ROADVIEW

Robust Automated Driving in Extreme Weather

Project No. 101069576

Deliverable 2.2

Use Cases and Scenarios

WP2 – Physical System Setup, Use Cases, Requirements, and Standards

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Partner short names

HH	Hogskolan Halmstad
LUA	Lapin Ammattikorkeakoulu OY
THI	Technische Hochschule Ingolstadt
VTI	Statens Vag- och Transportforskningsinstitut
CE	Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement
RISE	RISE Research Institutes of Sweden AB
FGI	Maanmittauslaitos – Finnish Geospatial Research Institute
Repli5	Repli5
S4	Sensible 4 OY
KO	Konrad GmbH
FORD	Ford Otomotiv Sanayi Arnonim Sirketi
CRF	Canon Research Centre France
ZF	ZF Friedrichshafen AG
accelCH	accelopment Schweiz AG
WMG	The University of Warwick

Abbreviations

ADS	Automated Driving System
CAV	Connected and Automated Vehicle
D	Deliverable
DAS	Driving Automation System
DDT	Dynamic Driving Task
EC	European Commission
EU	European Union
HEU	Horizon Europe
M	Month
MS	Milestone
OD	Operational Domain
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
WP	Work Package
VRU	Vulnerable Road User

Executive summary

This deliverable is created as the outcome of Task 2.2 "Definition of Use Cases Specifications" in the ROADVIEW project. ROADVIEW aims to develop robust and cost-efficient in-vehicle perception and decision-making systems for connected and automated vehicles (CAV) with enhanced performance under harsh weather conditions. To do so, Task 2.2 defined use cases that aim to create a framework for the ROADVIEW developments. Defining use cases and ODD is the first milestone in a development project. Our vision while selecting the use cases for ROADVIEW was to define a set of the most common users' experiences. Our work resulted in five general use cases: driving straight, coming to a full stop, interacting with VRUs, entering and exiting a lane. These general use cases address a large volume of real-life situations when considering different weather and traffic conditions on different road types. We decided to follow this methodology to narrow the focus on weather and traffic conditions, which aligns with ROADVIEW's aim.

It should be noted that operational design domains defined in Task 2.1 "Definition and expansion of ODDs taxonomy" are complementary information to understand the whole picture. Test cases will be created by combining different operational conditions and use cases. ROADVIEW developments will then be tested in software-in-the-loop, hardware-in-the-loop, and system-in-the-loop. Validated developments will be demonstrated in real-life environments whose scope is defined in this document. This deliverable first describes the objectives, methodology, and implementation. It is followed by the introduction, where we provide additional information about the usage of the document, drivable area, weather, and traffic. After the introduction, use cases are given with their definitions. Challenges regarding each use case are explained in depth. A sample scenario derived from a use-case is also provided. A conclusion is provided at the end of the document to summarise and conclude the document.

This deliverable was revised in May 2024, to address the concerns regarding the ability of simple use cases to test complex decision-making capabilities. Five additional scenarios for complex decision making were added. Regarding the simulation pictures, it should be noted that the simulation environment used in creating the pictures was the default environment of the simulation tool. With the creation of digital twins, we expect improvements in the quality of the simulation to represent real-world situations.

Objectives

Technology providers must develop systems that are able to handle a diverse set of weather conditions to enable the widespread deployment of autonomous vehicles. ROADVIEW aims to address driving in challenging weather conditions by developing robust perception and decision-making systems that can operate on different road types and facilitate safer driving when interacting with other road users. This deliverable defines use cases and scenarios for such systems. It should be noted that although there are 5 use cases, the number of possible scenarios is limitless through adding additional complexity in the driving environment.

The main goal of this deliverable is to specify a set of use cases and scenarios that are representative of day-to-day driving with the ability to add further complexity such as unexpected behaviours of other road users. These use cases and scenarios will provide a means of benchmarking the performance of current state-of-the-art perception and control algorithms against the improved and more robust ROADVIEW system. ROADVIEW intends to focus on testing the performance of the perception and control algorithms in the following three areas:

1. Harsh weather (as defined in deliverable D2.1 Section 2.1 Environmental condition)
2. Road type and their related driving speed – highway, urban and rural
3. Interaction with vulnerable road users (VRUs) and other vehicles that use the same road.

Methodology and Implementation

Leveraging the diverse expertise in the team, we followed a bottom-up approach to collect a comprehensive set of use cases. We first defined a large set of use cases specific to each road type. We then discussed which use cases reflected the real-life driving the most. By carefully curating use cases from different road types, we concluded a comprehensive set of use cases that is applicable and agnostic to different road types.

There might be hundreds of use cases for a CAV. Focusing on this complexity can severely damage ROADVIEW's focus. Instead, we emphasise the variety of harsh weather conditions in different road types covering different traffic conditions. The final work resulted in a well-bounded set of use cases with varying scenario options. In the tables of each use case, we include weather conditions, road conditions and road types that shall be used to define various scenarios.

One of the strengths of our working group was the diversity in expertise. In particular, the expertise from each partner was leveraged to ensure the set of use cases and scenarios provided sufficient coverage and were relevant. For example, S4 contributed with their experiences on rural roads by drawing upon their development and driving experience on rural roads in Finland. Similarly, FORD contributed with their experiences on highway roads based on their prior extensive experience of testing on highways in Turkey. ZF contributed with their experiences on urban areas, based on their previous experience in automotive and current product development across Europe.

To create ROADVIEW use cases and scenarios, we drew inspiration from several sources including scenario databases [1] such as SafetyPool (https://www.safetypool.ai/) as well as reports and research papers [2]–[6]. We intentionally did not want to create or directly consume a large set of scenarios from these sources to ensure the ROADVIEW use case and scenario set remained focused on facilitating the performance testing of the ROADVIEW system in different harsh weather conditions on different road types and where there are interactions with VRUs. Additionally, typical key features of scenario databases are the volume, variety, and edge and corner cases contained within them. This makes them well-suited for training machine learning algorithms to address, for instance, specific edge and corner cases. In ROADVIEW, we will primarily be using scenarios to test the ROADVIEW system performance rather than training such algorithms. Therefore, to benchmark the improvements provided by the ROADVIEW system over the current state-of-the-art systems, more targeted scenarios had to be designed. A further consideration was also which scenarios could be practically tested within the target simulation environments, XiL environments, proving grounds/controlled testing environments (CE, THI) and demonstration areas.

The initial use cases and scenarios that were developed were deliberatively designed to be as simple as possible. The first use case developed was a vehicle autonomously driving straight within its own lane. From this simple use case, it was then possible to develop scenarios by adding further details and complexity by changing parameters particularly related to the three areas listed above. For example, a scenario can be generated, where there emerges a pedestrian unexpectantly walking into the road, harsh weather is introduced and the level of rain in the scene is systematically increased in each test case. Subsequent use cases were created which included more technical driving manoeuvres following the same principle that more complexity can be added to create a broad set of scenarios to test the performance of the overall ROADVIEW system.

