is a more general scenario class than scenario class 41, because scenario class 41 specifies the presence of a pedestrian.

4.42.2 Formal description

Static environment The static environment consists of a road and a footway. The footway, i.e., a road dedicated for pedestrians, cyclists, and personal mobility devices, crosses the road. The crossing is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to drive straight.

Dynamic environment For this scenario category, no dynamic environment is considered.

Tags Figure 61b shows the tags that are assigned to this scenario category.

4.42.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 61a are described by at least the parameters mentioned at the beginning of this section on page 19.

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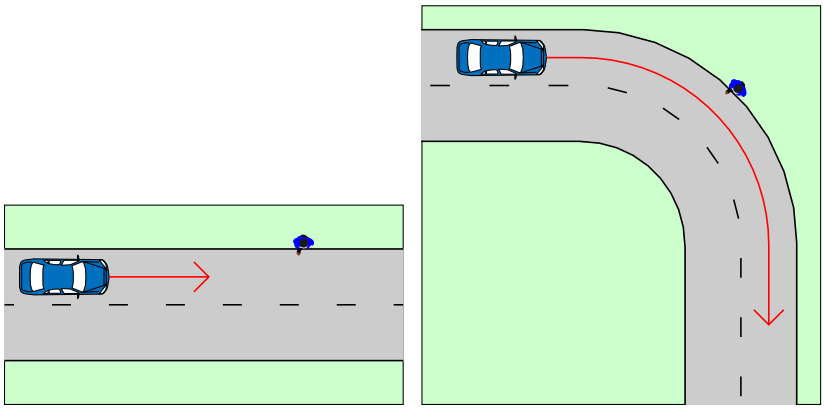
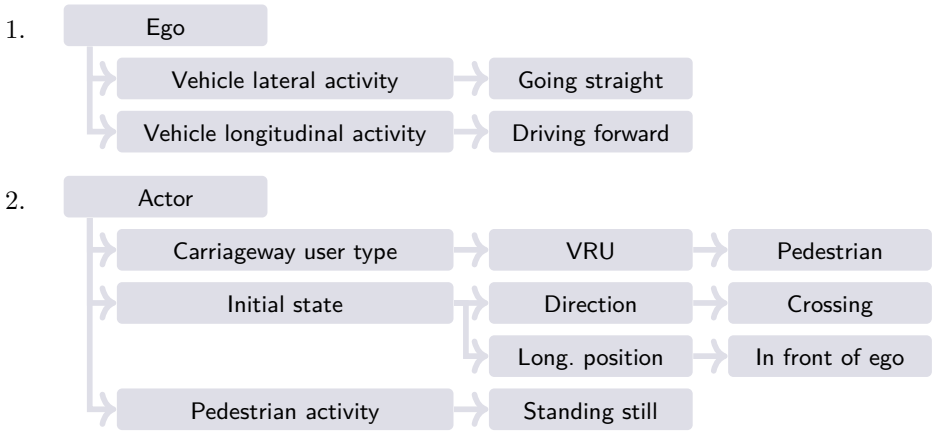
4.43 SC42: Pedestrian stationary at road side



(a) Schematic representation of SC42: Pedestrian stationary at road side.



(b) Tags of SC42: Pedestrian stationary at road side.

Figure 62: Schematic representation and tags of SC42: Pedestrian stationary at road side.

4.43.1 General description

The scenario is schematically shown in Figure 62a. The ego vehicle is following the road, approaching a pedestrian standing still at the road side. As the pedestrian is stationary, standing still, the ego vehicle should be capable to distinguish this principally safe situation from an unsafe situation where the pedestrian is about to cross the road. It is expected that the ego vehicle does not act (by braking or steering) upon the presence of the standstill pedestrian. This might be challenging for the ego vehicle, especially on a curved road where the pedestrian might appear in the corridor of the vehicle.

4.43.2 Formal description

Static environment The static environment consists of a single road.

Ego vehicle The objective of the ego vehicle is to drive straight.

Dynamic environment The dynamic environment consists of a pedestrian that is at standstill at the side of the road. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

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Tags Figure 62b shows the tags that are assigned to this scenario category.

4.43.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 62a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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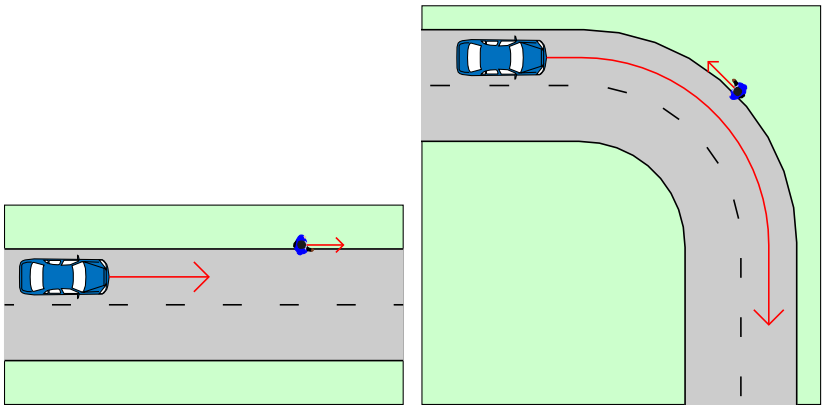
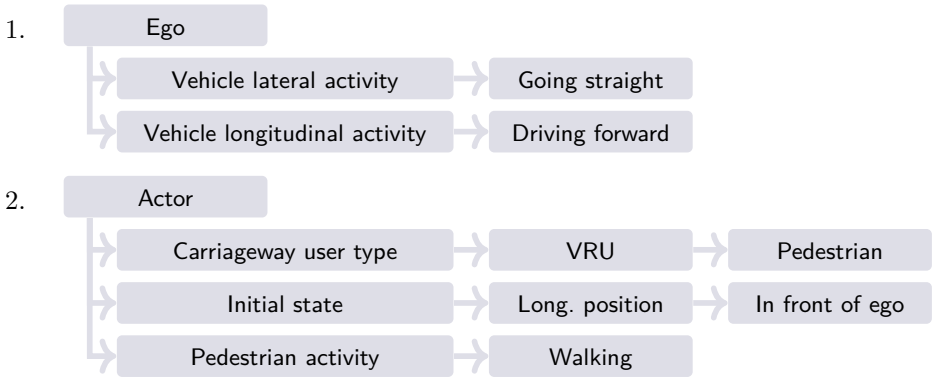
4.44 SC43: Pedestrian walking along the road



(a) Schematic representation of SC43: Pedestrian walking along the road.



(b) Tags of SC43: Pedestrian walking along the road.

Figure 63: Schematic representation and tags of SC43: Pedestrian walking along the road.

4.44.1 General description

The scenario is schematically shown in Figure 63a. The ego vehicle is following the road, approaching a pedestrian that is walking along the road. The ego vehicle should be capable to distinguish this principally safe situation from an unsafe situation where the pedestrian is about to cross the road. The ego vehicle might act by slowing down and turning slightly away from the pedestrian. This might be challenging for the ego vehicle, especially on a curved road where the pedestrian might appear in the corridor of the vehicle.

4.44.2 Formal description

Static environment The static environment consists of a single road.

Ego vehicle The objective of the ego vehicle is to drive straight.

Dynamic environment The dynamic environment consists of a pedestrian that is walking along the road. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

Tags Figure 63b shows the tags that are assigned to this scenario category.

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4.44.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 63a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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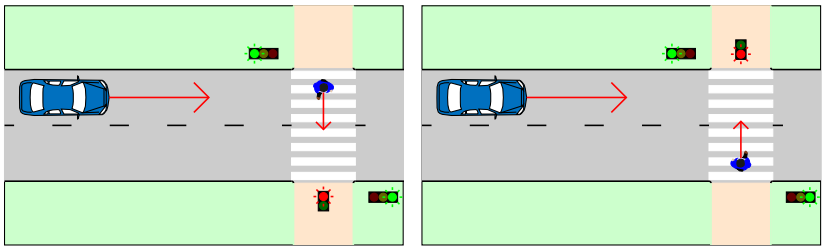
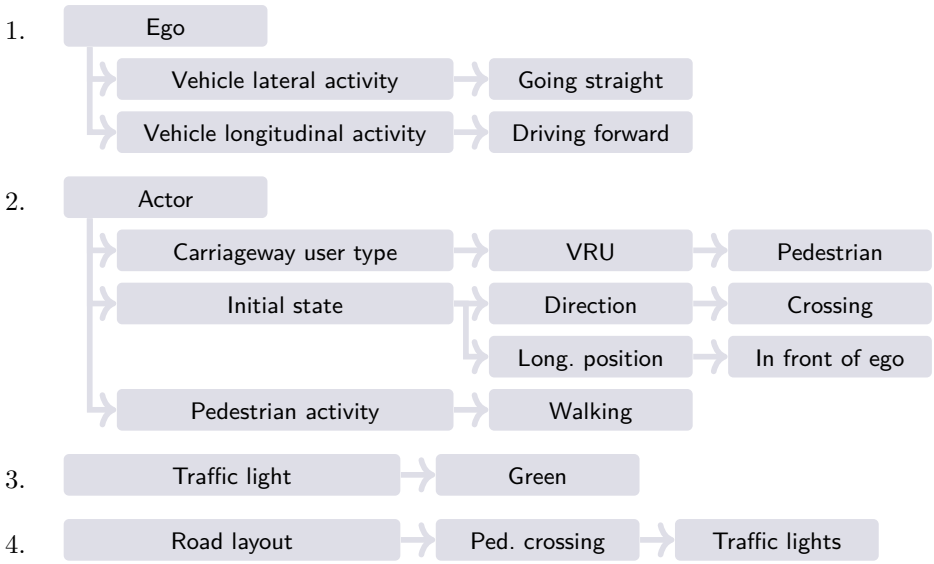
4.45 SC44: Pedestrian running a red light



(a) Schematic representation of SC44: Pedestrian running a red light.



(b) Tags of SC44: Pedestrian running a red light.

Figure 64: Schematic representation and tags of SC44: Pedestrian running a red light.

4.45.1 General description

The scenario is schematically shown in Figure 64a. The ego vehicle is approaching a pedestrian crossing that is equipped with traffic light signals. The traffic signal for the ego vehicle is green. At the same time, a pedestrian is running through the red light. The ego vehicle might need to adopt its speed to stay at a safe distance from the pedestrian.

4.45.2 Formal description

Static environment The static environment consists of a road and a footway. The footway, i.e., a road dedicated for pedestrians, cyclists, and personal mobility devices, crosses the road. The crossing is equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to drive straight.

