ROADVIEW

Robust Automated Driving in Extreme Weather

Project No. 101069576

Deliverable D2.1

Definition of the complex environment conditions

WP2 – Physical system setup, use cases, requirements and standards

Authors	Fredrik Warg (RISE), Sebastien Liandrat (CE), Valentina Donzella (WMG), Graham Lee (WMG), Pak Hung Chan (WMG), Reija Viinanen (S4), Antti Kangasrääsiö (S4), Umut Cihan (Ford), Heikki Hyyti (FGI), Tobias Waldheuer (ZF), Yuri Poledna (THI), Jalmari Matilainen (S4), Anders Thorsén (RISE).
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Partner short names

HH	Halmstad University
LUA	Lapin Ammattikorkeakoulu
THI	Technische Hochschule Ingolstadt
VTI	Statens Vag- och Transportforskningsinstitut
CE	CEREMA
RISE	RISE Research Institutes OF Sweden
FGI	Maanmittauslaitos – Finnish Geospatial Research Institute
S4	Sensible 4 OY
FORD	Ford Otomotiv Sanayi A.S
CRF	Canon Research Centre France S.A.S.
ZF	ZF Friedrichshafen AG
accelCH	accelopment Schweiz AG
WMG	Warwick Manufacturing Group, University of Warwick

Abbreviations

ADS	Automated Driving System
CAV	Connected Automated Vehicle
D	Deliverable
DAS	Driving Automation System
DDT	Dynamic Driving Task
DSD	Droplet Size Distribution
EC	European Commission
EU	European Union
FMCW	Frequency Modulated Continuous Wave
HEU	Horizon Europe
M	Month
MOR	Meteorological Optical Range
MRC	Minimal Risk Condition
MS	Milestone
OD	Operational Domain
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
WP	Work Package

Executive summary

The overarching goal of the ROADVIEW project is performance improvements in perception and decision-making subsystems for connected automated vehicles (CAVs) under harsh weather conditions such as rain, fog, or snow, which is necessary to enable the widespread use of automated vehicles. In support of this overarching goal, this deliverable (D2.1) describes complex environments—including levels of harsh weather conditions and density of heterogeneous traffic—to be used for the R&D activities and evaluations in WPs 3 – 8. The environment descriptions are in the form of operational design domain (ODD) definitions meant to be combined with the use cases defined in D2.2. The ODD definitions are specified by using and extending the ODD taxonomy defined in ISO 34503 [3], considering the needs of the ROADVIEW use cases, and the environmental conditions especially relevant for the sensor types investigated in the project.

This deliverable first defines terminology related to driving automation systems, ODDs, and testing—where a key purpose is to verify that the CAV operates safely within its ODD. Then harsh weather conditions and the main sensor types intended to be used in the project are discussed. Sensors are investigated with respect to which weather conditions and which metrics for these conditions are relevant to perform verification against the defined ODD (e.g., rain metrics can be intensity specified in mm/h and droplet size distribution). Next follows a discussion on particularly relevant ODD attributes and why we have chosen certain metrics and classifications, and in some instances added new attributes not mentioned in ISO 34503. Finally, ODD definitions are developed for the different types of road environments, or drivable areas, defined in D2.2, i.e., highway, urban traffic, and rural road. D2.2 also defines several use cases for automated vehicles that are relevant for these drivable areas and will be used by the other WPs, together with the ODD definitions from this deliverable, to create test scenarios.

Objectives

The main objective of this deliverable is to create ODD definitions for the use cases investigated in the project, especially detailing harsh weather conditions with a focus on rain, fog, and snow. By combining these harsh conditions with use cases defined in D2.2, the project will have the basis for working on perception and decision-making improvements for such conditions, and for defining relevant test cases to apply in different test environments used in the project (simulation, x-in-the-Loop, weather test facilities, test tracks, and open-road tests). Together, D2.1 and D2.2 aim to fulfil ROADVIEW Objective 1: Define complex environmental conditions and use case specifications.

Methodology and implementation

Since the overarching goal of ROADVIEW is to improve performance for CAVs in harsh weather conditions, this deliverable aims to specify an ODD taxonomy specifically including (1) operational conditions relevant for harsh weather conditions with respect to the design and verification of advanced environmental sensors and decision-making systems, and (2) operational conditions relevant for the specific use-cases to be evaluated in the project.

The methodology was to, as far as possible, make sure the project uses ODD taxonomy and other terminology from existing sources, in particular existing or soon-to-be-released standards [1][2][3][4][6], to make sure we use terms in a way already established in the automotive domain and avoid inventing new terms where there are already existing alternatives. Given this starting point, a group of experts in sensor technology, test environments, and the providers of use cases have collected and analysed what kind of harsh conditions should be included, and if there is a need to refine the existing ODD taxonomy with new or more detailed attributes or new metrics. Finally, an ODD definition is developed corresponding to each of the three types of drivable areas defined in D2.2.

Outcomes

This deliverable provides initial ODD definitions covering the drivable areas developed in deliverable D2.2—urban (city) traffic, (multi-lane) highway, and (single-lane) rural road, with and without infrastructure extensions—given our knowledge in the early phases of the ROADVIEW project. Refinements that may be necessary during the project will be described in later project deliverables.

Next steps

The use cases are further defined in deliverable D2.2. The further work towards the overarching goal performed in ROADVIEW WP 3-8 will use the ODD taxonomy and use case specifications as input for the evaluation and demonstration of the improvements developed in the project. Evaluation of the system prototypes used in the project is part of the integration and demonstration work package (WP8).

1 Introduction

Driving automation features (e.g., a highway pilot or urban chauffeur) can be defined by their level of driving automation—which specifies the level of involvement required by a human user—and the operational design domain —which specifies the operating conditions the feature is designed to handle [2]. That means any limitations of the feature with respect to operating conditions such as speed, road conditions, traffic, or weather conditions must be specified as its ODD. A safe driving automation feature must (i) always operate safely with its specified automation level within its specified ODD, (ii) never be activated outside its ODD, and (iii) be able to execute a safe fallback if required by the automation level, whenever a performance-critical failure occurs or before the vehicle risks exiting the ODD while the feature is activated. Hence, to evaluate a driving automation feature, it is necessary to clearly specify the level of automation and the ODD for the feature. From this, it also follows that it will be necessary to specify the ODD using attributes and metrics which can be used in the implementation, testing, and operational phases of the lifecycle to be able to fulfil conditions (i)-(iii) stated above.

This report aims to develop ODD definitions for the sets of use cases targeted in the ROADVIEW project. Since there are still open questions when it comes to which attributes, parameters and levels of harsh conditions will be most relevant, the definitions in this report shall be seen as starting points given our current understanding, which should be updated as the project gains knowledge on how to handle these conditions.

2 Terminology and Definitions

This chapter defines and explains the key terms used in the deliverable to provide a common use and understanding for the purposes of the ROADVIEW project. Some of these terms are used widely and with slightly different meanings in different contexts. However, the meaning described below is the one assumed in this project. When possible, we adopt definitions from existing road vehicle standards.

2.1 Terms Related to Driving Automation Systems

Brief descriptions of key terms for driving automation are given in Table 1. The main sources are ISO/SAE PAS 22736 [2], which defines a taxonomy and terms for driving automation systems, and ISO 34503 [3], which defines a taxonomy for operational design domains.

Figure 1 illustrates a taxonomy of levels of driving automation defined in ISO/SAE PAS 22736, and how some of the terms in the table relate to the automation levels. The term ODD, which in short defines the operating conditions a driving automation system is designed for, is further discussed in Section 2.1.1. However, it can be noted that all levels of driving automation except level 5 have a limited ODD, which means these limits of applicable driving conditions must be defined. The interpretation of an unlimited ODD (level 5) is that the automation has at least the same capabilities as a (proficient) human driver for all conditions of on-road driving.