Each use case is complemented by an Operational Design Domain Specification provided by Task 2.1 *"Definition and Expansion of ODDs taxonomy"*. This is required because each scenario can take place in different operational conditions not specified within this document. With combinations of different scenarios and different operational conditions, we can define real-life settings that are measurable.

The set of use cases and scenarios developed in this deliverable will be further expanded upon in Task 7.1 to form an overall test plan where specific test cases will be created with further parameter details along with the intended test location/method.

Outcome

By the end of our study, we reached a set of use cases and a set of initial conditions for creating a scenario. By setting different initial conditions, we can reach a vast number of scenarios. ROADVIEW developments should work robustly in these defined use cases and scenarios.

1 Introduction

Autonomous driving technology has a great potential to transform our society. On the other hand, before adopting ADS on a large scale we need to ensure that autonomous vehicles can operate safely and effectively under harsh weather conditions and different traffic scenarios. ROADVIEW consortium was established to develop perception and decision-making solutions for this necessity.

The aim of ROADVIEW WP2 is to define a detailed physical system setup, including general use cases, requirements and standards. This document is the deliverable for the second task of WP2, that aims to define use case specifications to be considered in the following WPs.

As a combined working group for Task 2.1 and Task 2.2 consisting of members from RISE, HH, WMG, THI, CE, FGI, S4, FORD, ZF, we discussed upon definition and expansion of ODDs taxonomy and definition of use case specifications. The reason we worked together was the complementary nature of the two topics. ODD defines the operational boundaries and constraints for the ADS while use cases define the specific usage of the ADS. To define development requirements, ODD and use cases should be taken into account simultaneously. That is also the reason, there are many references to the D2.1 ”Definitions of the Complex Environmental Conditions” in this document.

In the first part of the introduction, the reader can find how to use this deliverable. The latter parts of the introduction explain the attributes of ODD that ROADVIEW focuses on. Introduction is critical to the reader, in the sense that it complements the use cases. By choosing different settings for these attributes of ODD, we create the scenarios for ROADVIEW developments should work.

1.1 Usage of the deliverable

Operational Design Domain (ODD) can be defined using a wide range of attributes[7]. Detailed information is given in D2.1. Generally, an operational design domain is defined by considering three main areas: scenery, environmental conditions and dynamic elements (See Fig. 1). There are different attributes that define each main area. For the sake of ROADVIEW's development ambitions we decided to focus our efforts into 3 attributes of the operational design domain:

1. Drivable Area
2. Weather
3. Traffic

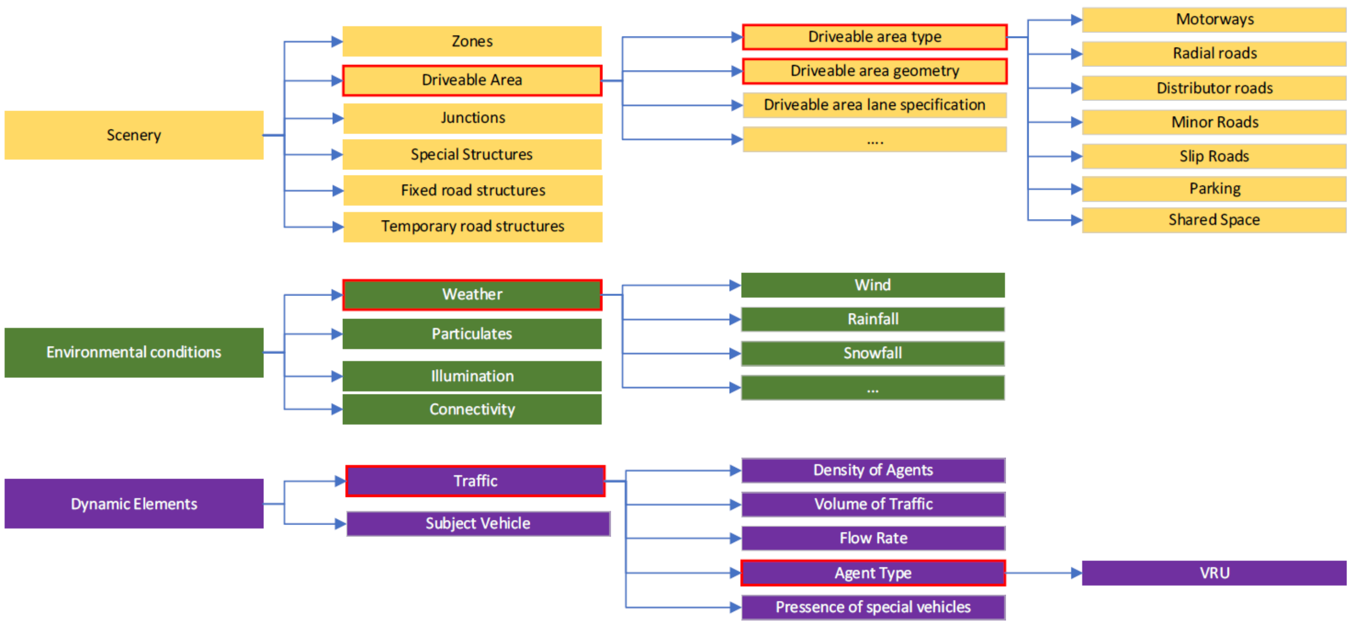

Figure 1 Target ODD Attributes from D2.1

Drivable area is a critical aspect of scenery, especially for our project, as harsh weather conditions affect different drivable area types in distinct ways. Highway, urban and rural roads are our focus road types which correspond to different drivable area types. ROADVIEW consortium consists of members with knowledge upon different road types which will later diverse the demonstrations and enhance the impact of the project.

Environmental conditions refer to a diverse set of attributes. ROADVIEW narrows down its focus on weather conditions. Effects of each weather condition can vary upon the road type and use case. Challenging harsh weather conditions for each use case are given in the use case tables.

Dynamic elements refer to the traffic and the subject vehicle. Use case definitions are based on the condition of the subject vehicle which we call ”ego *vehicle“* throughout this document. The variable of dynamic elements are the agents. Traffic includes motorised vehicles as well as VRUs. ROADVIEW aims to put an emphasis on VRUs by pointing out interactions between ego vehicle and VRUs that can threaten safety under harsh weather conditions.

To understand the use cases, a figure, a table and a verbal explanation is provided for each use case. Each figure represents an example of the respective use case for the urban road type. The use case can occur differently in different road types. The table summarises the initial conditions for the use cases. They include the possible attribute sets and any combination of the initial conditions might be present while the system is operational.