Dynamic environment The dynamic environment consists of the traffic light signal and a pedestrian that crosses the road while running through the red traffic light. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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Tags Figure 64b shows the tags that are assigned to this scenario category.

4.45.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 64a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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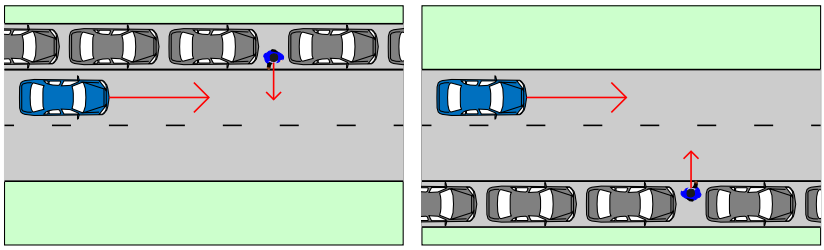
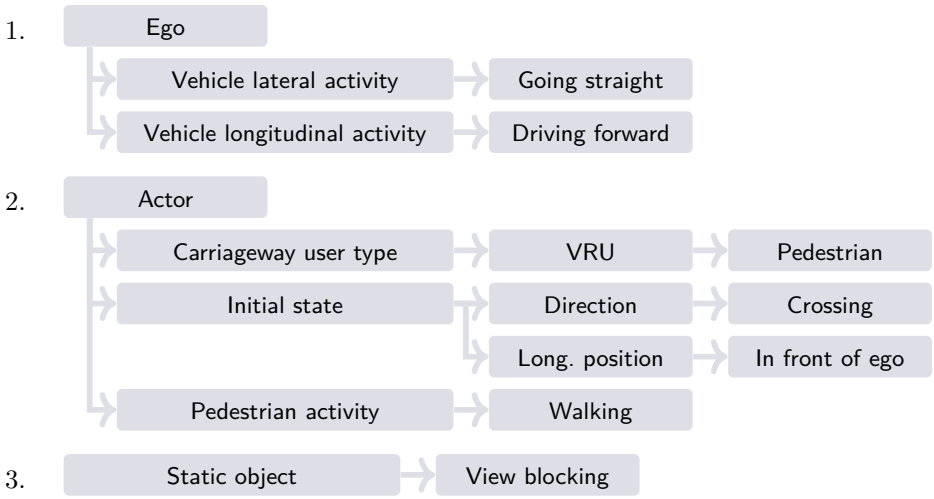
4.46 SC45: Pedestrian crossing from behind an obstruction



(a) Schematic representation of SC45: Pedestrian crossing from behind an obstruction.



(b) Tags of SC45: Pedestrian crossing from behind an obstruction.

Figure 65: Schematic representation and tags of SC45: Pedestrian crossing from behind an obstruction.

4.46.1 General description

The scenario is schematically shown in Figure 65a. The ego vehicle is driving on a road while a pedestrian crosses the road. The pedestrian is initially outside the view of the ego vehicle due to an obstruction. This obstruction is not specified, but this can be, for example, a parked vehicle (Figure 65a).

4.46.2 Formal description

Static environment The static environment consists of a road with a speed limit denoted by $v_{\max}$ and an object that is obstructing the view of the ego vehicle, such that the pedestrian is (partially) out of view. The object is described by the parameter vector θ_{object}. The parameter vector contains the position of the object and might contain, amongst others, its size.

Ego vehicle The objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consists of the pedestrian that crosses the road. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

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Tags Figure 65b shows the tags that are assigned to this scenario category.

4.46.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 65a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The static object is described with the parameter vector θ_{object}.
- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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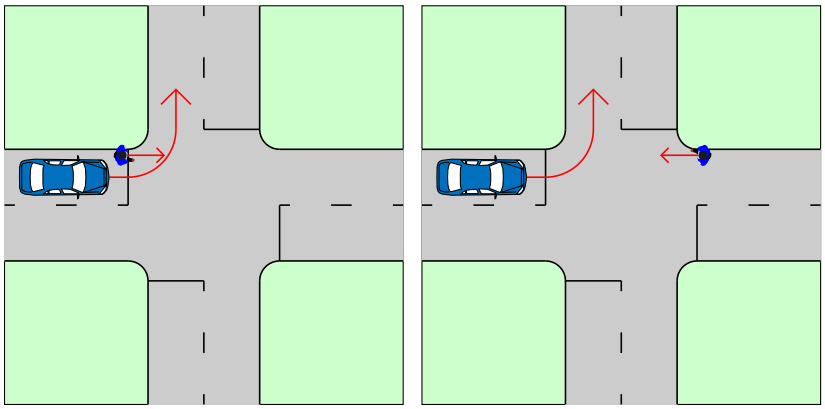
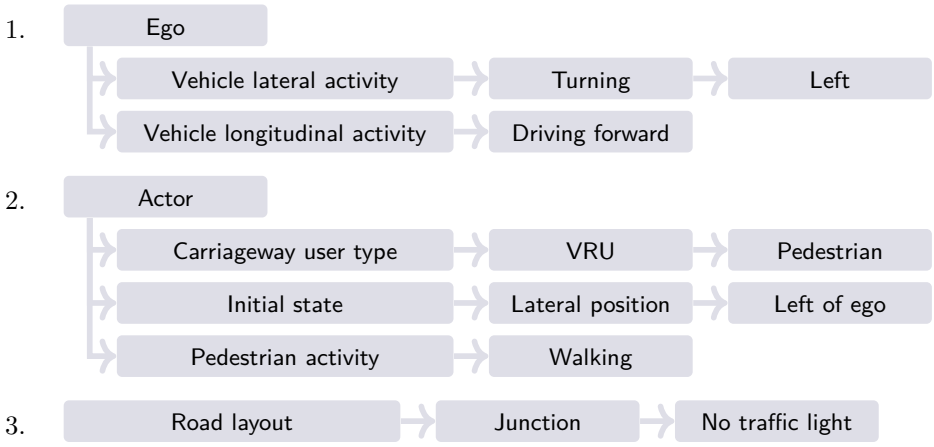
4.47 SC46: Pedestrian at left turn at non-signalized junction



(a) Schematic representation of SC46: Pedestrian at left turn at non-signalized junction.



(b) Tags of SC46: Pedestrian at left turn at non-signalized junction.

Figure 66: Schematic representation and tags of SC46: Pedestrian at left turn at non-signalized junction.

4.47.1 General description

The scenario is schematically shown in Figure 66a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. The junction is not equipped with traffic light signals. A pedestrian is walking on the left side of the ego vehicle. The walking direction of the pedestrian is not specified. Therefore, the pedestrian might walk towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the pedestrian is initially on the left side of the ego vehicle while the ego vehicle intends to turn left, it might be possible that the trajectories of the pedestrian and the ego vehicle intersect.

4.47.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

Dynamic environment The dynamic environment consists of a pedestrian. The pedestrian is initially on the left of the ego vehicle. The position of the pedestrian is described

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by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

Tags Figure 66b shows the tags that are assigned to this scenario category.

4.47.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 66a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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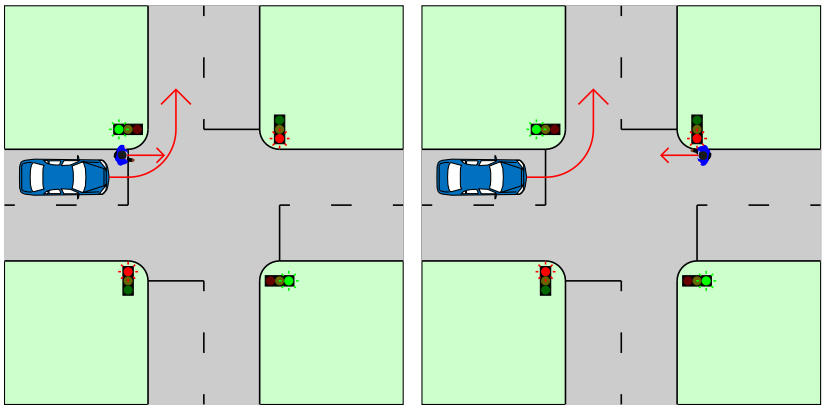
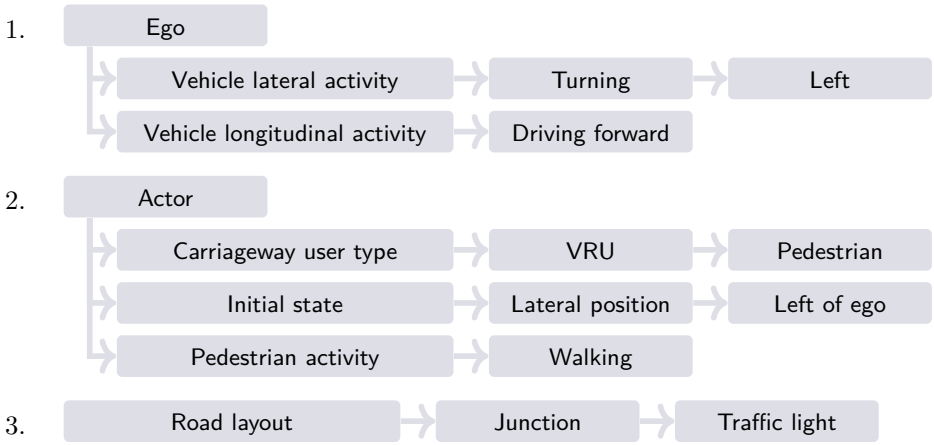
4.48 SC47: Pedestrian at left turn at signalized junction



(a) Schematic representation of SC47: Pedestrian at left turn at signalized junction.



(b) Tags of SC47: Pedestrian at left turn at signalized junction.

Figure 67: Schematic representation and tags of SC47: Pedestrian at left turn at signalized junction.

4.48.1 General description

The scenario is schematically shown in Figure 67a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. The junction is equipped with traffic light signals. A pedestrian is walking on the left side of the ego vehicle. The walking direction of the pedestrian is not specified. Therefore, the pedestrian might walk towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the pedestrian is initially on the left side of the ego vehicle while the ego vehicle intends to turn left, it might be possible that the trajectories of the pedestrian and the ego vehicle intersect.

4.48.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

Dynamic environment The dynamic environment consists of a pedestrian. The pedestrian is initially on the left of the ego vehicle. The position of the pedestrian is described

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by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 67b shows the tags that are assigned to this scenario category.