Table 1 Terms related to driving automation systems.

Term	Short description
DAS—Driving automation system	Automated system that performs all or part of the driving task (see also definition of DDT) on a sustained basis.
Driving automation feature	A feature is a specific automated task implemented by a DAS, e.g., highway pilot or valet parking. A feature is defined by the use case, automation level, and ODD. A DAS may support several distinct features.
Level of driving automation	Taxonomy of automation describing the capabilities of different types of driving automation systems. Levels 1-5 describe increasingly advanced automation.

ADS—Automated Driving System	A driving automation system of level 3-5 according to the levels of driving automation.
CAV—Connected and Automated Vehicle	Combination of driving automation and functionality depending on wireless connection (e.g., use of cloud services, vehicle-to-vehicle, or vehicle-to-infrastructure communication).
OEDR—Object and Event Detection and Response	The function of monitoring the driving environment to detect objects and events and executing appropriate responses.
DDT—Dynamic Driving Task	The act of operating the vehicle on an operational and tactical level, including motion control (steering, accelerating, braking), and OEDR. Different parts of the DDT can be handled by either a human driver or a driving automation system, as defined by the automation levels.
DDT fallback	Response given a system failure or upon an ODD exit. The response can be achieving a minimal risk condition (MRC) or a user taking over the DDT.
ODD — Operational Design Domain	Operating conditions under which a given driving automation system, or feature thereof, is specifically designed to function. The ODD includes, but is not limited to, the environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics [2]. For ROADVIEW, the ODD includes the set of adverse weather conditions where the ADS should be able to operate. A more detailed definition of the term is given in 2.1.1. ODD essentially defines the operating environment for which a system is designed for – and as such it is a specification of the system.
OD — Operational Domain TOD—Target Operational Domain COD—Current Operational Domain	OD is “Any set of operating conditions, 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. This set can be used to describe real world conditions in certain environments, geography, synthetic conditions for testing, and other various purposes” [3]. TOD is “Any set of operating conditions describing location(s) in which an ADS will be expected to operate […]” [3]. The difference between ODD and TOD is thus that the ODD expresses an ADS specification while the TOD is a description of a specific real-life environment. The ODD of an ADS must thus include all aspects of a TOD where the ADS is expected to be deployed. COD is “The specific set of operating conditions which exists currently in the immediate vicinity of an ADS […]” [3] OD essentially describes the aggregated environmental conditions over a time interval and geographic region – *a description of “real life”.*

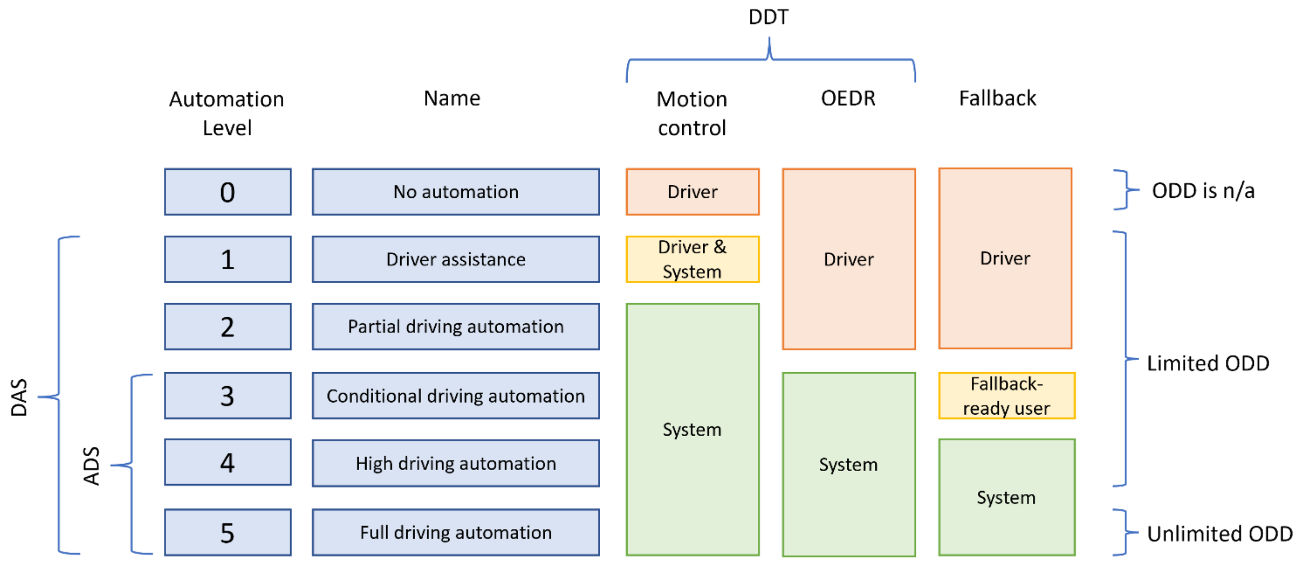


Figure 1 Taxonomy of levels of driving automation, based on [2].

2.1.1 Operational Design Domain (ODD)

The term ODD was first defined in the SAE standard J3016 Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems in 2016. The current version of the standard J3016:2021 defines 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 [1].

The same definition has also been adopted by the joint ISO/SAE PAS 22736:2021 - Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles [2]. The definitions related to driving automation in these two (very similar) documents are widely used and accepted in the automotive domain and also adopted in this project.

This definition of an ODD should give an intuitive understanding of its use but does not elaborate on what kind of operating conditions are meaningful to define. Instead, other works have published full or partial taxonomies of what an ODD definition should contain over the years, e.g., [25][26][27][28][29]. Currently, ISO 34503 - Road Vehicles — Test scenarios for automated driving systems — Taxonomy for operational design domain [3], is in draft and expected to be published during the course of this project. In turn, this standard has used BSI PAS 1883 [4] as input and reuses the base taxonomy from that document. The taxonomy in this deliverable reuses and expands upon that taxonomy. The top-level attributes of the taxonomy are illustrated in Figure 2. These attributes then have sub-attributes and, when applicable, metrics and classes. For instance, the weather attribute has rain as one of its sub-attributes. Rain can be quantified, e.g., as classes light rain, moderate rain and heavy rain, where each class is defined by a range of precipitation measured in mm/h. The ODD taxonomy is extensible, meaning stakeholders may add/extend attributes or sub-attributes as long as the extensions are coherent with the existing set. The ODD definitions in Sec. 6 use the full taxonomy and some ROADVIEW refinements.

A key point of an ODD definition, also stressed by ISO 34503 [3], is that the ODD needs to be testable. This also follows from the three criteria for safe driving automation stated in Section 1. This implies that the attributes and metrics need to be specified in such a way that they are observable and quantifiable for the purposes of testing that these criteria are fulfilled and also that the attributes, when relevant, are observable by the operational DAS such that it can determine if it is inside the ODD, nearing an ODD exit (to be able to execute a DDT fallback before exit), or already outside the ODD (to prevent activation). See also Section 2.2.3 on ODD and testing.