1.2 Drivable Area

Drivable area refers to the physical space which vehicles use to operate. To put it in other words, drivable area definition of a vehicle sets the boundaries for its safe and effective usage. Drivable area is defined by a combination of factors, including area type, geometry and lane specification. The ROADVIEW project focuses on the area type and geometry.

Drivable area types included in the ROADVIEW project can be categorised as motorways (highway road) and distributor roads (urban road) and local roads (rural road). For the sake of clarity we will use the terms highway road, urban road and local road. Demonstrations will take place in the road types: highway road, urban road and local roads. Understanding conditions for each road type is critical as there are different challenges for each. Drivable area geometry type depends mostly on the road type which is explained further in D2.1. For all of the use cases and scenarios roads have a right hand traffic flow.

1.2.1 Highway Road

Highways are unidirectional lane-divided roads, designed to ease traffic and create optimal flow of vehicles (See Fig. 2). They are closed to pedestrians and non-motorised vehicles, thus, interactions with VRUs is limited. Upper speed limits are generally high for highways and there are usually lower speed limits as well. These regulations are to ensure the optimal flow of vehicles. Perception systems needs to detect other vehicles from a long range of distance due to the high speeds. Decision-making systems need to detect road conditions such as slipperiness with high accuracy. ROADVIEW will develop perception and decision-making systems robust to harsh weather conditions and diverse traffic conditions in highway roads.

Figure 2 Simulation of Highway Road with Sunny Weather

1.2.2 Urban Road

Urban areas are highly populated, frequently used residence areas (See Fig.3). Speed limits are lower than that of highways. Pedestrians are allowed to enter the road through the crosswalks, and the cyclists use the road in either the outermost lane or their dedicated lane. Hence, interactions with VRUs create a major challenge. Traffic control is the other major challenge. There might be areas with different speed limits or where usage of a lane is dedicated for specific vehicles. All in all, perception systems should detect traffic lights, traffic signs and VRUs under any weather condition. Decision-making systems should take their decisions according to reducing the risk of contact with VRUs and compliance with the traffic control. Efforts of ROADVIEW will be put in creating robust perception and decision-making systems to fulfill these particular requirements.

Figure 3 Simulation of Urban Road with Sunny Weather

1.2.3 Rural Road

Rural areas host less people than urban areas (See Fig. 4). As a result, rural roads are usually narrower (e.g., single wide shared lane, or two narrow lanes, one in each direction) and can be made of more variety of materials than just asphalt. There are more curves on the roads and road conditions may not be so frequently maintained, with holes or missing visible lanes. Pedestrians can enter any road without crosswalks and there may be other VRUs like cyclists or animals. Perception systems should detect road conditions, VRUs, vehicles coming from the opposite lane under any weather condition. Decision-making systems should take decisions according to the road conditions. These systems should be able to mitigate the risk of contacting with VRUs, vehicles from the opposite and the ego lane.

Figure 4 Simulation of Rural Road with Sunny Weather

1.3 Weather

Weather is an important part of use case definition for ADS, as it can have a significant impact on the performance of the various sensors. Effects of weather conditions are different for each sensor type. While heavy rain reduce visibility for cameras, direct sunlight manipulates LiDARs to collect low accuracy point clouds. Another factor to consider is the effect of harsh weather conditions on road conditions. Autonomous vehicles without a road condition detection and weather aware decision-making systems can fail to account for slipperiness of the road or impact of wind on vehicles momentum.

Harsh weather conditions effect the road conditions and the performance of sensors. To ensure safety, autonomous vehicles should account for harsh weather conditions. ROADVIEW partners will take the weather scenarios listed for each use case as the guide for development requirements.

Figure 5 Simulation of Highway Road with Rain

Figure 6 Simulation of Highway Road with Fog

In higher speeds, the ADS should be able to perceive dynamic elements from further distances due to the greater braking distance. Noise factors such as fog and rain can damage the perception systems performance. One other factor for braking distance is the road conditions. Slippery roads due to rain or snow have larger braking distances. Highway roads are the most vulnerable to these conditions as the average speeds are higher than the other road types. In Figures 5 and 6 you can find how different weather conditions look for the same use case in highway environment. These figures are important to understand how a single use case can be transformed into various scenarios.

Figure 7 Simulation of Urban Road with Rain

Figure 8 Simulation of Urban Road with Fog

Challenges of harsh weather conditions does not only affect highway roads. With the affected perception systems, interactions with pedestrians and cyclists present a critical threat to ADSs on the rural and urban environments. Reduced visibility due to rain, fog or snow should be tackled by the system to ensure safety of the VRUs. In Figures 7 and 8 you can find how rainy and foggy weather look for the same use case in an urban environment. Rural roads also involve interactions with wild or domesticated animals. This unpredictable dynamic element can threat the decision-making system as well. In Figures 9 and 10 you can find how rainy and foggy weather look for the same use case in rural environment.

Figure 9 Simulation of Rural Road with Rain

Figure 10 Simulation of Rural Road with Fog

Snow is one of the most challenging harsh weather conditions. Other from its effect on sensors, it can introduce further complexities to the perception systems. For instance, when a road is covered by snow the lane detection becomes impossible. ADS should handle localisation and lateral motion control without needing the lane marks. While road maintenance generally removes the snow from the road, there are still times when the road is covered by snow. This challenge is very plausible for rural roads as they are often less maintained than urban or highway roads and snow can stay on the roads for a long time. In Figures 11 and 12 you can find how snow on the road look for the same use case in rural environment.

Figure 11 Simulation of Rural Road with Snow (Moderate)

Figure 12 Simulation of Rural Road with Snow (High)

Braking distance is also affected by the snow. As it was mentioned above, highway roads are vulnerable to slipperiness. In Figures 13 and figure 14 you can find the simulation of highway roads covered in snow. The figures include pictures of day and night to show how cameras can be affected by lighting conditions mentioned in D2.1.

Figure 13 Simulation of Highway Road with Snow (Day)

Figure 14 Simulation of Highway Road with Snow (Night)

Effects of snowfall is different from the snow on the roads. Snowflakes can interfere with the laser beams of LiDAR, resulting in misinterpreted data. While radar is not heavily affected by snow, heavy snowfall might impact its performance by causing unintended reflections. Cameras on the other hand will be heavily affected by the reduced visibility. In figures 15 and 16 you can find the simulation of snowfall in different densities on rural roads.

Figure 15 Simulation of Rural Road with Snowfall (High)

Figure 16 Simulation of Rural Road with Snowfall (Low)

1.4 Traffic

Dynamic elements of an ODD consist of the ego vehicle and the traffic. For Task 2.2, we considered the condition of the ego vehicle as the reference point. This approach is meaningful as ADS perceives the situation in the same manner. ROADVIEW aims to focus on different traffic scenarios and create innovations that can handle variations in the traffic density. Road type is one of the main differentiators for traffic conditions. We see significantly different traffic conditions regarding the flow rate, volume of traffic and density of agents in different road types. To serve the projects purposes, we will focus on traffic agents.