4.48.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 67a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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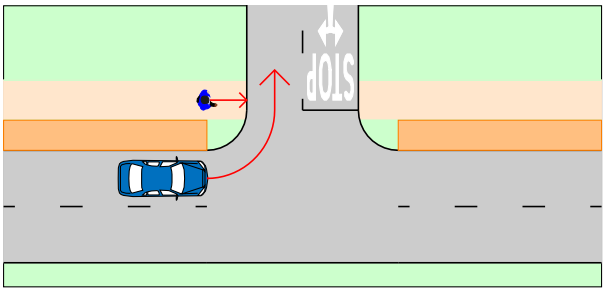
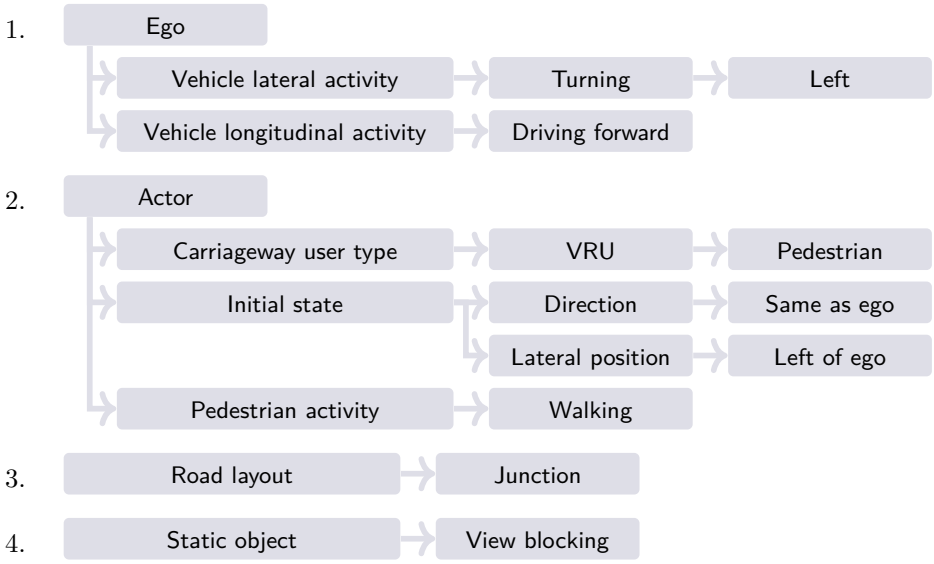
4.49 SC48: Pedestrian in same direction obstructed at ego left turn



(a) Schematic representation of SC48: Pedestrian in same direction obstructed at ego left turn.



(b) Tags of SC48: Pedestrian in same direction obstructed at ego left turn.

Figure 68: Schematic representation and tags of SC48: Pedestrian in same direction obstructed at ego left turn.

4.49.1 General description

The scenario is schematically shown in Figure 68a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. It is not specified whether the junction is equipped with traffic light signals. A pedestrian is approaching the junction from the same direction on the left side of the road (from the perspective of the ego vehicle). The pedestrian goes straight at the junction such that the trajectories of the ego vehicle and the pedestrian intersect. The view from the ego vehicle to the pedestrian is obstructed, e.g., by bushes or a hedge.

4.49.2 Formal description

Static environment The static environment consists of a junction. The junction is possibly equipped with traffic light signals. Budges or hedges in between the sidewalk and the main road are present that obstruct the view of the pedestrian from the perspective of the ego vehicle.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

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Dynamic environment The dynamic environment consists of a pedestrian that crosses the junction. The pedestrian is initially on the left side of the ego vehicle and on the same side of the junction. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component. In case the junction is equipped with traffic lights, the status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 68b shows the tags that are assigned to this scenario category.

4.49.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 68a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.
- The status of the traffic light signals, in case the junction is equipped with traffic lights, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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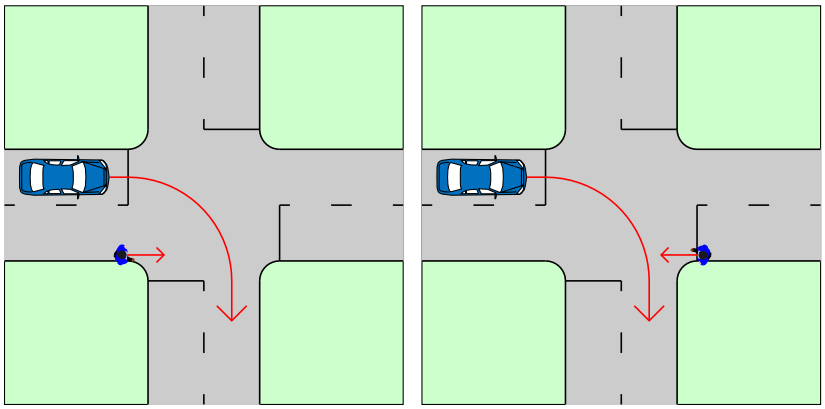
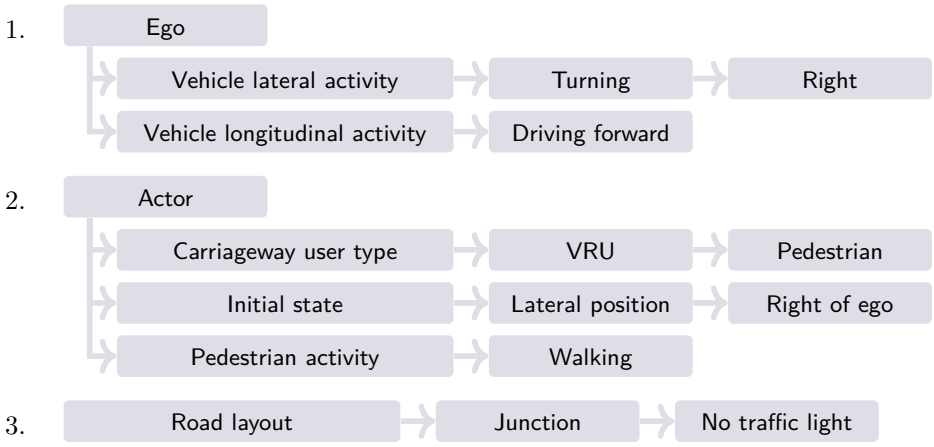
4.50 SC49: Pedestrian at right turn at non-signalized junction



(a) Schematic representation of SC49: Pedestrian at right turn at non-signalized junction.



(b) Tags of SC49: Pedestrian at right turn at non-signalized junction.

Figure 69: Schematic representation and tags of SC49: Pedestrian at right turn at non-signalized junction.

4.50.1 General description

The scenario is schematically shown in Figure 69a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn right. The junction is not equipped with traffic light signals. A pedestrian is walking on the right side of the ego vehicle. The walking direction of the pedestrian is not specified. Therefore, the pedestrian might walk towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the pedestrian is initially on the right side of the ego vehicle while the ego vehicle intends to turn right, it might be possible that the trajectories of the pedestrian and the ego vehicle intersect.

4.50.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn right at the junction.

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Dynamic environment The dynamic environment consists of a pedestrian. The pedestrian is initially on the right of the ego vehicle. The position of the pedestrian is described by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component.

Tags Figure 69b shows the tags that are assigned to this scenario category.

4.50.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 69a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.

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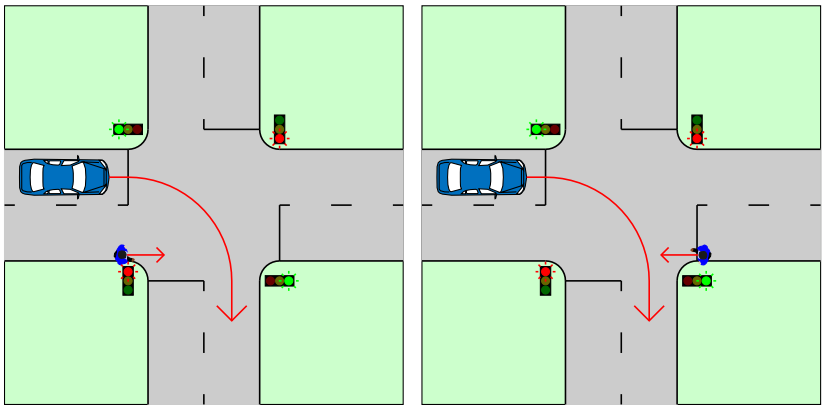
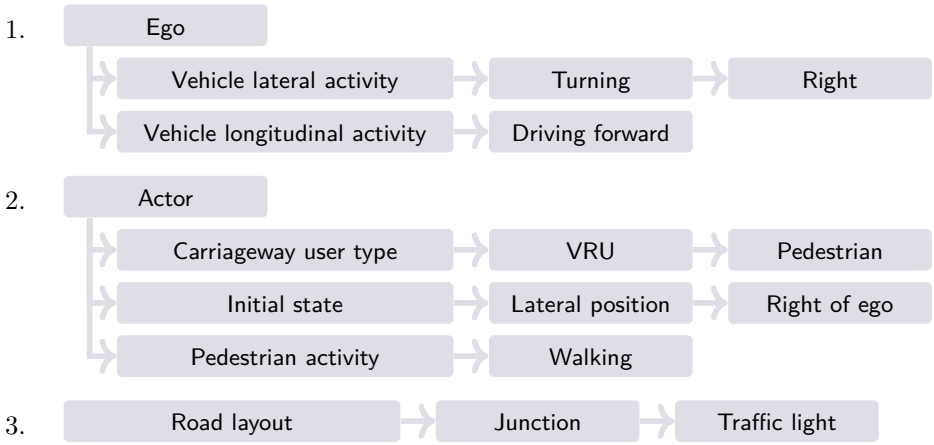
4.51 SC50: Pedestrian at right turn at signalized junction



(a) Schematic representation of SC50: Pedestrian at right turn at signalized junction.



(b) Tags of SC50: Pedestrian at right turn at signalized junction.

Figure 70: Schematic representation and tags of SC50: Pedestrian at right turn at signalized junction.

4.51.1 General description

The scenario is schematically shown in Figure 70a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn right. The junction is equipped with traffic light signals. A pedestrian is walking on the right side of the ego vehicle. The walking direction of the pedestrian is not specified. Therefore, the pedestrian might walk towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the pedestrian is initially on the right side of the ego vehicle while the ego vehicle intends to turn right, it might be possible that the trajectories of the pedestrian and the ego vehicle intersect.

4.51.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn right at the junction.

Dynamic environment The dynamic environment consists of a pedestrian. The pedestrian is initially on the right of the ego vehicle. The position of the pedestrian is described

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by a parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector. Note that $x_{\text{ped}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 70b shows the tags that are assigned to this scenario category.