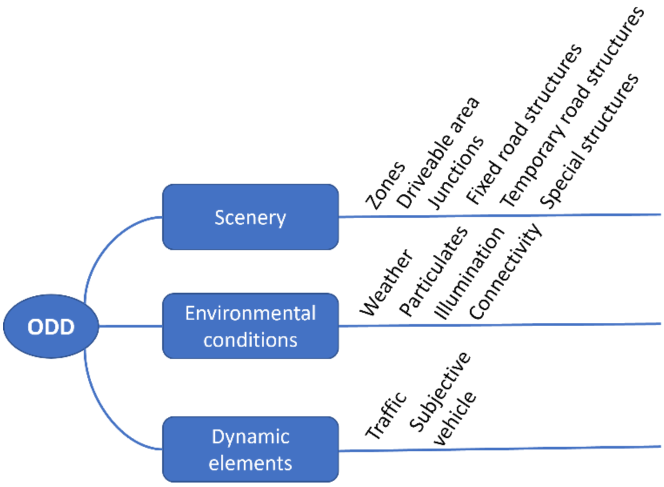


Figure 2 Base ODD Taxonomy from [3].

2.1.2 ODD vs OD

As mentioned, the ODD is part of the design specification of a DAS, and therefore defines the operational conditions under which the DAS is designed to operate safely. In contrast, an OD is not a design specification but a description of all plausible real-world conditions. In particular, a target OD (TOD) is the real-world conditions a specific DAS is expected to experience. The difference between the OD and the TOD highlights the differences between the real-world conditions in general, and the conditions in the region where the DAS is designed to be deployed. The difference between the OD and the ODD highlights the design limitations of the DAS [3]. There may be attributes or occurrences in the TOD that are not covered in the ODD. As the DAS may not be safe to operate outside its ODD, it is necessary to have mechanisms in the DAS that can execute a fallback manoeuvre when the DAS is about to exit the ODD. Therefore, it is important to define the boundary between the ODD and the OD clearly.

TOD is a description of the real world applicable for, e.g., a specific geographic area, while current OD (COD) is the real-time operational domain, i.e., the exact conditions the DAS experiences at a particular point in time.

2.2 Terms Related to Testing and Evaluation

This section discusses terms related to testing, and especially to scenario-based evaluation methods where primarily terms from ISO 34501 have been used [6]. Table 2 gives some short definitions of terms related to testing and evaluation, while the following subchapters give a deeper explanation and references pertaining to some of the terms.

Table 2 Terms related to testing and evaluation.

Term	Short description
Demonstration	"The act of showing of proving something.[1]" In the context of ROADVIEW, several pilot demonstrations, using vehicles equipped with ADS, are performed in various environments to showcase the project results.

[1] https://www.britannica.com/dictionary/demonstration

Use case	One definition of use case is "a specific situation in which a product or service could potentially be used[2]". In the context of the ROADVIEW project, initial sets of use cases are defined in D2.2 representing typical use of different ADS features. Each use case is described and includes a scenario that can be used for evaluation.
Test case	A generic term for any type of test on any CAV implementation abstraction level. Common test case types include: software component tests, integration tests between software components, simulation-in-the-loop tests, hardware-in-the-loop tests, vehicle-in-the-loop tests, closed area vehicle tests, open-road vehicle tests.
Scenario	Sequence of the scenes usually including the ADS(s)/subject vehicle(s), and its/their interactions[3] in the process of performing the DDT [6]. A Scenario describes a sequence of scenes, where a scene in turn consists of all entities (scenery and dynamic entities). A scenario may also include events and triggers.
Scene	Snapshot of all entities including, but not limited to the ADS, subject vehicle, scenery, dynamic environment, and all actors and observer's self-representations, and the relationships between those entities [6].
Scenery	Also called static environment is the set of all static entities, i.e., entities that are unchanged during a scenario [6].
Static entity	Entity that does not experience state change during a scenario, e.g., road surface, signs, buildings [6].
Dynamic entity	Entity that experiences state changes during a scenario, e.g., vehicles and pedestrians [6].
Event, trigger	Events are pre-determined changes to an entity in a scenario. Events can be defined in various ways, such as time from scenario start or a certain spatial configuration of the dynamic entities (e.g., the ego vehicle stopping before a pedestrian crossing may trigger an event where a pedestrian crosses the road). An event that initiates or ends an action by some actor in the scenario can also be called a trigger.
Test scenario	Scenario intended for testing and assessment of ADS(s)/subject vehicle(s) [6]. Test scenarios are used to specify test cases for the ADS. A single high-level test scenario can influence a large number of test cases, at multiple implementation abstraction levels. A test scenario may include additional information to the scenario for testing purposes, such as HMI events, test data, success criteria, error checks. Test scenarios are typically used in scenario-based testing methods for system-level tests.
Edge case, corner case	In software engineering, an edge case is a problem occurring at the extreme of an operating parameter, while a corner case is a combination of several parameter at extreme values, constituting a corner of the configuration space.

[2] https://www.oxfordlearnersdictionaries.com/definition/english/use-case
[3] Interaction with e.g., other systems or road users.

	In the context of ADS development, an edge case or corner case is usually defined as an unusual but possible situation that automated vehicles need to handle, but that is unlikely to occur during normal test driving.

2.2.1 Testing Environmental Conditions

Environmental conditions describe weather conditions such as rain or snow, particulates such as fog and dust, atmospheric conditions such as temperature, humidity, and pressure, connectivity (e.g., 5G connection quality), and illumination.

The focus of the ROADVIEW project is to investigate environmental conditions, and especially harsh weather conditions like rain, fog, and snow. This section provides some illustrations of such conditions from different test environments. Figure 3 and Figure 4 illustrate fog and rain conditions with different illumination. Table 3 further illustrates some adverse conditions with bad weather in different illumination, also with comparison between real (test track) photos and a simulated environment. Table 4 shows different conditions of snow on the ground and ongoing snowfall (illustrations from the simulator).

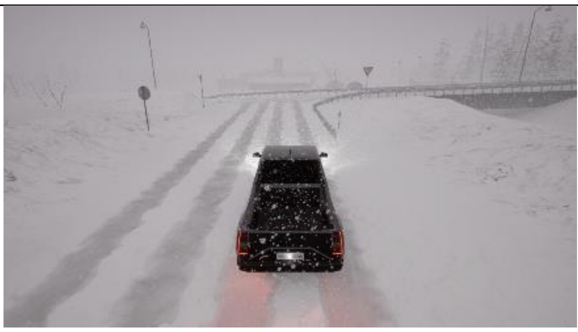
Figure 3 Left, foggy conditions in daytime. Right, rainy conditions at night.

Figure 4 Top row: daylight conditions. Bottom row: night-time conditions. From left to right: clear conditions, light fog, dense fog, light rain, heavy rain.

Table 3 Illustration of weather and illumination, real vehicles (top row) and simulation (bottom row).

Weather / Scenario	Day	Night	Rain
Real EuroNCAP Scenario CCRs			
Virtual EuroNCAP Scenario CCRs			

Table 4 Illustration of snow on the ground (top row) and snowfall (bottom row).

	Low	High
Snow on ground		
Snowfall		

2.2.2 Scenario Abstraction Levels

Scenarios are typically used in the development and testing of automated vehicles. Influential work in this area has come from the Pegasus project[4], including the use of scenarios at different levels of abstraction. Originally, scenarios were defined as functional, logical, and concrete [7]. Later, an additional type called abstract scenarios was also introduced [8].

The different abstraction levels of scenarios are described in Table 5, from the highest abstraction level of functional scenarios to the lowest level of concrete scenarios. An Abstract scenario adds formalisation to a Functional scenario, specifying a subset. A Logical scenario adds parameterization to an Abstract scenario, specifying a subset. A Concrete scenario adds parameter values to a Logical scenario, specifying an instance. Hence, the number of scenarios needed typically increases as the abstraction level decrease.

In ROADVIEW, the scenarios for the use cases in D2.2 are expressed on the abstraction level of functional scenarios. These can later in the project be detailed to lower abstraction levels by combining the scenarios with ODD parameters from this deliverable. The final test scenarios for the different test environments in the project should be on the concrete scenario abstraction level.

Table 5 Scenario representation on different abstraction levels.