Traffic consists of agents. Agents are entities in traffic that make decisions or take actions that can affect the movement of road users. Drivers, pedestrians, cyclists are human agents of traffic while we can consider autonomous vehicles as the non-human agents. For the projects purposes we focus on Vulnerable Road Users (VRU). VRUs refer to road users that have little to no protection in case of an accident. VRUs include pedestrians, cyclists, and mobility device users. Safety of VRU interactions is a bigger concern for autonomous vehicles. When a VRU is present the ADS should perceive the VRU and minimize the risk of contact in any situation. This can be challenging in harsh weather conditions due to reduced visibility and poor road conditions. Use case 3 is specific to interactions with VRUs and other use cases address the possibility of VRU encounters as a corner case.

Density of agents is a density measure of traffic and it is an important part of every scenario definition. Cameras, LiDAR and radars depend on reflection of on some sort of light beam. This makes them vulnerable to vision blockage. Other vehicles on the road might block the vision of sensors and limit the perception range needed to detect VRUs. In initial scenario conditions you will find density of motor vehicles, which also refers to traffic density. Regarding different traffic densities there exists challenges for each use case. Developments of ROADVIEW shall give consideration to listed traffic densities for each use case and account for its impact under harsh weather conditions.

2 ROADVIEW Use Cases and Scenarios

2.1 Use Cases

To define each use case, we used a modular approach. In the general description, basic conditions of the ego vehicle and relevant attributes are given. Trigger conditions specify the circumstances that necessitate the expected behaviour from the vehicle. Expected behaviour is the goal of the autonomous vehicle in the described use case.

When we look at the initial scenario conditions table, we see the elements of a scenario that is applicable to the use case. If a condition is specified as “Include”, it means that the autonomous vehicle should perform the expected behaviour under any setting of that condition. For example, if the “lead vehicle in ego lane” is specified as include, the autonomous vehicle should perform the expected behaviour in the presence or absence of the lead vehicle in ego lane.

If a condition is specified as “Conditional”, there exists further explanation in parentheses. The autonomous vehicle should perform the expected behaviour only under the settings specified in the parentheses. If a condition is specified as exclude, the autonomous vehicle should not perform the expected behaviour under that condition.

General setting includes further explanation to the use case. It is intended to further inform the reader about the use case. In challenges, there are conditions that might severely affect the autonomous vehicle. These challenges are the corner cases, that can test the limits of the perception and decision-making systems.

2.1.1 Driving Straight

General Description

The ego vehicle travels on the ego lane.

Trigger Conditions

Ego vehicle determines the appropriate lane and travels within the lane’s boundaries. There might be a vehicle in the ego lane in front of the ego vehicle.

Expected Behaviour

Ego vehicle follows an ego lane with a target speed. If a leading vehicle is present, slower or faster than the autonomous car, then the speed is adjusted. There might be interruptions due to the presence of a VRU, such as a pedestrian passing on urban roads or an animal crossing on rural roads. In such conditions the ego vehicle is expected to perceive the event and mitigate the risk by decreasing the speed or coming to a full stop if necessary.

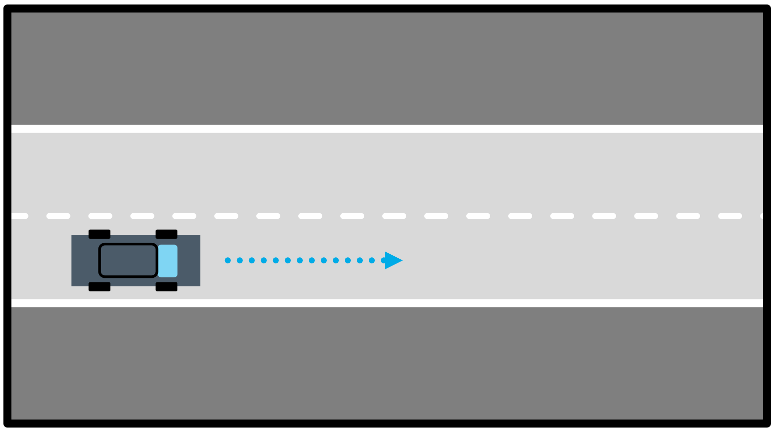

Figure 17 Example of Driving Straight

Table 1 Set of Initial Scenario Conditions for Use Case 1

Initial Scenario Conditions	
Ego vehicle position with respect to road	Conditional (Any lane but leftmost)
Lead vehicle in ego lane	Include
Left Lane Free	Include
VRU/Unknown	Conditional (Road interruptions might occur)
Right Lane Free	Include
Road geometry	Conditional (As specified in D2.1)
Road type	Conditional (Highway, Urban, Rural)
Drivable Area	Conditional (as specified in D2.1 with specific attention to Icy, Wet, Dry, Covered in Snow)
Weather	Conditional (as specified in D2.1 with specific attention to Heavy Rain, Heavy Snow, Dense Continental Fog)
Density of Dynamic Elements (Traffic Density)	Conditional (Low, Moderate, High)
Connectivity	Include

General Setting

This use case focuses on the ADS's ability to navigate safely in a straight roadway. The vehicle must maintain a safe speed and distance from other road users. The definition of safe speed can be interpreted differently in different drivable areas. Vehicles must accurately perceive and diagnose the road conditions such as slipperiness, drivable area, location, and speed of other road users.

Challenges (Corner Cases)

Harsh weather conditions, such as heavy rain, snow, or ice, can significantly impact driving straight. When snow accumulates on the sensors, it can significantly reduce the performance of the sensors. In such cases, assessment of sensor performance is critical. These conditions can reduce visibility, making it harder for the ADS to detect other road users.

In addition, harsh weather conditions can cause unpredictable road conditions, such as slick or slippery roads, making it more challenging to maintain a safe speed and distance from other vehicles. This can increase the risk of accidents, mainly if the autonomous driving system cannot accurately detect and respond to sudden environmental changes, such as sudden stops or lane changes by other vehicles. This is especially risky under moderate traffic density as overtakings are more common. On the other hand, high traffic densities generally involve many stop-and-go's which creates the risk of VRU's crossing the road unexpectedly.

2.1.2 Coming to A Full Stop

General Description

The ego vehicle approaches an obstacle (e.g., a bus) and stops in the ego lane.

Trigger Conditions

An obstacle in the ego lane is detected.

Expected Behaviour

The ego vehicle decelerates and comes to a full stop. As soon the ego lane is available again, the ego vehicle accelerates to resume the target speed.