4.51.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 70a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the pedestrian, denoted by the parametrized function $x_{\text{ped}}(t, \theta_{\text{ped}})$, where t denotes the time and θ_{ped} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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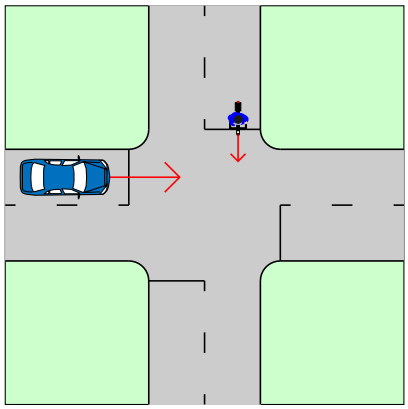
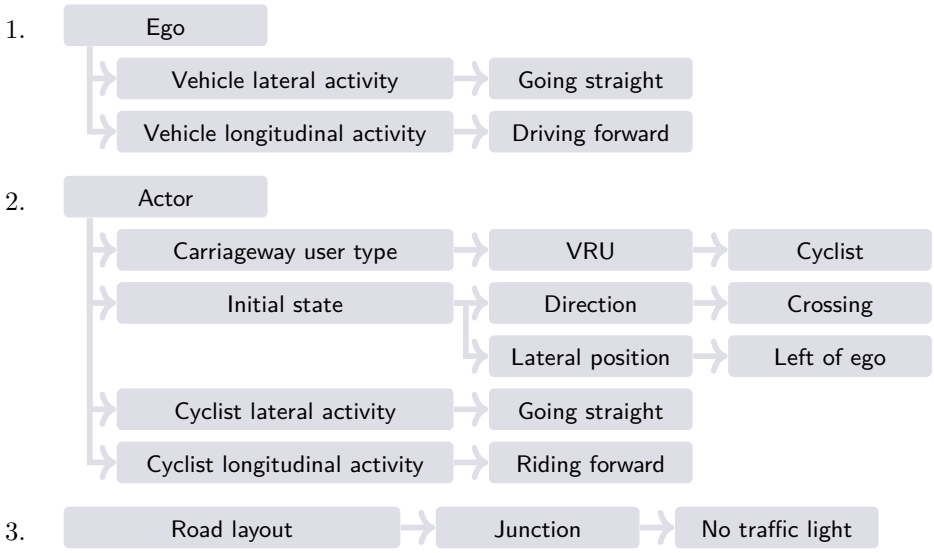
4.52 SC51: Cyclist crossing from left side at non-signalized junction



(a) Schematic representation of SC51: Cyclist crossing from left side at non-signalized junction.



(b) Tags of SC51: Cyclist crossing from left side at non-signalized junction.

Figure 71: Schematic representation and tags of SC51: Cyclist crossing from left side at non-signalized junction.

4.52.1 General description

The scenario is schematically shown in Figure 71a. The ego vehicle is approaching a junction at which the ego vehicle intends to go straight. The junction is not equipped with traffic light signals. A cyclist is approaching the junction from the left of the ego vehicle. The trajectories of the ego vehicle and the cyclist intersect.

4.52.2 Formal description

Static environment The static environment consists of a junction. The junction is no equipped with traffic light signals. Traffic signs might be present to indicate priorities.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

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Dynamic environment The dynamic environment consists of a cyclist that crosses the junction. The cyclist approaches the junction from the left of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 71b shows the tags that are assigned to this scenario category.

4.52.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 71a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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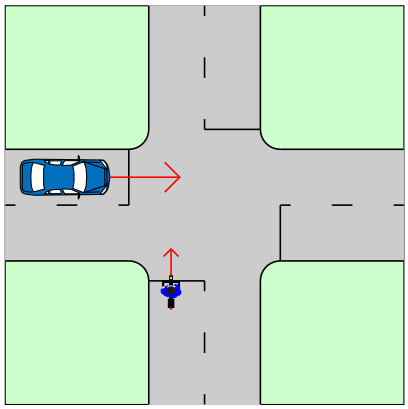
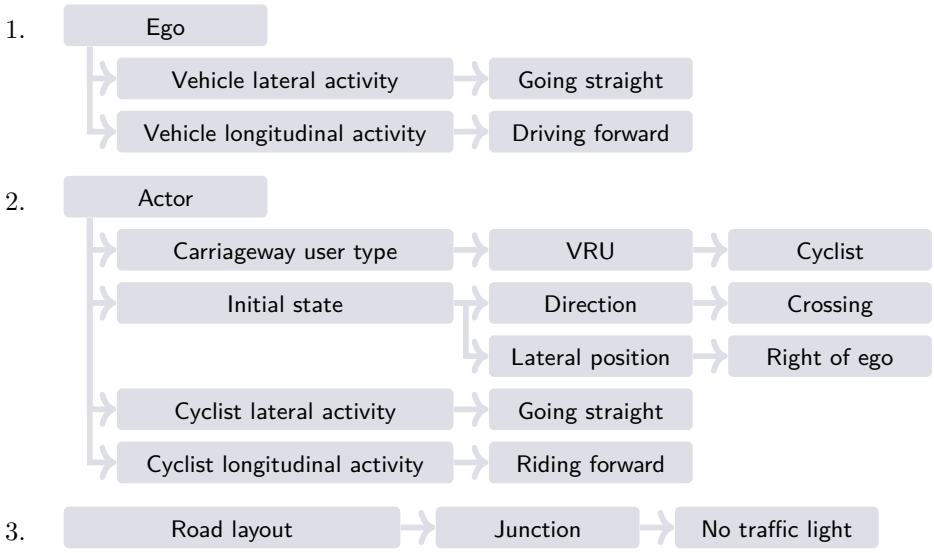
4.53 SC52: Cyclist crossing from right side at non-signalized junction



(a) Schematic representation of SC52: Cyclist crossing from right side at non-signalized junction.



(b) Tags of SC52: Cyclist crossing from right side at non-signalized junction.

Figure 72: Schematic representation and tags of SC52: Cyclist crossing from right side at non-signalized junction.

4.53.1 General description

The scenario is schematically shown in Figure 72a. The ego vehicle is approaching a junction at which the ego vehicle intends to go straight. The junction is not equipped with traffic light signals. A cyclist is approaching the junction from the right of the ego vehicle. The trajectories of the ego vehicle and the cyclist intersect.

4.53.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals. Traffic signs might be present to indicate priorities.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

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Dynamic environment The dynamic environment consists of a cyclist that crosses the junction. The cyclist approaches the junction from the right of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 72b shows the tags that are assigned to this scenario category.

4.53.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 72a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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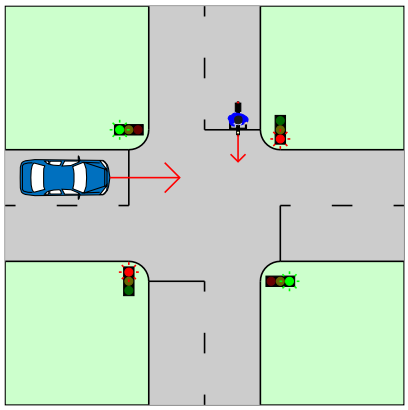
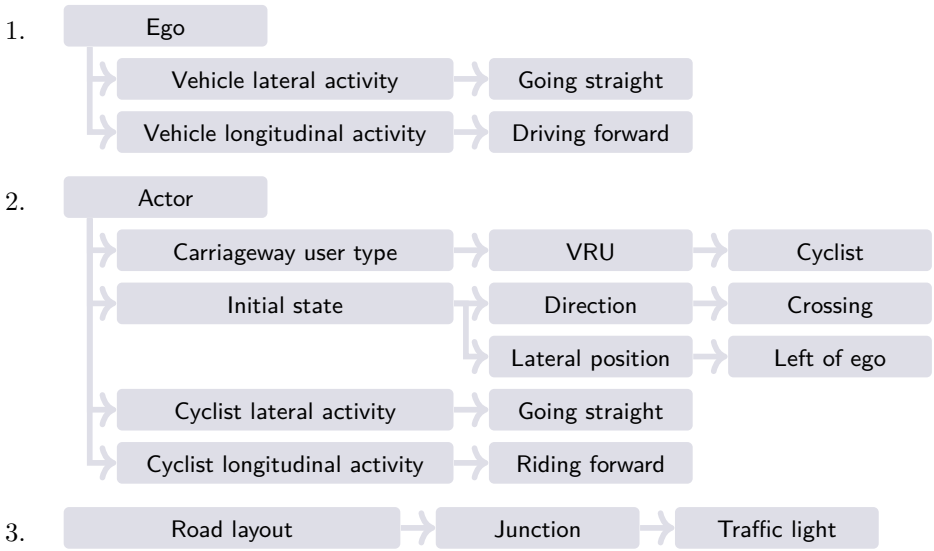
4.54 SC53: Cyclist crossing from left side at signalized junction



(a) Schematic representation of SC53: Cyclist crossing from left side at signalized junction.



(b) Tags of SC53: Cyclist crossing from left side at signalized junction.

Figure 73: Schematic representation and tags of SC53: Cyclist crossing from left side at signalized junction.

4.54.1 General description

The scenario is schematically shown in Figure 73a. The ego vehicle is approaching a junction at which the ego vehicle intends to go straight. The junction is equipped with traffic light signals. A cyclist is approaching the junction from the left of the ego vehicle. The trajectories of the ego vehicle and the cyclist intersect.

4.54.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

Dynamic environment The dynamic environment consists of a cyclist that crosses the junction. The cyclist approaches the junction from the left of the ego vehicle. The position

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of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 73b shows the tags that are assigned to this scenario category.