Abstraction level	Scenario description	Example
Functional scenario	Natural language description on high level. Non-formal.	Highway driving in lane following another vehicle.
Abstract scenario	Formalized and machine-readable using suitable ontologies. Include descriptions of relations such as cause-effect.	Description in e.g., traffic sequence charts [9] of in lane driving following another vehicle.
Logical scenario	Parameterized representation with ranges and distributions of parameter values.	Lanes = [1…3], lane width = [2.0m…3.0m], … (more parameter ranges/distributions pertaining to ODD and other actors in scenario).
Concrete scenario	Fixed scenario parameters with a specific scenery, and chain of events.	Lanes = 2, lane width = 2.3m, … (more specific parameters pertaining to ODD and other actors in scenario).

2.2.3 Test Scenarios vs. OD, TOD and ODD

Reliable testing is based on verifying the correct function of the ADS over the full TOD. Generally, there is an infinite number of possible Test scenarios. Thus, for practical purposes, a finite set of Test scenarios needs to be selected. This test set should be designed to be representative of the TOD, and to cover the borderline cases near the boundary of the ODD, including Test scenarios where the border is crossed during the Test scenario. It is also important to include Test scenarios both clearly within and outside of the ODD, as illustrated in Figure 5. Tests outside and at the border of the ODD are necessary to verify that the conditions described in Sec. 1 are fulfilled.

Test scenarios are crucial to be objectively and fully defined. This guarantees that the Test scenarios are interpreted similarly by different stakeholders, leading to objective and consistent test results, instead of relying on subjective interpretation of abstract scenarios, and on subjective evaluation of the test results.

[4] https://pegasus-family.de/

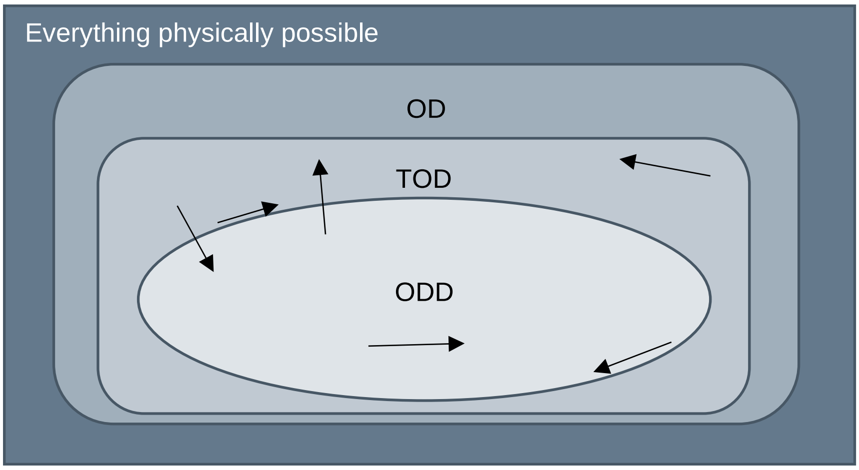


Figure 5 Visualization of the relation between OD, TOD and ODD, with arrows representing possible Test scenarios (imagined as sequences of scenes).

3 Harsh Weather Conditions

This chapter describes the three main weather phenomena investigated in the ROADVIEW project, namely rain, fog, and snow, as well as discusses the most common metrics used to characterize these weather conditions.

3.1 Rain

Rain is a common phenomenon consisting of water droplets falling from the atmosphere, where water vapour condenses due to changes in pressure and temperature [11][12]. Relevant is both the direct phenomena of falling water, and indirect effects such as wet road surface or road spray. It should be noted that in near-zero conditions, rain and snow could be mixed, which is discussed in Sec. 3.3.

3.1.1 Relevant Parameters

One of the most important parameters is the macroscopic parameter used to measure the “quantity” of rain: the rainfall rate. Rainfall rate is characterized by the height of accumulated water on the ground due to rain during a period. It represents the volume of water falling on a surface per unit of time. The unit of rainfall rate is millimetres per hour (mm/h): 1mm/h corresponds to $1L/m^2/h$.

Another important parameter of rain is the particle size distribution of raindrops. Raindrops generally have diameters in the millimetre range, varying from 0.5 to 5 mm. To be noted, it is about 100-1000 times the size of fog particle size. Rain with a droplet size (Ø) of below 0.5 mm is called drizzle and is typically not measurable with rain gauges. Droplets with Ø > 4 mm and even up to 8 mm can be found mostly in torrential downpours in tropical regions.

ISO 34503 [3] mentions additional potential parameters for rain, including type (dynamic/frontal, convective, orographic/relief), rate of onset, interval, and spatial scale. The rate of onset can be very important to know to be able to detect the near ODD exit condition (i.e., time available to go to MRC before rain rate is higher than capability).

3.2 Fog

In the “Meteoterm“ terminology database of the World Meteorological Organization (WMO), fog is defined as the “Suspension of very small, usually microscopic water droplets in the air, generally reducing the horizontal visibility at the Earth's surface to less than 1 km” [11][12][13]. Fogs of all types originate when the temperature and dew point of the air become identical (or nearly so).

Different fog types exist with various formation mechanisms:

- Radiation fog: Radiative cooling of the surface under clear sky. This type frequently occurs in continental climates
- Advection fog: Moist, warm air flowing over water with different temperatures. This type frequently occurs in coastal regions

- Steam fog: Very cold air flowing over much warmer water
- Stratus-lowering fog: Gradual lowering of the base of a low cloud down to the surface
- Precipitation fog: Evaporation of precipitation, mixing of air-masses at a warm front
- Upslope fog: Adiabatic cooling of air being forced to lift by the topography

To take into consideration a large majority of cases, it is possible to focus only on radiation and advection fog types, which are also the most documented in science ([14][15][16]).

To be noted, haze is not considered as fog because it does not contain activated droplets larger than the critical size according to Köhler theory [17]. The same idea with mist that may be considered an intermediate between fog and haze; its particles are smaller (a few micrometres maximum) in size, it has lower relative humidity than fog, and does not obstruct visibility to the same extent. At last, near industrial areas, fog is often mixed with smoke, and this combination has been known as smog. However, fog droplets are usually absent in photochemical smog, which only contain inactivated haze droplets. In the ROADVIEW project, the focus is on fog, not haze, mist or smog.

3.2.1 Relevant Parameters

One of the most important parameters of fog is visibility, also called Meteorological Optical Range (MOR). The visibility is defined to correspond to the human capacity to see objects at distance. To calculate the visibility there are two definitions, but the most used is the visibility by contrast. The theory of Koschmieder describes the apparent contrast of an object against the horizon. A threshold of contrast of 0.05 (5 %) is assumed to be the limit of what the eye can distinguish. This visibility distance is well approximated as being inversely proportional to the atmospheric extinction coefficient [12]. Visibility is often measured with a transmissiometer or a diffusiometer.

Another important parameter of fog is the droplet size distribution (DSD), which has a direct impact on the extinction coefficient and then the visibility. The DSD is represented mathematically by the function n(D), describing the concentration of droplets (number per cm3) of diameter D. DSD can be measured with a particle size (PSA). (PSA).

- Radiation fog (“Continental fog”) is composed mostly of small droplets (few µm).
- Advection fog (“Sea fog”) is usually composed with big droplets (> 5 -10 µm).

In a road context, fog is typically considered to exist when visibility is less than 200 meters, when visibility is less than 50 meters, it is dense fog.