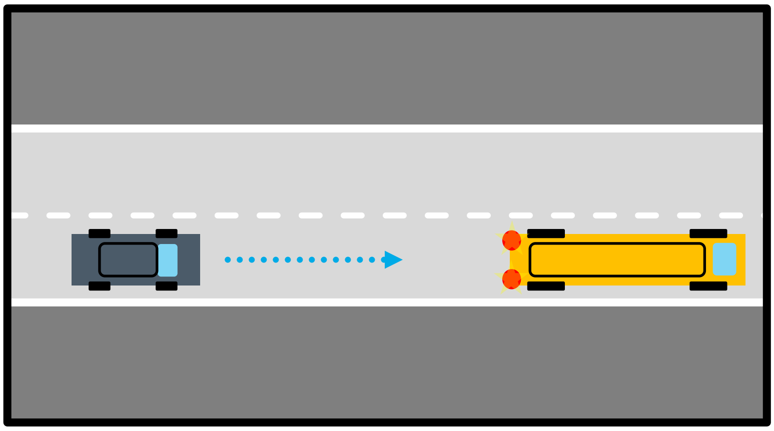

Figure 18 Example of Coming to a Full Stop

General Setting

A typical example could be a bus at a bus stop. In such a scenario, the view of the road ahead is blocked. In this case, the car must decelerate according to the circumstances and also stop if necessary. Another example trigger condition for this use case might be a VRU, which suddenly tries to cross the road.

Challenges (Corner Cases)

In difficult weather conditions, recognizing an object on the road and coming to a full stop is non-trivial. In difficult weather conditions, it can be difficult to detect (more minor) obstacles and vulnerable road users due to reduced visibility.

Another aspect is the road conditions. Slipperiness can significantly increase the required braking distance especially when the speeds are high due to low traffic density. An autonomous vehicle should be able to perceive the vehicle in the front, from the required braking distance. Only then, it can react to a sudden stop. This creates a challenge for both decision making and the perception system.

Table 2 Set of Initial Scenario Conditions for Use Case 2

Initial Scenario Conditions	
Ego vehicle position with respect to road	Conditional (Rightmost)
Lead vehicle in ego lane	Include
Left Lane Free	Include
VRU/Unknown	Include

Right Lane Free	Include
Road geometry	Conditional (As specified in D2.1)
Road type	Highway, Urban, Rural
Target Drivable Area	Conditional (as specified in D2.1 with specific attention to Icy, Wet, Dry)
Weather	Conditional (as specified in D2.1 with specific attention to Heavy Rain, Heavy Snow, Dense Continental Fog)
Density of Dynamic Elements (Traffic Density)	Conditional (Low, Moderate)
Connectivity	Include

2.1.3 Interacting With VRU

General Description

The ego vehicle approaches VRU.

Trigger Conditions

VRU is detected.

Expected Behaviour

The ego vehicle decelerates and comes to a full stop. When ego lane is free, the ego vehicle accelerates to the target speed.

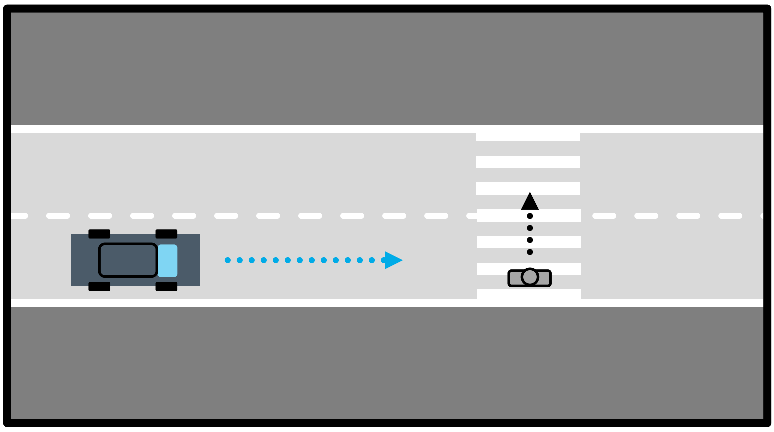

Figure 19 Example of Interacting With VRU

Table 3 Set of Initial Scenario Conditions for Use Case 3

Initial Scenario Conditions	
Ego vehicle position with respect to road	Conditional (Rightmost)
Lead vehicle in ego lane	Include
Left Lane Free	Include
VRU/Unknown	Include
Right Lane Free	Include
Road geometry	Conditional (As specified in D2.1)
Road type	Conditional (Urban, Rural)
Target Drivable Area	Conditional (as specified in D2.1 with specific attention to Icy, Wet, Dry)
Weather	Conditional (as specified in D2.1 with specific attention to Heavy Rain, Heavy Snow, Dense Continental Fog)
Density of Dynamic Elements (Traffic Density)	Conditional (Low, Moderate, High)
Connectivity	Include

General Setting

A crosswalk is typical of this use case. Pedestrians and often also cyclists cross the street at this point. The vehicle must recognize the crosswalk safely and the VRU must also be recognized. Traffic signs and prior information on HD-maps can also be used to detect a crosswalk.

Challenges (Corner Cases)

Even in very difficult weather conditions (rain, snow, fog) people and other vulnerable road users must be detected safely. Road conditions are also very important. The system should be aware of the slipperiness and calculate appropriate braking distance.

Under moderate and high traffic densites, a leading vehicle in ego lane might block the cameras. In such cases, performance of other sensors are critical as they might also underperform due to harsh weather conditions. This risk is relatively lower in low traffic density.

2.1.4 Entering a Lane

General Description

Ego vehicle is in sideway of the road. An example might be a car parked in sideways of an urban road. This can be interpreted differently for highway and urban drivable areas such as entering the road from service area, emergency lane or lane merger.

Trigger Conditions

The ego vehicle plans to enter the lane which is a part of the planned trajectory. When there is no approaching vehicle or obstacle on the planned lane, the ego vehicle enters the lane.

Expected Behaviour

Ego vehicle enters ego lane and accelerates to the target speed.

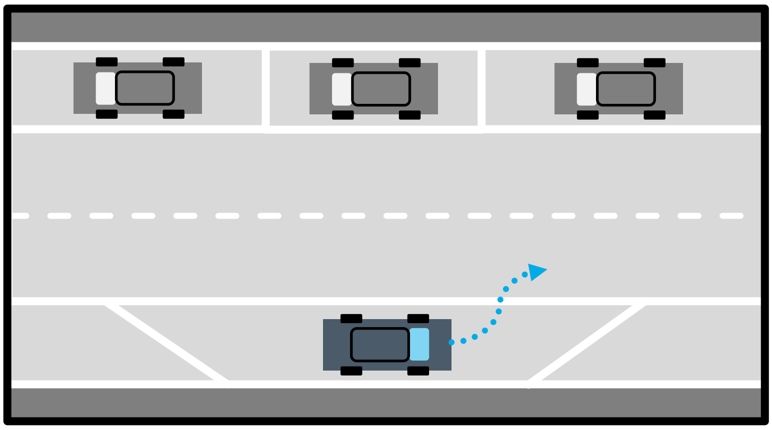

Figure 20 Example of Entering a Lane

Table 4 Set of Initial Scenario Conditions for Use Case 4

Initial Scenario Conditions	
Ego vehicle position with respect to road	Conditional (Vehicle in sideway of the road next to the lane in the direction of travel.)
Lead vehicle in ego lane	Include
Left Lane Free	Include
VRU/Unknown	Include
Right Lane Free	Include
Road geometry	Conditional (As specified in D2.1)
Road type	Conditional (Highway, Urban, Rural)
Target Drivable Area	Conditional (as specified in D2.1 with specific attention to Icy, Wet, Dry)