4.54.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 73a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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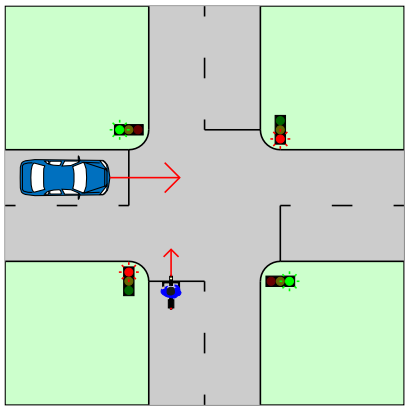
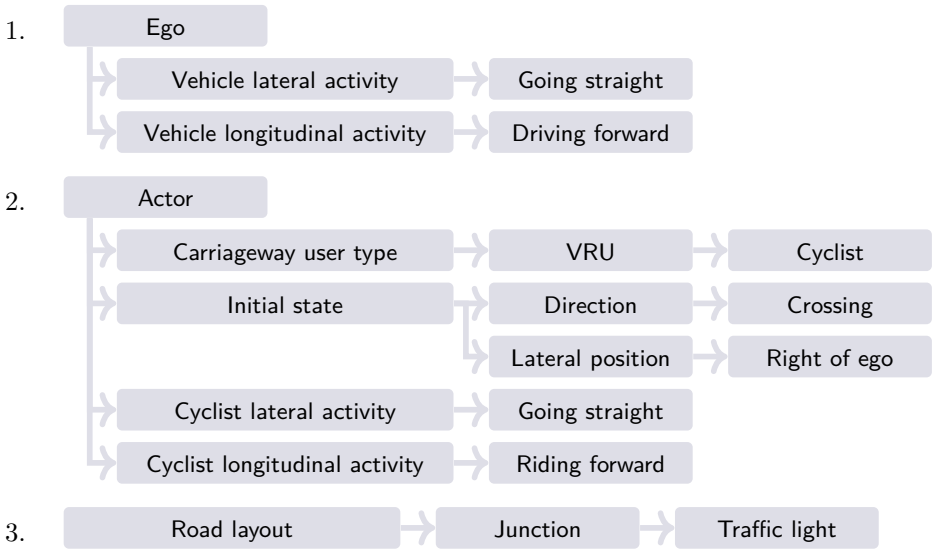
4.55 SC54: Cyclist crossing from right side at signalized junction



(a) Schematic representation of SC54: Cyclist crossing from right side at signalized junction.



(b) Tags of SC54: Cyclist crossing from right side at signalized junction.

Figure 74: Schematic representation and tags of SC54: Cyclist crossing from right side at signalized junction.

4.55.1 General description

The scenario is schematically shown in Figure 74a. The ego vehicle is approaching a junction at which the ego vehicle intends to go straight. The junction is equipped with traffic light signals. A cyclist is approaching the junction from the right of the ego vehicle. The trajectories of the ego vehicle and the cyclist intersect.

4.55.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight at the junction.

Dynamic environment The dynamic environment consists of a cyclist that crosses the junction. The cyclist approaches the junction from the right of the ego vehicle. The position

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of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 74b shows the tags that are assigned to this scenario category.

4.55.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 74a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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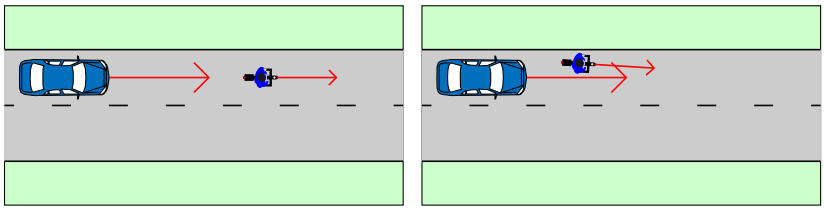
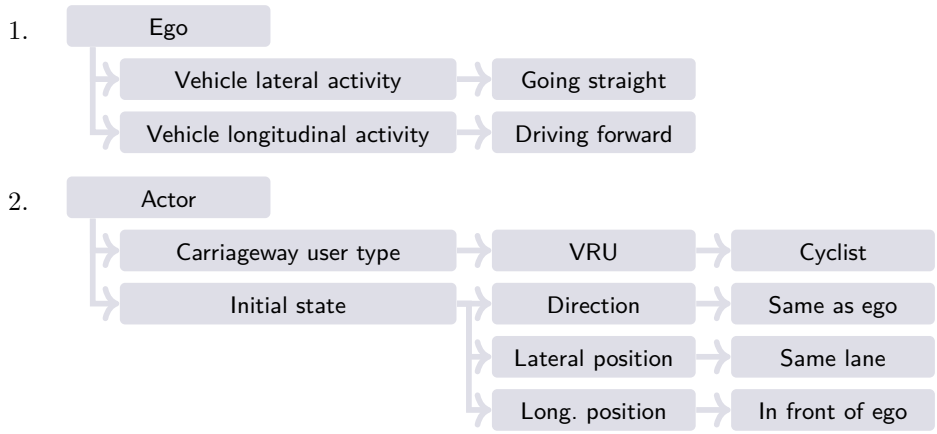
4.56 SC55: Ego vehicle approaching cyclist riding in same direction



(a) Schematic representation of SC55: Ego vehicle approaching cyclist riding in same direction.



(b) Tags of SC55: Ego vehicle approaching cyclist riding in same direction.

Figure 75: Schematic representation and tags of SC55: Ego vehicle approaching cyclist riding in same direction.

4.56.1 General description

The scenario is schematically shown in Figure 75a. The ego vehicle is driving towards a cyclist that is riding in the same direction. The initial intention of the ego vehicle is to drive straight. To safely pass the cyclist, the ego vehicle might need to divert its path. Another possibility is that the ego vehicle brakes such that the ego vehicle stays behind the cyclist.

Note that the cyclist might ride straight, but it may also swerve as shown in the second scene in Figure 75a.

4.56.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The initial objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consists of a cyclist that is initially in front of the ego vehicle while riding in the same direction as the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 75b shows the tags that are assigned to this scenario category.

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4.56.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 75a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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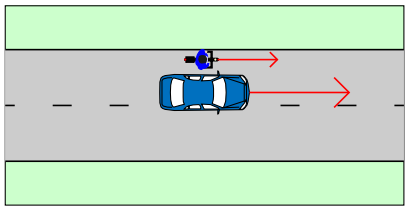
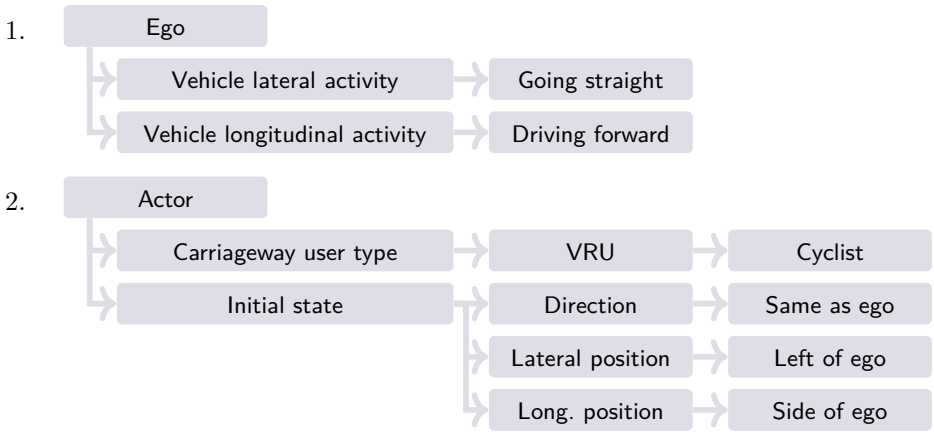
4.57 SC56: Ego vehicle driving alongside a cyclist



(a) Schematic representation of SC56: Ego vehicle driving alongside a cyclist.



(b) Tags of SC56: Ego vehicle driving alongside a cyclist.

Figure 76: Schematic representation and tags of SC56: Ego vehicle driving alongside a cyclist.

4.57.1 General description

The scenario is schematically shown in Figure 76a. The ego vehicle is driving straight while a cyclist is riding on the left side of the road in the same direction as the ego vehicle. This might be because the ego vehicle is overtaking a cyclist. Alternatively, it is also possible that the cyclist overtakes the ego vehicle from the left. To prevent a collision between the ego vehicle and the cyclist, the ego vehicle might need to divert its path.

4.57.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consists of a cyclist that is initially on the left of the ego vehicle while riding in the same direction as the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 76b shows the tags that are assigned to this scenario category.

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4.57.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 76a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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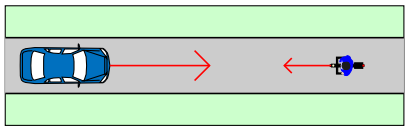
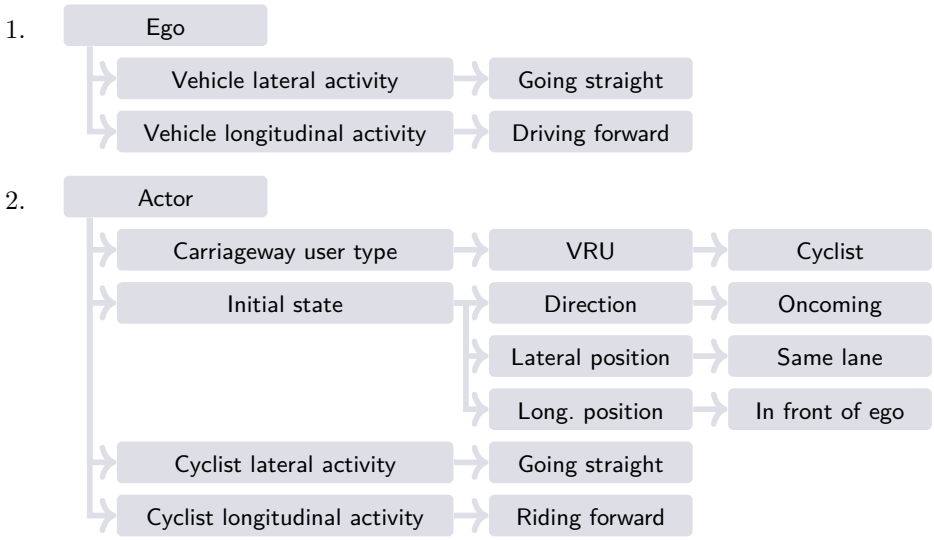
4.58 SC57: Cyclist and ego vehicle driving in opposite direction



(a) Schematic representation of SC57: Cyclist and ego vehicle driving in opposite direction.



(b) Tags of SC57: Cyclist and ego vehicle driving in opposite direction.

Figure 77: Schematic representation and tags of SC57: Cyclist and ego vehicle driving in opposite direction.

4.58.1 General description

The scenario is schematically shown in Figure 77a. The ego vehicle is driving in the opposite direction of a cyclist. Therefore, the ego vehicle is expected to slow down or to stop when the cyclist is passing the ego vehicle, although the initial objective of the ego vehicle is to continue driving. Although the situation is not further specified, this situation often happen at small streets where space is even more limited by, for example, parked vehicles as shown in Figure 77a.

4.58.2 Formal description

Static environment No further details are specified for the static environment.