3.3 Snow

Snow is, like rain, atmospheric water vapour, but due to low temperature, frozen into icy crystals. Snow falls in flakes and stays on the ground as a white layer if the ground is cold enough. The characteristic of the snow is highly dependent on the combination of temperature and humidity. In near-zero conditions, rain and snow could be mixed, and at near zero or even plus degrees, snowflakes can be big and stick to surfaces in a completely different way compared to snow in colder temperatures. In severe frost, even the smallest amount of precipitation affects visibility strongly, and there is typically also circulating snow from the ground on the road.

3.3.1 Relevant Parameters

The size of the snowflakes and intensity are good basic metrics; important is the dependency on temperature (temp/humidity combination). Meteorologically, the intensity of snowfall is typically measured converted to water (e.g., in mm/h), but it may be difficult to make use of for practical purposes when there are many dependent variables. In aviation, the intensity of the snowfall has typically been approached in terms of (human) visibility, but even that method determines the intensity.

The intensity of snowfall can be characterized by the visibility or the water equivalent content of a rainfall incident. The visibility here is the same for fog, meteorological optical range (MOR) [11] [12].

In addition to these parameters, snow can be characterized by the snowflake size distribution or the snowflake mass distribution. However, they are less practical (e.g., to measure) than visibility or equivalent water content. It can also be relevant to measure the depth of the accumulated snow.

4 Sensor Impact from Harsh Weather

Even though the ODD is part of the problem domain and not intrinsically technology-specific, the way each technology works will influence which parameters are relevant for some of the ODD attributes. As mentioned in ISO 34503, an ODD definition also needs to be testable [3]. For instance, are droplet size and/or intensity the most useful parameters to use for rain to be able to test an ADS implementation against its defined ODD, or do we need to characterise rain in some other metric? For that reason, this section discusses the main sensor types used in the ROADVIEW project, and what is currently known about the impact of adverse weather on the sensors. As the project focus is rain, fog, and snow, emphasis is placed on these weather conditions. As more knowledge is gained during the project, the weather attributes may have to be further refined.

An overview of sensors for automotive and their main advantages and disadvantages is provided in Sec. I -II- III of a review paper from WMG [18]. Figure 6, also from [18], compares performance parameters for different environmental perception sensors.

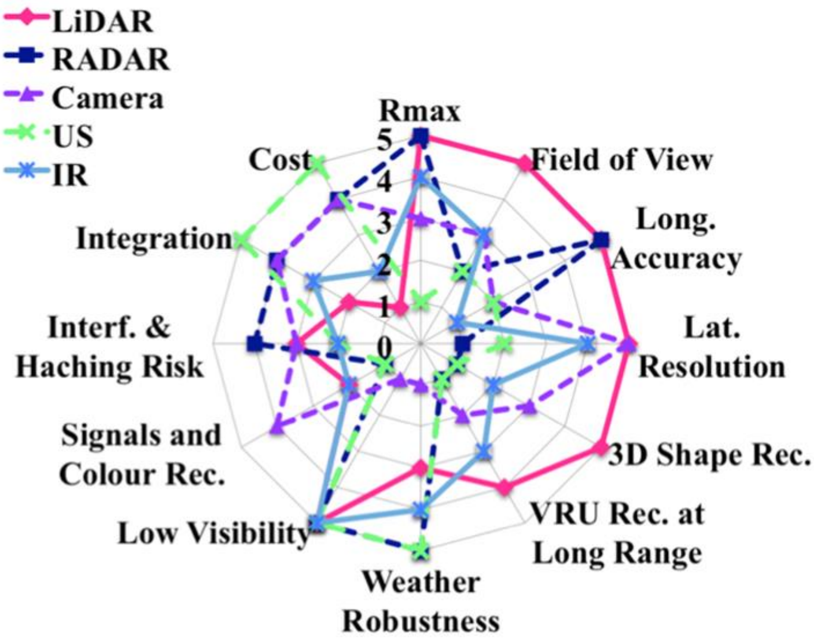


Figure 6 Performance of different environmental perception sensors, from [18]. Abbreviations: Interf. – interference; VRU - vulnerable road user; Rec. – recognition; Long. – longitudinal; Lat. – lateral, IR – infrared camera, US – ultrasound, Camera – RGB camera.

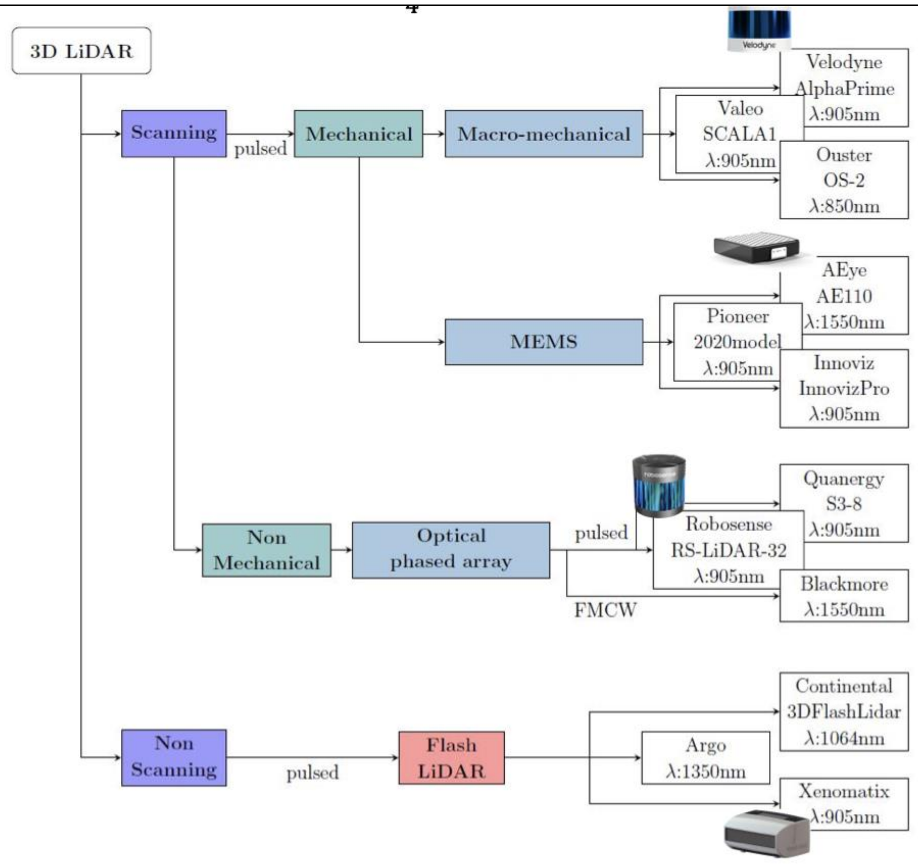
4.1.1 RGB Camera

Sensor type: RGB Camera	
Description	In a colour (red, green, blue; RGB) camera, visible light is focused through lenses and captured with a complementary metal oxide semiconductor (CMOS) sensor. It is a relatively low-cost sensor which can capture colours and contrasts. This sensor captures intensity of visible light per sensor pixel – usually combined with a Bayer (RGGB) filter (however other filters are possible and have been used as well). There are monocular, stereo, and depth cameras.
Weather impact - Known	<u>Rain</u> Rain droplets in the air may be captured by the sensor, leaving rain streaks (normally a brighter streak) on the image. As a result of rain, it creates changes to the

	environment, i.e., overcast lowering luminosity of the scene, surface wetness affecting reflectance, raindrops on lens causing artefacts. Interesting parameters: Rain rate, droplet size, droplet size distribution. <u>Fog</u> Fog implies a reduction of the visibility, which corresponds to a reduction of the contrast of the objects (including signs, road markings, obstacles, etc.) against the background, reducing range of what can be visible. Interesting parameters: optical attenuation, visibility (MOR), density distribution, droplet size distribution. <u>Snow</u> Snow creates near field obstructions from falling snow. For the far field, there is a decrease of contrast. Snow build-up on ground creates areas of high reflectance for light. Interesting parameters: Snow rate (e.g., cm/h), visibility, snow particle (flake) size, snow thickness (on ground). <u>Other attributes</u> The above-mentioned weather conditions can also interact with other parameters such as the overall luminosity of the scene, amount and type of clouds, sun or other light sources in the sensor field of view, wetness of surfaces, etc. Interesting parameters: Illumination of the scene (localised, even, light level).
Weather impact - Open questions	Impact of brightness in the scene and exposure settings, temperature dependence. Impact of camera calibration parameters, e.g., image signal processor (ISP) parameters, colour filter array (CFA) algorithm. Impact of other water droplet sources such as road spray.