Weather	Conditional (as specified in D2.1 with specific attention to Heavy Rain, Heavy Snow, Dense Continental Fog)
Density of Motor Vehicles (Traffic Density)	Conditional (Low,Moderate)
Connectivity	Include

General Setting

This use case contains an example situation for urban and rural roads. A vehicle must drive onto the road from a parking situation (parallel to the road). In this complex action, it must be ensured that the car drives onto the road without colliding with other vehicles or road users (including VRU) and that the approaching traffic is not obstructed. To master this use case, the side of the car and the front in particular must be monitored with sensors. An example for highway roads is entering from a service area such as a gas station.

Challenges

The dangers in front of concealed road users should be recognized here. This must be done in a wide range of weather conditions. Especially in heavy rain or snow, the visibility of camera or LiDAR systems can be weakened. If the view is blocked, the driving maneuver cannot be carried out because it is not possible to check whether the lane is clear.

Moderate traffic densities create a further perception challenge before carrying out the driving maneuver. When there are many vehicles using the lane, finding adequate gaps to enter is harder especially when the visibility is reduced due to harsh weather conditions. Entering a road with high traffic density can be easier as the other vehicles on the road needs to stop and let the ego vehicle enter. Such a scenario condition does not add value to ROADVIEW's purposes hence it is not included.

2.1.5 Exiting a Lane

General Description

The ego vehicle reaches the end of its planned trajectory on the road.

Trigger Conditions

The exit of the road is detected

Expected Behaviour

Ego vehicle drives into the exit.

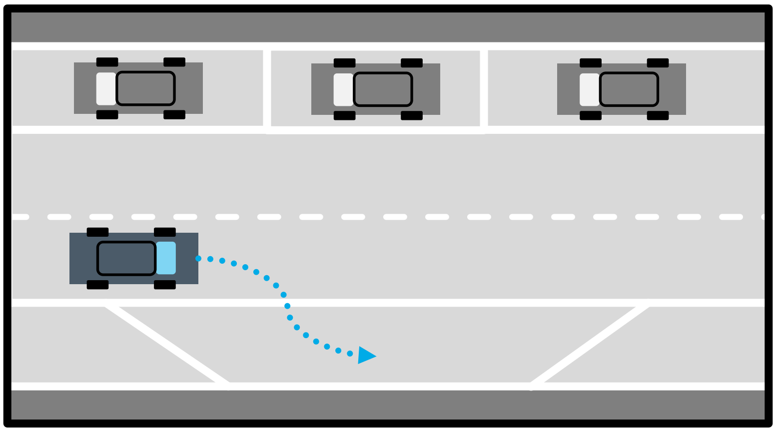

Figure 21 Example of Exiting a Lane

Table 5 Set of Initial Scenario Conditions for Use Case 5

Initial Scenario Conditions	
Ego vehicle position with respect to road	Conditional (Rightmost)
Lead vehicle in ego lane	Include
Left Lane Free	Include
VRU/Unknown	Include
Right Lane Free	Include
Road geometry	Conditional (As spesified in D2.1)
Road type	Conditional (Highway, Urban, Rural)
Target Drivable Area	Conditional (as specified in D2.1 with specific attention to Icy, Wet, Dry)
Weather	Conditional (as specified in D2.1 with specific attention to Heavy Rain, Heavy Snow, Dense Continental Fog)
Density of Motor Vehicles (Traffic Density)	Conditional(Low, Moderate, High)
Connectivity	Include

General Setting

This use case contains a typical example for urban and rural roads. A vehicle must drive off the road parallel to a parking lot. This complex action must ensure that the sufficiently large parking space is free (no other vehicles or (vulnerable) road users). To handle this use case, the side of the car and the front must be monitored with sensors. Here, the hazards are to be detected in front of obscured road users. This can be interpreted differently for highway and rural roads, such as exiting the road to a service area or emergency lane.

Challenges (Corner Cases)

Harsh weather conditions set a great challenge for this use case. Planned exit space (parking lot, service area etc.) must be free, when the ego vehicle exits the lane. To determine whether a VRU is present is more difficult than presence of a vehicle due to the size of a VRU. Reduced visibility and sensor performance of LiDARs and radars create the risk of faulty perceptions. Snow on sensors is also a great danger.

Under moderate and high traffic densities, detecting the right place to exit is challenging as there are vehicles blocking the front vision. In such cases, there are additional challenges to the perception systems. Usage of different sensor fusion techniques or infrastructure-based solutions might be beneficial in such cases.

2.2 Scenarios

Use cases and scenarios are complementary concepts. Based on use cases, scenarios provide more specific descriptions of the situation of the autonomous vehicle. At first glance, five use cases might seem few. Considering the scenarios that can be generated via initial scenario conditions, a great number emerges. Three scenarios are explicitly specified in this deliverable. Specifications for the other scenarios are given in the initial scenario conditions in Table 1, Table 2, Table 3, Table 4 and Table 5. The following methodology should be applied to create more explicit scenario specifications.

To understand how scenarios are described, we will first walk through how scenario 1 is created. We will consider use case 3 “Interacting with VRU”. Connectivity is an important operational design domain attribute enabling infrastructure-based solutions. These applications can play a key role while interacting with VRUs under harsh weather conditions.

We will first start by specifying the initial scenario conditions. If a condition is specified as “Include”, a development should work under such conditions. If the table defines a condition as “Include” we can choose to include it in a scenario description.

When the condition is specified as “Exclude”, a development does not have to work under such condition. So, we cannot include that condition in our scenario description. When the condition is specified as conditional, developments should work under only the specified condition. Hence, we must include the at least one of the specified conditions in the scenario description. After specifying the initial scenario condition, other ODD conditions can be specified with the help of D2.1.

For scenario 1, we will set the road type as Urban. Vehicles must stop and allow pedestrians to cross the road when they enter a crosswalk. Autonomous vehicle moves along the urban road and there is a crosswalk ahead. The perception system must detect the crosswalk under any weather condition. For scenario 1, heavy rain is present, and road is wet. Left lane is occupied and there are other vehicles on the right lane.