Ego vehicle The initial objective of the ego vehicle is to continue driving.

Dynamic environment The dynamic environment consists of a cyclist that is driving in the opposite direction of the ego vehicle in the same lane. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 77b shows the tags that are assigned to this scenario category.

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4.58.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 77a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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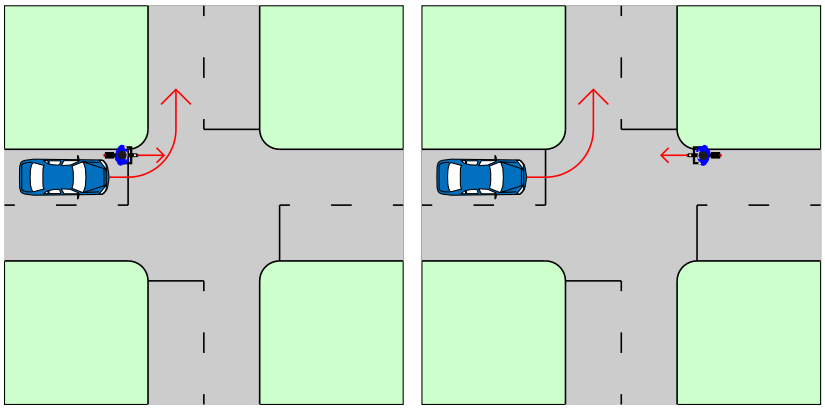
4.59 SC58: Cyclist at left turn at non-signalized junction



(a) Schematic representation of SC58: Cyclist at left turn at non-signalized junction.

1. Ego
   - Vehicle lateral activity → Turning → Left
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → VRU → Cyclist
   - Initial state → Lateral position → Left of ego
   - Cyclist lateral activity → Going straight
   - Cyclist longitudinal activity → Riding forward
3. Road layout → Junction → No traffic light

(b) Tags of SC58: Cyclist at left turn at non-signalized junction.

Figure 78: Schematic representation and tags of SC58: Cyclist at left turn at non-signalized junction.

4.59.1 General description

The scenario is schematically shown in Figure 78a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. The junction is not equipped with traffic light signals. A cyclist is riding on the left side of the ego vehicle. The riding direction of the cyclist is not specified. Therefore, the cyclist might ride towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the cyclist is initially on the left side of the ego vehicle while the ego vehicle intends to turn left, it might be possible that the trajectories of the cyclist and the ego vehicle intersect.

4.59.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

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Dynamic environment The dynamic environment consists of a cyclist. The cyclist is initially left of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 78b shows the tags that are assigned to this scenario category.

4.59.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 78a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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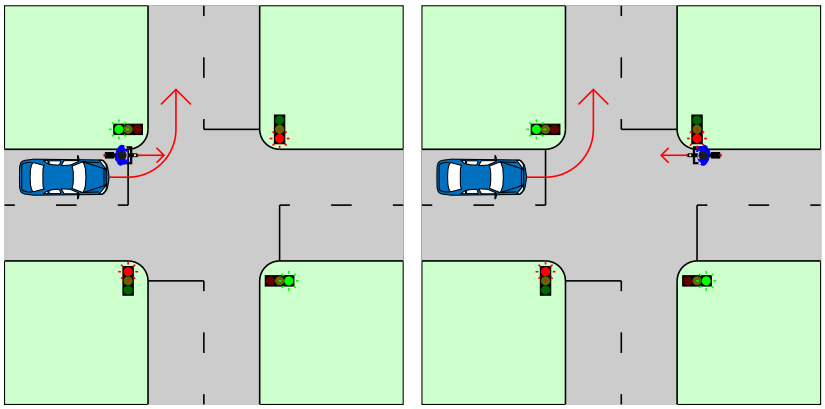
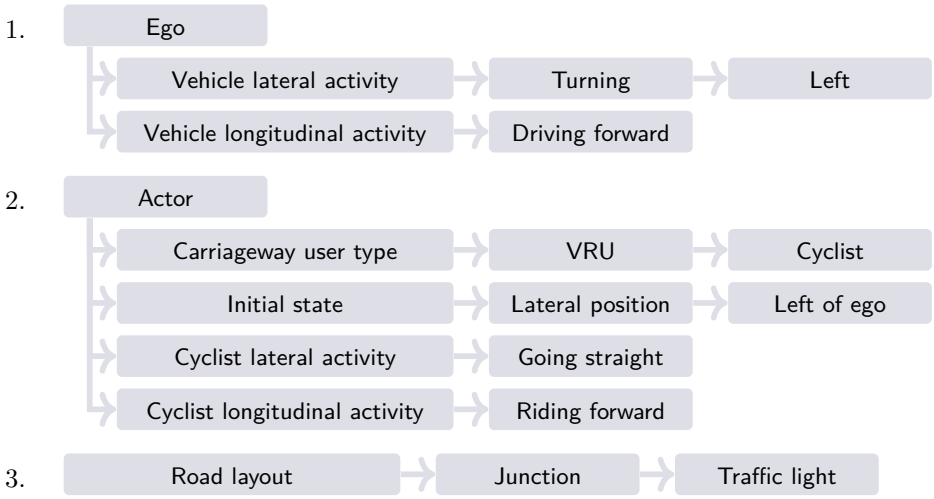
4.60 SC59: Cyclist at left turn at signalized junction



(a) Schematic representation of SC59: Cyclist at left turn at signalized junction.



(b) Tags of SC59: Cyclist at left turn at signalized junction.

Figure 79: Schematic representation and tags of SC59: Cyclist at left turn at signalized junction.

4.60.1 General description

The scenario is schematically shown in Figure 79a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. The junction is equipped with traffic light signals. A cyclist is riding on the left side of the ego vehicle. The riding direction of the cyclist is not specified. Therefore, the cyclist might ride towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the cyclist is initially on the left side of the ego vehicle while the ego vehicle intends to turn left, it might be possible that the trajectories of the cyclist and the ego vehicle intersect.

4.60.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

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Dynamic environment The dynamic environment consists of a cyclist. The cyclist is initially left of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 79b shows the tags that are assigned to this scenario category.

4.60.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 79a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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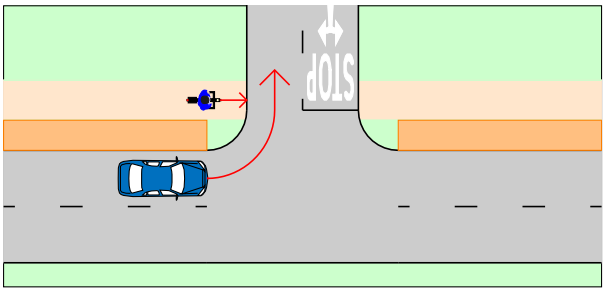
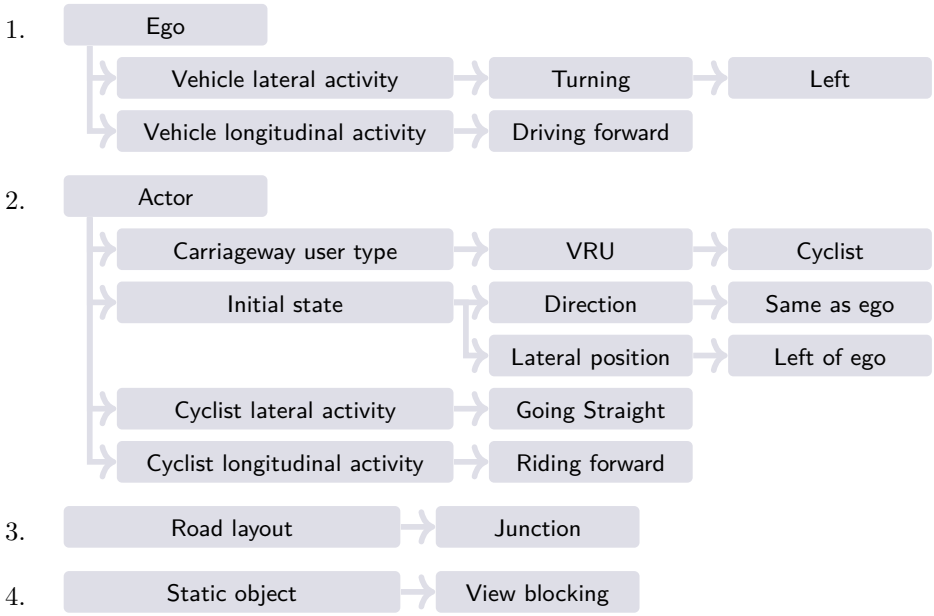
4.61 SC60: Cyclist driving in same direction obstructed at ego left turn



(a) Schematic representation of SC60: Cyclist driving in same direction obstructed at ego left turn.



(b) Tags of SC60: Cyclist driving in same direction obstructed at ego left turn.

Figure 80: Schematic representation and tags of SC60: Cyclist driving in same direction obstructed at ego left turn.

4.61.1 General description

The scenario is schematically shown in Figure 80a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn left. It is not specified whether the junction is equipped with traffic light signals. A cyclist is approaching the junction from the same direction on the left side of the road (from the perspective of the ego vehicle). The cyclist goes straight at the junction such that the trajectories of the ego vehicle and the cyclist intersect. The view from the ego vehicle to the cyclist is obstructed, e.g., by bushes or a hedge. Note that scenarios that belong to this scenario classes also belong to either scenario class 59 or scenario class 60.

4.61.2 Formal description

Static environment The static environment consists of a junction. The junction is possibly equipped with traffic light signals. Budges or hedges in between the sidewalk and the

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main road are present that obstruct the view of the cyclist from the perspective of the ego vehicle.

Ego vehicle The objective of the ego vehicle is to turn left at the junction.

Dynamic environment The dynamic environment consists of a cyclist that crosses the junction. The cyclist is initially on the left side of the ego vehicle and on the same side of the junction. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component. In case the junction is equipped with traffic lights, the status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 80b shows the tags that are assigned to this scenario category.