4.1.2 LiDAR

Sensor type: LiDAR	
Description	Light beam emitted in vertical channels and rotating horizontally. Emitted/Detected beams are in the near infrared (NIR) and for automotive the used wavelength is either in the range 850-910 nm or around 1550 nm. ROADVIEW will be looking to use mechanical scanning LiDAR due to costs and availability. A picture of different automotive LiDAR technologies is shown in the graph below (Figure 7), from [18].

	 **Figure 7 Overview of automotive LiDAR technologies.**
Weather impact - Known	<u>Rain</u> Rain has an impact on LiDARs both directly and indirectly, as it does for cameras. The direct impact comes from drops falling in the air. This impact causes an increase of background noise and decreased range, as shown in WMG work [19]. Beyon et al. [31] also investigates how LiDAR is attenuated and scattered as a function of droplet sizes. The work is underway in the literature to try to filter out these effects [30]. The impact of rain can also be indirect. As rain wets the surfaces and objects around the vehicle, the reflectivity level of these objects will change, which can have an impact on the reflected beams' intensity and direction. Also, the spray effect behind the wheels of moving vehicles creates a cloudy effect area, more like fog and with a strong impact on the LiDAR. Finally, the fact that the LiDAR itself is wet, and dirty, has a strong impact on the recorded data. Interesting parameters: droplet size distribution, rain rate. <u>Fog</u> Fog involves the presence of water droplets in the air, ranging in size from a few tenths of a micron to a few dozen microns. The droplets within this size range have an impact on light transmission (including the 350 - 2450 nm bandwidth), so any sensors using these wavelengths can be affected [10]. LiDARs often use wavelengths between 905 nm and 1550 nm, and are therefore affected by fog, i.e., detecting droplets as an obstacle instead of a real obstacle behind it.

	In practice, LiDAR within quite dense fog conditions will detect the fog as a fake wall in front of itself. Interesting parameters: Visibility (MOR), droplet size distribution. <u>Snow</u> Some known effects from [23]: • Powder snow takes off from the road surface when driven over. • In turbulent snow conditions, all tested sensors were blocked by the powder snow and their viewing distance was shortened. • None of the tested sensors performed significantly better than the others. 'Blooming' effects (objects appears bigger) on highly reflective areas (for instance areas covered in snow/ice) can be observed mostly by flashing type LiDARs. 'Ghost' effects (object appears multiple times) due to highly reflective areas (for instance areas covered in snow/ice) and the lens system. Interesting parameters: Snow rate (e.g., cm/h), visibility, snow particle (flake) size, snow thickness (on ground), swirling snow. <u>Other attributes</u> The spectrum of the sun includes the infrared range in which LiDAR sensors operate. 100 klux or 1000 W/m² can be considered as a typical daylight scenario. Depending on the technology, this can heavily lower the signal to noise ratio and might influence the post processed point clouds. In general LiDARs are quite robust against sunlight.
Weather impact - Open questions	Weather impact on different LiDAR technology, potential problem with wet/reflective road surfaces. Uncertain what are the most useful parameters for snow and LiDAR impact.

4.1.3 Radar

Sensor type: 4D Radar	
Description	Imaging radar (radio detection and ranging) sensors can be differentiated according to their technology. There are pulse radars and (frequency modulated) continuous wave (FMCW) radars. The latter technology is typical for automotive applications and will therefore be explained in more detail. The antenna of a 4D imaging radar emits a continuous radio wave (electromagnetic radiation in a certain spectrum) which has a very fast frequency increase (a frequency ramp). The propagating electromagnetic wave is reflected at the surface of surrounding objects and received again. The transmitted (Tx) and received (Rx) waves are mixed in the radar RF circuitry resulting in a signal containing the difference in frequency (**Δf)** between Tx and Rx signals. To measure distance with a FMCW radar, the difference in frequency between Tx and Rx signal is used to determine the time delay (**Δt**) of both signals. From this time delay the distance of an object can be derived by taking the speed of light into account (Figure 8). In order to measure the relative velocity of an object, multiple ramps are transmitted and received. If an object is moving away or towards the radar, the time delay changes for subsequent ramps and this leads to a change in the frequency difference over time (the Doppler effect) (Figure 9), and the relative frequency between Tx and Rx can be used to determine the increase in frequency caused by the Doppler effect. Using the

	Doppler effect, it is possible to calculate the relative speed between the transmitter and the object (Figure 10).