Table 6 Initial Scenario Conditions for Scenario 1

Initial Scenario Conditions	
Ego vehicle position with respect to road	Rightmost
Lead vehicle in ego lane	There is no lead vehicle in ego lane.
Left Lane Free	Left lane is not free
VRU/Unknown	There is a pedestrian crossing the street.
Right Lane Free	There are other vehicles in the right lane.
Road geometry	Horizontal, Undivided, Level plane, Straight Line,
Road type	Urban
Target Drivable Area	Wet
Weather	Heavy Rain
Density of Motor Vehicles (Traffic Density)	Low
Connectivity	V2X Enabled
Use Case	Interacting with VRU

For the next scenario description, we will focus on rural roads. A vehicle parked next to the road in the direction of travel is a situation that falls under use case 4 “Entering a Lane”. Rural roads often allow parking to the rightmost lane or there might be a designated parking space. Pedestrians use the sideways of the road. Heavy snow creates a perception challenge and increases the risk for VRUs. In this scenario, road condition is icy. This increases the braking distance, creating a challenge for the control system.

Table 7 Initial Scenario Conditions for Scenario 2

Initial Scenario Conditions	
Ego vehicle position with respect to road	Vehicle on the parking spot next to the lane in the direction of travel
Lead vehicle in ego lane	There is no lead vehicle in ego lane.
Left Lane Free	Left lane is free.
VRU/Unknown	Pedestrians on the sideways of the road.
Right Lane Free	Yes.
Road geometry	Horizontal, Undivided, Level plane, Straight Line,
Road type	Rural
Target Drivable Area	Icy
Weather	Heavy Snow
Density of Motor Vehicles (Traffic Density)	Moderate
Connectivity	V2X Enabled
Use Case	Entering a Lane

Highway road will be the focus of scenario 3. Fog is a very common challenge in Turkey’s highways as the roads occasionally pass over small mountains. Along with a wet road, dense continental fog will be present for scenario 3. The autonomous vehicle must detect the vehicles within its braking distance under such conditions. Due to moderate traffic density, there might be vehicles entering the ego lane. Such lane interruptions should be detected, and target speed must be adjusted with respect to the leading vehicle. Highways are closed to pedestrians however open motorcycle users. The autonomous vehicle must detect motorcycle users.

Table 8 Initial Scenario Conditions for Scenario 3

Initial Scenario Conditions	
Ego vehicle position with respect to road	Rightmost
Lead vehicle in ego lane	There is a lead vehicle in ego lane.

Left Lane Free	Left lane is not free.
VRU/Unknown	No pedestrians expected. Motorcycle users are present..
Right Lane Free	There is a vehicle in right lane.
Road geometry	Horizontal, Undivided, Level plane, Straight Line,
Road type	Highway
Target Drivable Area	Wet
Weather	Dense Continental Fog
Density of Motor Vehicles (Traffic Density)	Moderate
Connectivity	V2X Enabled
Use Case	Driving Straight

To illustrate the development process for scenario 1, we can look at the proposed infrastructure-based solution to the challenge specified in use case 3. As the connectivity is enabled, V2X communication can help the autonomous vehicle deal with the perception and decision-making challenges under heavy rain.

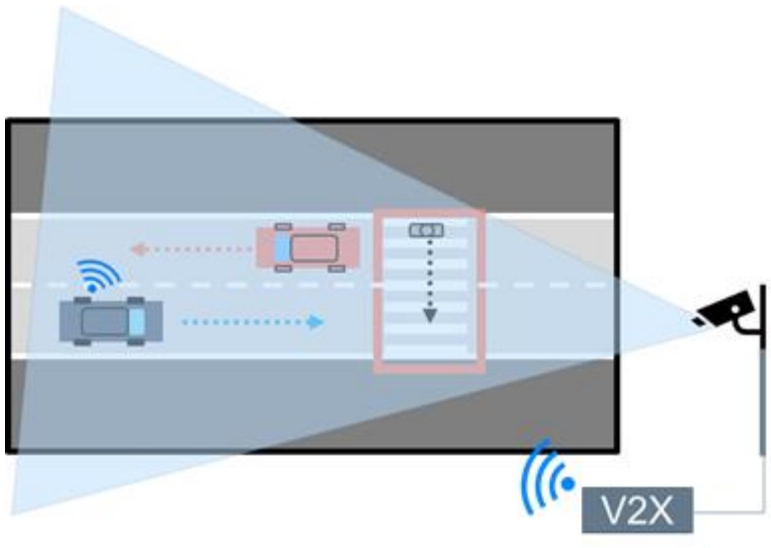

Figure 22 Proposed Infrastructure Based Solution to the Scenario Example

The ego vehicle approaches a crosswalk on the street. A pedestrian is crossing the street behind another car driving in the reverse direction of the autonomous car. Due to the another passing vehicle, the view of the pedestrian can not be seen by the ego vehicle.

Crosswalk is detected by the ego vehcile’s perception system. Pedestrian is detected by the infrastructure-based perception system that is sending a V2X message containing the pedestrian position and velocity or an indication if the crosswalk area is free.

The ego vehicle is decelerating and is coming to a stop, if necessary. When ego lane is free, the ego vehicle accelerates to its target speed.

2.3 Scenarios For Complex Decision Making

At first glance, it might be hard to imagine how these simple use cases will be the basis for scenarios that can test complex decision-making. However, the strategic choice of these use cases allows for constructing layered scenarios that combine multiple elements, thereby testing the AVs' capabilities to their limits. Here are further explanations and examples:

Strategic Use Case Selection

The use cases were chosen for their frequency in everyday driving and their potential to be expanded into more complex scenarios. Each use case tests different aspects of the AV's operational capabilities:

- **Driving Straight:** Tests the vehicle's ability to maintain lane discipline and respond to changes in speed and obstacles while navigating a straight path.
- **Coming to a Full Stop:** Challenges the vehicle's perception systems and decision-making algorithms in accurately detecting stop signals and obstacles and executing a safe stop.
- **Interacting with VRUs:** Examines the vehicle's response to unpredictable pedestrian movements and ensures safety protocols are met under various conditions.
- **Entering and Exiting a Lane:** Tests the vehicle's ability to merge into and exit from traffic, a common yet complex maneuver that involves multiple decision-making processes.

Development of Complex Decision-Making

We can derive complex scenarios from the primary use cases outlined to simulate challenging environments and critical driving situations. Each scenario is designed to test specific aspects of the AV's decision-making capabilities under stress, providing insights into the robustness and reliability of the ROADVIEW system. To constitute concrete examples, we defined the following sample scenarios below:

Emergency Stop / Lane Exit due to Work Zone

Roads regularly go under maintenance, and some lanes are temporarily closed to traffic. This situation threatens the safety of road users under adverse weather conditions since the stop signs could be occluded by rain, snow or fog. When the driver notices the stop sign later than needed, the driver needs to check the surroundings and enter the left adjacent if there is no vehicle in the right adjacent lane. Emergency braking is needed when there is no free lane to avoid collisions with the work zone. This situation is an example of the use case entering a lane and coming to a full stop depending on the occupancy of the adjacent lane.