4.61.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 80a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, in case the junction is equipped with traffic lights, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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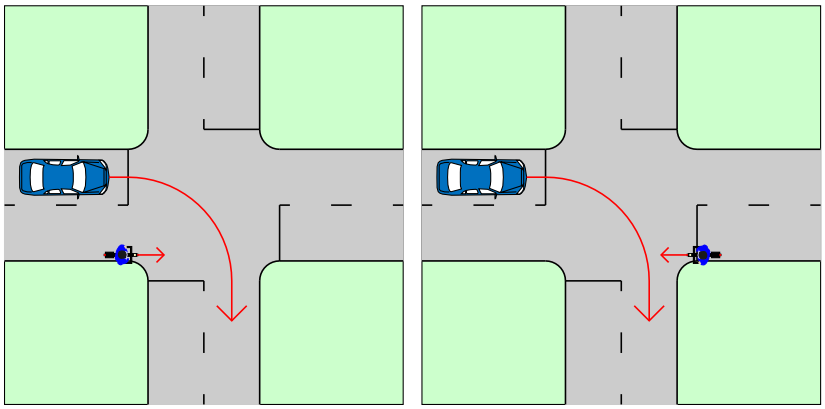
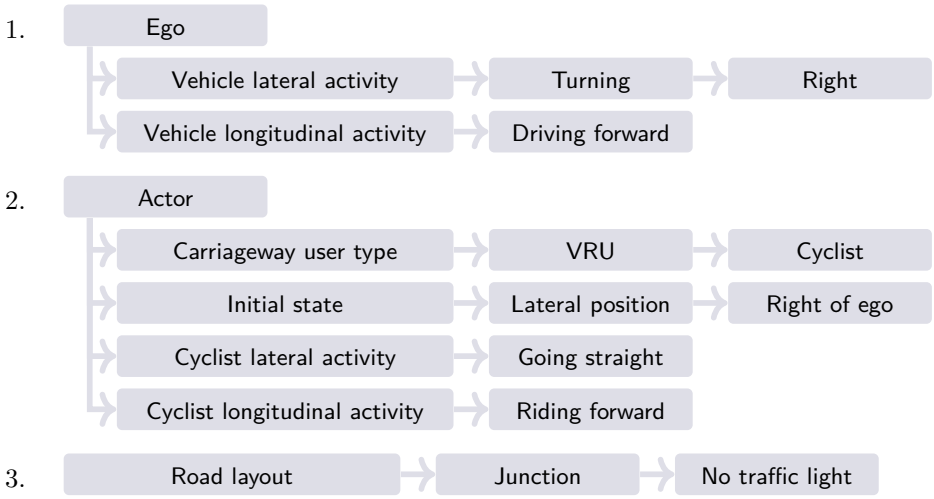
4.62 SC61: Cyclist at right turn at non-signalized junction



(a) Schematic representation of SC61: Cyclist at right turn at non-signalized junction.



(b) Tags of SC61: Cyclist at right turn at non-signalized junction.

Figure 81: Schematic representation and tags of SC61: Cyclist at right turn at non-signalized junction.

4.62.1 General description

The scenario is schematically shown in Figure 81a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn right. The junction is not equipped with traffic light signals. A cyclist is riding on the right side of the ego vehicle. The riding direction of the cyclist is not specified. Therefore, the cyclist might ride towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the cyclist is initially on the right side of the ego vehicle while the ego vehicle intends to turn right, it might be possible that the trajectories of the cyclist and the ego vehicle intersect.

4.62.2 Formal description

Static environment The static environment consists of a junction. The junction is not equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn right at the junction.

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Dynamic environment The dynamic environment consists of a cyclist. The cyclist is initially on the right of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 81b shows the tags that are assigned to this scenario category.

4.62.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 81a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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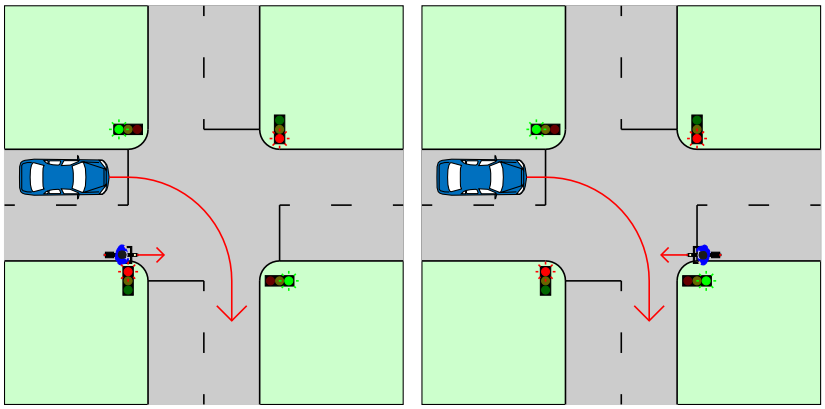
4.63 SC62: Cyclist at right turn at signalized junction



(a) Schematic representation of SC62: Cyclist at right turn at signalized junction.

1. Ego
   - Vehicle lateral activity → Turning → Right
   - Vehicle longitudinal activity → Driving forward
2. Actor
   - Carriageway user type → VRU → Cyclist
   - Initial state → Lateral position → Right of ego
   - Cyclist lateral activity → Going straight
   - Cyclist longitudinal activity → Riding forward
3. Road layout → Junction → Traffic light

(b) Tags of SC62: Cyclist at right turn at signalized junction.

Figure 82: Schematic representation and tags of SC62: Cyclist at right turn at signalized junction.

4.63.1 General description

The scenario is schematically shown in Figure 82a. The ego vehicle is approaching a junction at which the ego vehicle intends to turn right. The junction is equipped with traffic light signals. A cyclist is riding on the right side of the ego vehicle. The riding direction of the cyclist is not specified. Therefore, the cyclist might ride towards the ego vehicle, in the same direction, or perpendicular to the ego vehicle, etc. Because the cyclist is initially on the right side of the ego vehicle while the ego vehicle intends to turn right, it might be possible that the trajectories of the cyclist and the ego vehicle intersect.

4.63.2 Formal description

Static environment The static environment consists of a junction. The junction is equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to turn right at the junction.

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Dynamic environment The dynamic environment consists of a cyclist. The cyclist is initially on the right of the ego vehicle. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component. The status of the traffic light signals is described by a parametrized function $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

Tags Figure 82b shows the tags that are assigned to this scenario category.

4.63.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 82a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameters:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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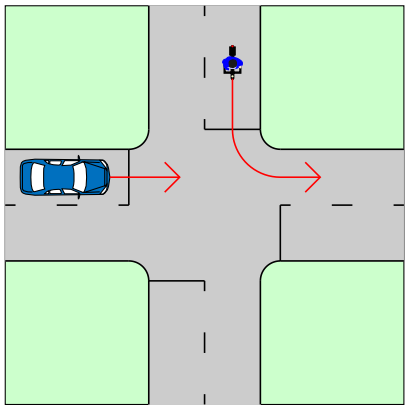
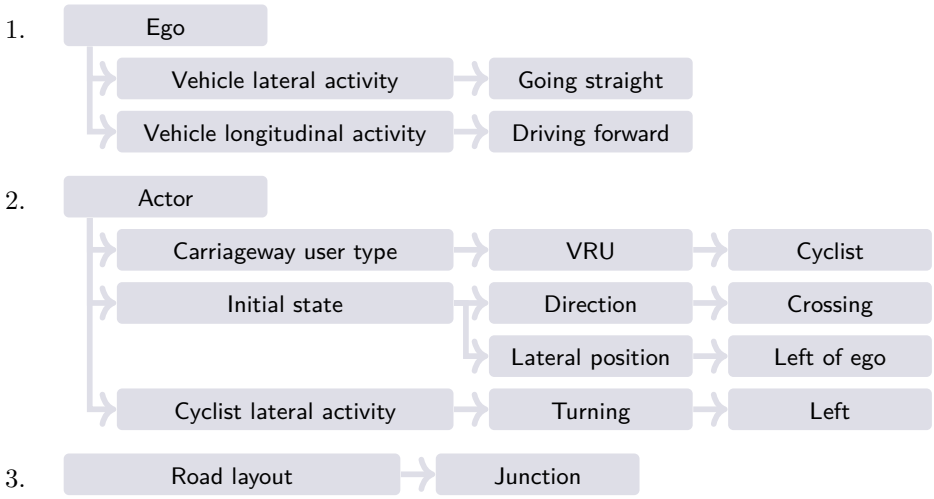
4.64 SC66: Cyclist turning left and ends up in lane of ego vehicle



(a) Schematic representation of SC66: Cyclist turning left and ends up in lane of ego vehicle.



(b) Tags of SC66: Cyclist turning left and ends up in lane of ego vehicle.

Figure 83: Schematic representation and tags of SC66: Cyclist turning left and ends up in lane of ego vehicle.

4.64.1 General description

The scenario is schematically shown in Figure 83a. The ego vehicle and a cyclist approach a non-signalized junction. The cyclist is coming from the left side of the ego vehicle. The ego vehicle intends to go straight while the cyclist turns left at the junction, such that the ego vehicle and the cyclist end up in the same lane.

4.64.2 Formal description

Static environment The static environment consists of a junction. The junction is possibly equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight.

Dynamic environment The dynamic environment consists of a cyclist that turns left at the junction. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$,

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where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 83b shows the tags that are assigned to this scenario category.

4.64.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 83a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, in case the junction is equipped with traffic lights, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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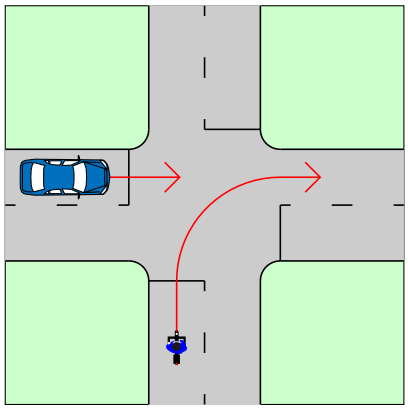
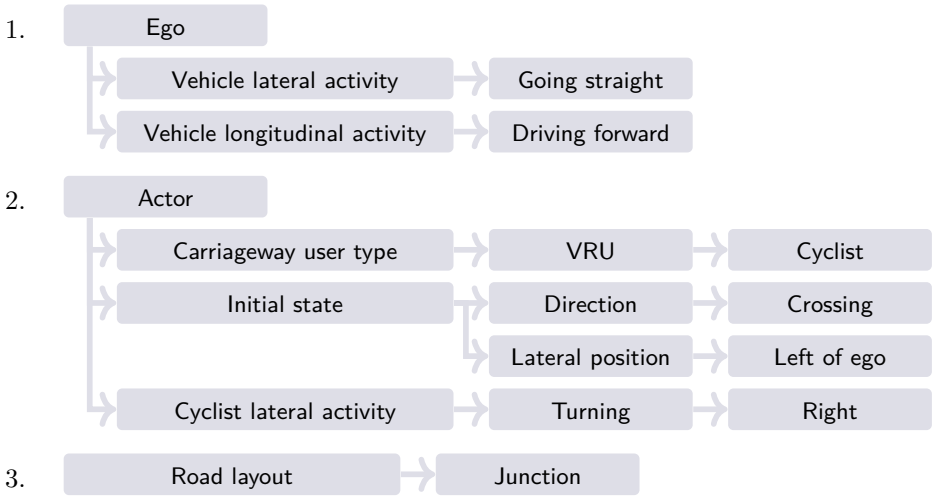
4.65 SC67: Cyclist turning right and ends up in lane of ego vehicle



(a) Schematic representation of SC67: Cyclist turning right and ends up in lane of ego vehicle.