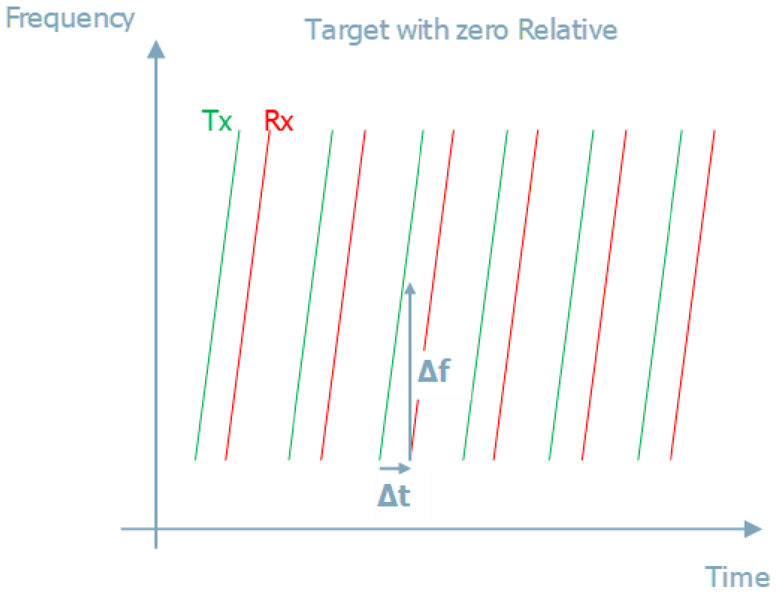


Figure 8 Frequency-time diagram radar – zero Relative Velocity

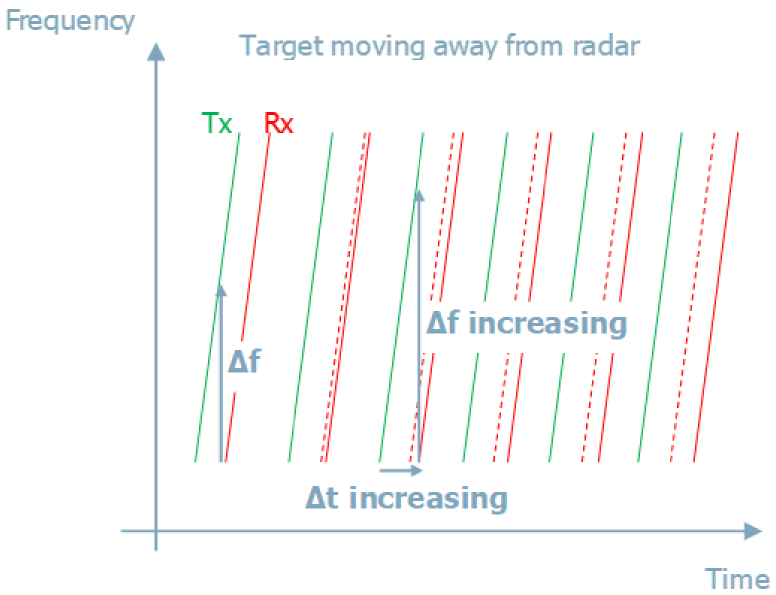


Figure 9 Frequency-time diagram radar – object moving away from radar

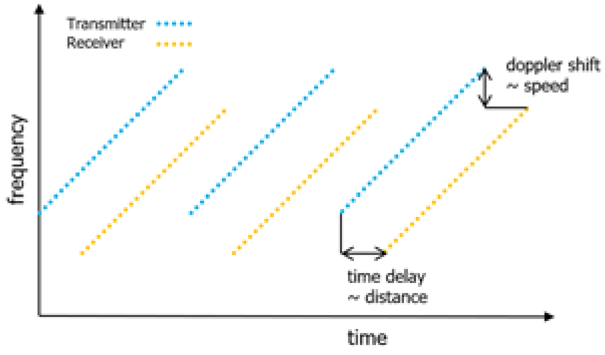


Figure 10 Frequency-time diagram radar

In order to measure four dimensions (radial distance and speed, elevation and azimuth), which is necessary for advanced automotive applications, the radar has to measure spatially. This can be done with a transmitter and receiver antenna array and the ability for electrical 2D beamforming (no mechanical moving parts for scanning). The shape of the beam (total radiation pattern) is determined by the antenna array (geometry, number and spacing and the radiation pattern of the single antenna itself). It is possible to measure the direction of the reflected signal in azimuth and elevation with multiple receiver antennas. Due to spatially separated receiving antennas, there is a time delay for the reflected signal for each antenna. With this timing difference and the geometrical layout, the angle of the object can be calculated. With this information a point cloud can be generated containing information in 4 dimensions (range, radial velocity, azimuth angle and elevation angle) for each point.

The radar is able to discriminate objects in any of the 4 dimensions, for example, if there are 2 objects at the same range, azimuth and elevation but they are travelling at different speeds, the radar can provide an independent detection for both objects. An example of a 4D radar is shown in Figure 11.

Figure 11 ZF ProWave 4D imaging radar

Typical parameters:

- Frequency: 77 GHz
- Range: Multiple Modes (short-range 100m, mid-range 200m, long-range 350m)
- Azimuth: +- 60, +- 45°, +- 20° (short, mid and long-range)
- Elevation: +- 15°

Advantages:

	• Selectable Range mode • Direct measurement of speed • Determining the angle of elevation (Surroundings in 3D and speed) • Work equally well in poor visibility conditions such as oncoming headlight glare, rain, or fog (compared to camera or LiDAR) • Multiple channels • Concealed installation possible • Privacy by design • Robust against weather conditions (compared to State-of-the-Art LiDAR) Disadvantages: • Lower resolution compared to State-of-the-Art LiDAR
Weather impact - Known	Rain and Fog Based on previous work, 77GHz is less affected by light rain and fog compared to camera and LiDAR. However, harsh weather conditions might have an impact on RADAR performance, as shown for example in [23]. Moreover, wetness of objects or water films/spray can have implications on RADAR performance. Interesting parameters: Rain rate, droplet size, droplet distribution. Snow RADAR might be affected by particles of big size, so it is expected that big snowflakes might have implications, as well as snow build up on objects. Interesting parameters: Snow rate (based on cm/h), visibility, snow particle size.
Weather impact - **Open questions**	Impact of heavy rain not well known, the signal to noise ratio could be reduced (lowers performance). Impact of ice on the radar cover not well known. Potential Reflectivity/Radar Cross Section variation due to precipitation. No detailed investigation with respect to other extreme weather conditions is done explicitly with current simulation software. Holistic approach in investigation the effect of snow on RADAR needed.

4.1.4 Thermal Camera

Sensor type: Thermographic (thermal/infrared) Camera	
Description	A thermal camera (also called infrared camera or thermal camera) is a sensor that creates an image using infrared (IR) radiation. Infrared cameras are sensitive to wavelengths from about 1 µm to about 14 µm. Low-cost sensors are usually uncooled vanadium oxide (VOx) microbolometers such as Flir Boson [20], which are passive sensors in the far IR and have a spectral range of 7.5 µm to 14 µm. These sensors are able to detect the black body radiation emitted from each object. Thermal cameras are not the main project focus and will e.g., not be modelled in simulators (WP3), but nevertheless may be used to some extent in the project (e.g., in WP5 to detect road slipperiness) and some information is therefore included here.

Weather impact - Known	• Atmosphere transition of 10 µm under foggy conditions is better than 5 µm. LWIR system such as Flir Boson is favourable [21]. • Best at short distances (a few 100 meters) [21]. • At a distance between 10 and 25 m, objects can be detected under very thick fog conditions (up to a meteorological optical range (MOR) of 13 m) [22].
Weather impact - Open questions	No knowledge about powder snow or snowflakes effect to detection of objects in IR imagers.

5 Considerations for ODD Attributes

Below we discuss ODD attributes particularly interesting for the ROADVIEW project, and give a motivation why certain classifications, metrics, and limits have been selected. Except for the modifications or amendments discussed in this chapter, the standard attributes from ISO 34503 have been used in our ODD definitions.

In general, we have opted to use already existing classifications and ranges as these promote a common understanding on e.g., what constitutes light or heavy rain. This also gives classes that are comparable between implementations and easy to convey (e.g., “the ADS handles light and moderate rain, but not heavy or violent rain”).

It should be noted, however, that for a particular ADS implementation/sensor setup, it might make more sense to use other ranges to define what is inside or outside the ODD, or to highlight different performance levels. Such limits may depend on, e.g., the application of the system and sensor performance in different ranges. For example, if the implementation would depend on detecting rain levels and this detection has a specific performance characteristic (which is not necessarily linear throughout the range), then this characteristic together with the needed confidence level of the measure, which in turn depends on the risk level, may determine the limit where the ADS must execute the fallback to be certain not to leave the ODD. Such limits, however, are very implementation specific.

As the focus of the project is on adverse weather conditions, some attributes are more closely considered, as illustrated by the highlighted (red boxes) attributes in Figure 12, mainly some of the weather attributes, drivable area, and presence of some other traffic agents. The other attributes are determined by the conditions given by the capability and context for the demonstrations, use cases and scenarios as described in deliverable D2.2, but there is no focus on extending these capabilities in the project.