Table 9 Initial Scenario Conditions for Scenario 4 (Emergency Stop due to Work Zone)

Initial Scenario Conditions	
Ego vehicle position with respect to road	Any lane
Lead vehicle in ego lane	There is no vehicle in the ego lane.
Left Lane Free	Left lane is not free.
VRU/Unknown	Pedestrians are inside the workzone.
Right Lane Free	The vehicle is in the rightmost lane.
Road geometry	Horizontal, Solid Barier, Level plane, Straight Line,
Road type	Highway
Target Drivable Area	Icy
Weather	Moderate Snow
Density of Motor Vehicles (Traffic Density)	High
Connectivity	V2X Enabled

Use Case	Coming to a full stop

Table 10 Initial Scenario Conditions for Scenario 5 (Entering a lane due to Work Zone)

Initial Scenario Conditions	
Ego vehicle position with respect to road	Any lane
Lead vehicle in ego lane	There is no vehicle in the ego lane.
Left Lane Free	Left lane is free.
VRU/Unknown	Pedestrians are inside the workzone.
Right Lane Free	The vehicle is in the rightmost lane.
Road geometry	Horizontal, Solid Barier, Level plane, Straight Line,
Road type	Highway
Target Drivable Area	Wet
Weather	Moderate Rain
Density of Motor Vehicles (Traffic Density)	Low
Connectivity	V2X Enabled
Use Case	Coming to a full stop

VRU Cluster Interaction

This scenario focuses on an AV's interaction with a cluster of Vulnerable Road Users (VRUs), such as a group of pedestrians or cyclists unexpectedly crossing the road. This test evaluates the vehicle's ability to detect, assess, and respond to multiple VRUs under complex and potentially hazardous conditions. The decision-making challenge comes from an accurate perception of the VRUs' movements and ability to act safely. This scenario is not often expected in the highway road type but can be expected in urban roads.

Table 11 Initial Scenario Conditions for Scenario 6

Initial Scenario Conditions	
Ego vehicle position with respect to road	Rightmost lane
Lead vehicle in ego lane	There is no vehicle in the ego lane.
Left Lane Free	The left lane is free.
VRU/Unknown	A group of VRUs, possibly including children or cyclists, begins to cross the street at an undesignated crossing area, increasing the unpredictability of the scenario.
Right Lane Free	The vehicle is in the rightmost lane.
Road geometry	Horizontal, Undivided, Level plane, Straight Line,
Road type	Urban
Target Drivable Area	Wet
Weather	Heavy Rain
Density of Motor Vehicles (Traffic Density)	Moderate

Connectivity	V2X Enabled
Use Case	Interacting with VRUs

Unexpected Animal Crossing

Rural roads are often near the natural habitats of animals. This increases the chance of an encounter between an animal and a vehicle. Rural areas commonly have higher incidents of animals on the road and the AV should be able to handle this complex decision-making scenario. This scenario is critical for assessing the AV's ability to handle unexpected events that pose significant safety risks. Upon detecting an unexpected animal crossing, the AV must quickly evaluate several response options based on the immediacy of the threat, the vehicle’s speed, road conditions, and available maneuver space.

Table 12 Initial Scenario Conditions for Scenario 7

Initial Scenario Conditions	
Ego vehicle position with respect to road	Rightmost lane (typically presents a higher likelihood of encountering animals, especially in rural settings)
Lead vehicle in ego lane	There is no vehicle in the ego lane.
Left Lane Free	Not applicable (one-lane road).
VRU/Unknown	An animal crossing (such as a deer or other large animal, which can suddenly appear and cross the road)
Right Lane Free	Not applicable (one-lane road).
Road geometry	Horizontal, Undivided, Level plane, Straight Line,
Road type	Rural
Target Drivable Area	Icy
Weather	Light Continental Fog
Density of Motor Vehicles (Traffic Density)	Low
Connectivity	V2X Enabled
Use Case	Driving Straight

Complex Intersection Navigation

Urban roads include several intersections where vehicles decide on their movement based on other vehicles intentions. The autonomous vehicle's (AV's) performance in managing intricate driving decisions at a busy urban intersection where multiple vehicle paths converge depends on complex decision-making capabilities. Various vehicles—including cars, buses, delivery trucks, and motorcycles—enter and exit the intersection from different directions, often under the control of complex traffic signal systems. The challenge in this scenario stems from the necessity to navigate in an environment with heavy traffic signals, pedestrian crosswalks (not included in this specific scenario), and the unpredictable behavior of urban drivers.

Table 13 Initial Scenario Conditions for Scenario 8

Initial Scenario Conditions	
Ego vehicle position with respect to road	Approaching the intersection in the rightmost lane.

Lead vehicle in ego lane	There are leading vehicles in the ego lane. (with erratic behaviors like sudden stopping or abrupt lane changes common in urban settings)
Left Lane Free	The left lane is occupied.
VRU/Unknown	Not included.
Right Lane Free	The right lane is occupied.
Road geometry	Horizontal, Divided, Staggered Junction, Level plane, Straight Line,
Road type	Urban
Target Drivable Area	Icy
Weather	Light Rain
Density of Motor Vehicles (Traffic Density)	High
Connectivity	V2X Enabled
Use Case	Driving Straight

3 Conclusions

Transportation is a critical enabler of modern society. People and goods move across borders to raise our standards of living. Transportation technologies are undoubtedly open to innovation to become safer and more sustainable. Autonomous driving is one of the key emerging technologies that promise to transform land transportation by improving safety, reducing congestion, and enhancing accessible mobility.

To become an operational option for day-to-day usage, there are many challenges against which autonomous vehicles should prove their robust performance. Weather is one of the most critical challenges for autonomous vehicles, as sensors that enable autonomy are heavily affected by different weather conditions.

The ROADVIEW project aims to tackle the effects of harsh weather conditions on autonomous vehicles by developing robust perception and decision-making systems. This document defines use cases for which ROADVIEW developments should work.

Use cases provide a general description of the situation. There are 5 use cases defined in this document to serve the purpose of defining boundaries for autonomous driving capabilities. These use cases are independent of operational design domain attributes. By using the use cases and operational design domains several scenarios can be created. Scenarios are more specific definitions that include all operational design domain attributes that will define requirements for developments. Comprehensive details upon operational design domain are provided in the deliverable D2.1. Numerous scenarios and test cases can be created by combining different weather conditions, driveable area types and road conditions. We followed this approach to focus on the development efforts to tackle challenges regarding harsh weather conditions. Additional information regarding scenarios is also given in the use cases. All in all, the further work in ROADVIEW shall consider this document as the framework for the developments.

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