(b) Tags of SC67: Cyclist turning right and ends up in lane of ego vehicle.

Figure 84: Schematic representation and tags of SC67: Cyclist turning right and ends up in lane of ego vehicle.

4.65.1 General description

The scenario is schematically shown in Figure 84a. The ego vehicle and a cyclist approach a non-signalized junction. The cyclist is coming from the right side of the ego vehicle. The ego vehicle intends to go straight while the cyclist turns right at the junction, such that the ego vehicle and the cyclist end up in the same lane.

4.65.2 Formal description

Static environment The static environment consists of a junction. The junction is possibly equipped with traffic light signals.

Ego vehicle The objective of the ego vehicle is to go straight.

Dynamic environment The dynamic environment consists of a cyclist that turns right at the junction. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$,

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where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 84b shows the tags that are assigned to this scenario category.

4.65.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 84a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.
- The status of the traffic light signals, in case the junction is equipped with traffic lights, which is a parametrized function over time, denoted by $s_{\text{TL}}(t, \theta_{\text{TL}})$, where t denotes the time and θ_{TL} denotes the parameter vector.

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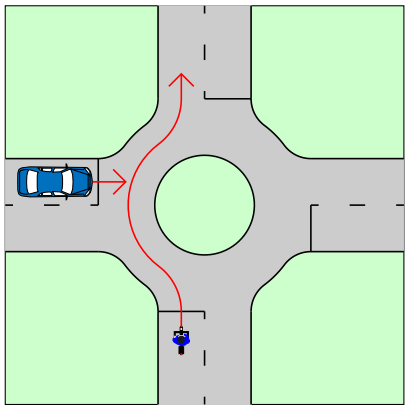
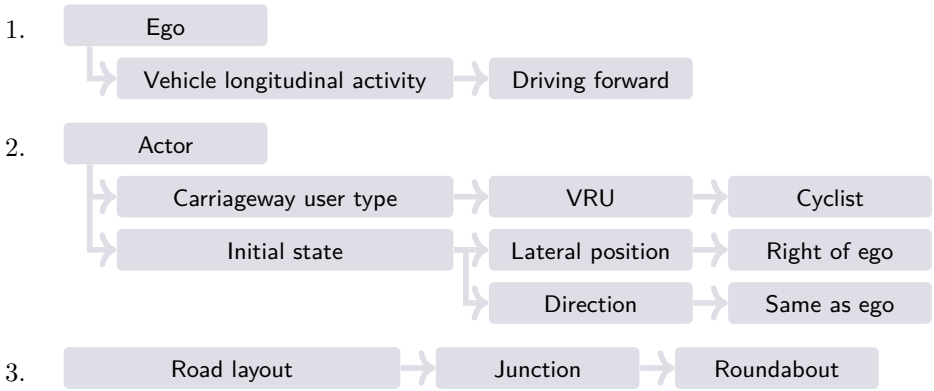
4.66 SC63: Entering a roundabout with a cyclist



(a) Schematic representation of SC63: Entering a roundabout with a cyclist.



(b) Tags of SC63: Entering a roundabout with a cyclist.

Figure 85: Schematic representation and tags of SC63: Entering a roundabout with a cyclist.

4.66.1 General description

The scenario is schematically shown in Figure 85a. The ego vehicle is approaching a roundabout. There is a cyclist on the roundabout or a cyclist is approaching the roundabout from another direction. In any case, because the junction is a roundabout, the other vehicle approaches the ego vehicle from the right. It might be the case that the ego vehicle needs to give priority to the other vehicle. Figure 57a shows a roundabout with a single lane. However, this scenario category also includes roundabouts with multiple lanes.

4.66.2 Formal description

Static environment The static environment consists of a roundabout with one or multiple lanes. The roundabout is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to turn left, go straight or turn right on the roundabout.

Dynamic environment The dynamic environment consists of a cyclist that also approaches the roundabout or that is already at the roundabout. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

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Tags Figure 85b shows the tags that are assigned to this scenario category.

4.66.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 85a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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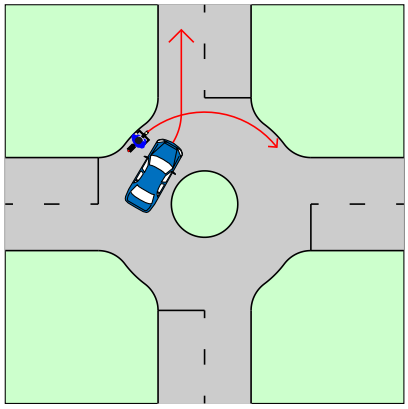
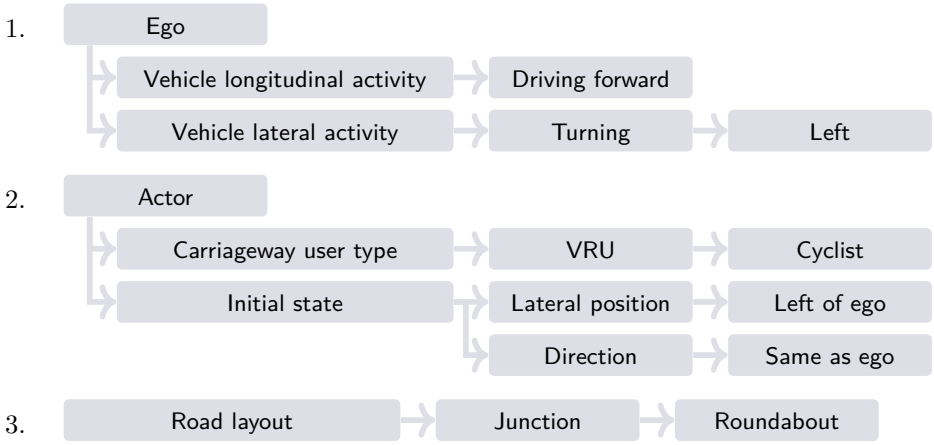
4.67 SC64: Leaving a roundabout with a cyclist



(a) Schematic representation of SC64: Leaving a roundabout with a cyclist.



(b) Tags of SC64: Leaving a roundabout with a cyclist.

Figure 86: Schematic representation and tags of SC64: Leaving a roundabout with a cyclist.

4.67.1 General description

The scenario is schematically shown in Figure 86a. The ego vehicle is leaving a roundabout. There is a cyclist on the roundabout. In case the cyclist does not leave the roundabout at the same exit as the ego vehicle does, it might be that the ego vehicle needs to give priority to the cyclist.

4.67.2 Formal description

Static environment The static environment consists of a roundabout with one or multiple lanes. The roundabout is not equipped with traffic lights.

Ego vehicle The objective of the ego vehicle is to exit the roundabout.

Dynamic environment The dynamic environment consists of a cyclist that rides at the roundabout. The position of the cyclist is described by a parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector. Note that $x_{\text{cyc}}(\cdot)$ has an easting and a northing component.

Tags Figure 86b shows the tags that are assigned to this scenario category.

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4.67.3 Parameters

The scenarios that belong to the scenario category depicted in Figure 86a are described by at least the parameters mentioned at the beginning of this section on page 19 and the following parameter:

- The position of the cyclist, denoted by the parametrized function $x_{\text{cyc}}(t, \theta_{\text{cyc}})$, where t denotes the time and θ_{cyc} denotes the parameter vector.

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5 Conclusion

This document describes 67 scenario categories that are considered to be relevant for the generation of test cases in the safety assessment of automated vehicles. A system of tags has been proposed to differentiate the different scenario categories. Tags are used to make a selection of scenarios (a scenario category) from the large collection of scenarios that describe what an AV can encounter when driving on the public road. In addition to TNO's expertize in categorization of scenarios for testing of vehicles, literature of accident causes and scenarios of accidents in different countries has been used to determine which scenarios are relevant for automated vehicles. For each of the 67 scenario categories, the set of appropriate tags has been provided, together with a sketch of the scenario category.

We aimed to provide an exhaustive list of tags and scenario categories. However, depending on the application, the list of tags might not be exhaustive enough. Similarly, it is very likely that, for some applications, (more specific) scenario categories are missing in this report. Hence, this report is likely to change in due time, which is why this report has a version number. In subsequent versions of this report, more tags and more scenario categories might be added.

The next step towards the generation of test cases for the assessment of AVs is aimed at the quantification of parameters that describe the different scenarios. Each scenario that is captured by a data collection vehicle can be characterized by quantifying the scenario parameters. Where tagging of the scenario provides a qualitative scenario description, quantification of the characteristic scenario parameters is needed to determine the parameter distributions given a large number of scenarios that are encountered on the road. An example of such a characteristic parameter is the maximum lateral speed of the vehicle during a cut-in scenario. This maximum lateral speed gives an indication of the aggressiveness with which the cut-in on the road is performed. Although this parameter on its own does not provide sufficient information to indicate whether a scenario was safety critical or not, in combination with the longitudinal distance at which the aggressive cut-in was performed, such an assessment of safety criticality of the scenario becomes feasible. It is the objective to drive many kilometres through areas in which AVs will be deployed and to quantify the parameters for each of the encountered scenarios to provide probability density functions for the different parameters. The scenario categories in combination with these parameter distributions describe the real world that the AV needs to be capable to drive through in an appropriate and safe way.

In a subsequent step, test cases are generated by selecting those scenarios and those parameter values from the collection of quantified scenarios, that are relevant for the AV and that can be used to assess the key performance indicators for the AV with respect to safety. Relevance in this case is strongly related to the AV's Operational Design Domain (ODD); only test cases that address the ODD (and the borders of the ODD) need to be selected.

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Acknowledgement

This report is based on a formal deliverable ("Scenario classes for the assessment of automated vehicle", Version 1.2, REP190123_56_Scenario_Classes) of CETRAN, the Centre of Excellence for Testing and Research of Autonomous Vehicles — Nanyang Technological University, Singapore, that is supported by the Land Transport Authority (LTA) of Singapore. We would like to thank the LTA for their support and their valuable feedback.

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