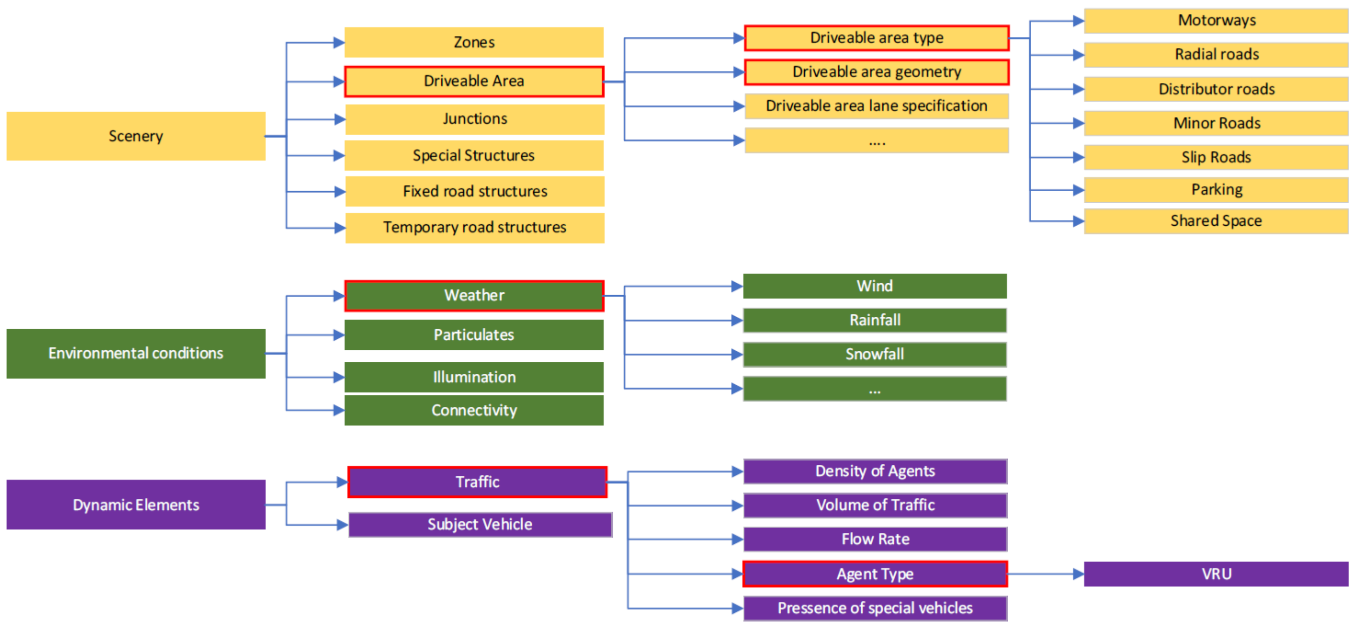


Figure 12 ODD Attributes (simplified from [3]).

5.1 Weather Attributes

In ROADVIEW, data collection for modelling and validation (WP3), and testing-in-the-loop (WP7) are done in two test facilities for rain and fog, provided by partners Carissma and Cerema, by simulation, and on open-road or test tracks. When applicable, the capabilities of the controlled test facilities are mentioned for each attribute below.

5.1.1 Rain

The characteristics and typical metrics for rain are described in Sec. 3.1. The most common metrics used are quantity of rain, or rainfall rate, typically measured in mm/h. Another important parameter is droplet size distribution (DSD). In this section, we investigate typical range classifications and make a choice of parameters for the ODD definitions in ROADVIEW.

5.1.1.1 Ranges

There are several different range classifications, i.e., discretization where ranges of mm/h are assigned specific designations, such as light or heavy rain. Table 6 shows three examples of such rain rate classifications.

Table 6 Rain classification examples.

ISO 34503		Met Office (UK)		NF P99-320 (France)	
Classification	Range	Classification	Range	Classification	Range
No Rain	0 mm/h			Very Light	< 0.1mm/h
Light	< 2.5 mm/h	Slight	< 2mm/h	Light	0.1 – 2.5 mm/h
Moderate	2.5 – 7.6 mm/h	Moderate	2–10 mm/h	Moderate	2.5 – 7.5 mm/h
Heavy	7.6 – 50 mm/h	Heavy	10–50 mm/h	Strong	> 7.5 mm/h
Violent	50 – 100 mm/h	Violent	> 50 mm/h		
Cloudburst	> 100 mm/h				

5.1.1.2 Rain in ODD Definition

For the ODD definitions in the project, we use the designations from the ODD Taxonomy standard ISO 34503 [3]. In addition, we add the possibility of using droplet sizes. We have currently added the three major categories of drizzle (Ø > 4 mm) , normal rain 0.5 > Ø > 5 mm, and torrential rain Ø > 5 mm. However, it is possible this need to be refined further during the project.

In the ODD definition, rain is captured both as the direct phenomena of falling water, due to its potential impact on sensors, and indirectly as conditions of the road surface (wet surface, puddles). The combination of rain and traffic is also discussed in Sec. 5.1.4 (road spray).

Other parameters mentioned in ISO 34503, such as interval, spatial scale, dynamic/frontal, or rate of onset, have not currently been included as the application for testing is not clear.

5.1.1.3 Test capabilities

There are two physical test facilities for rain tests in the project:

- In the Carissma facility, rain rates of 16-99 mm/h can be generated. The rate is measurable, controllable, and validated.
- In the Cerema facility, rain rates of 16-180 mm/h can be generated. There are two different setups (Tunnel and G-house) where the rain can be controlled in a few different working ranges.

At the test facilities constant raindrop speed and no wind is typically assumed. It is currently not possible to create phenomena such as combination of wind and rain, rain from different directions, or rain bursts with quickly varying intensity.

In addition to physical tests, simulation can be used [19].

5.1.2 Fog

The characteristics and typical metrics for fog are described in Sec. 3.2. The most common metrics are visibility measured in MOR, and droplet size distribution.

5.1.2.1 Ranges

Table 7 provides example classifications for fog based on visibility. ISO 34503 does not provide any pre-defined classification for fog.

Table 7 Fog classification examples (Abbreviation: vis-visibility).

ISO 34503		Met Office (UK)		NF P99-320 (France)	
Classification	Range	Classification	Range	Classification	Range
N/a	N/a	Aviation	< 1000m		
		Effect on motorist and public	< 200m	1	200 m < vis < 400 m
		Severe disruption	< 50 m	2	200 m < vis < 100m
				3	100 m < vis < 50 m
				4	vis < 50 m

5.1.2.2 Fog in ODD Definition

ISO 34503 does not propose a fog classification but mentions that visibility (in MOR) can be useful. It also mentions the dependency on size distribution of particles.

For ROADVIEW, a visibility classification has been added according to Table 8. This classification is based on experience from the test facilities. Fog has been classified into the two sub-attributes sea fog and continental fog, as they differ in typical particle size distribution. For both types of fog, the main metric is visibility expressed in MOR.

Table 8 Fog classes used in ROADVIEW.

Fog attribute	Fog classes	Metric
Sea fog	Dense sea	10 < MOR < 30 m
	Medium sea	30 < MOR < 60 m
	Light sea fog	MOR > 60 m
Continental fog	Dense continental	10 < MOR < 30 m
	Medium continental	30 < MOR < 60 m
	Light continental	MOR > 60 m

5.1.2.3 Test Capabilities

There are two physical test facilities for fog tests in the project:

- In the Carissma facility, fog with visibility 10-100 m can be generated. The rate is measurable and to some extent controllable.
- In the Cerema facility, fog with visibility 10-400+ m can be generated, but it can be maintained at between 10-80 m. Droplets of 0.8 micron for radiative fog, and 0.8-8 micron for advective fog.

In addition to physical tests, simulation can be used.

5.1.3 Snow

The characteristics and typical metrics for fog are described in Sec. 3.3. The most common metrics are visibility measured in MOR, or water equivalent content. Flake size distribution is another possible metric, but more difficult to measure.

5.1.3.1 Ranges

Like for rain, there are also several snow range classifications. ISO 34503 use visibility as basis for snow classes, A comparison is shown in Table 9. The snow categories in water equivalent content according to World Meteorological Organization (WMO):

- Light: water equivalent < 1.0 mm/h
- Moderate: 1.0 mm/h < water equivalent < 5.0 mm/h
- Heavy: water equivalent > 5.0 mm/h

Table 9 Snow classification examples (Abbreviation: vis-visibility).

ISO 34503		Met Office (UK)		U.S. Federal Meteorological Handbook	
Classification	Range	Classification	Range	Classification	Range
No Snow	N/a				
Light Snow	vis > 1 km	Slight	< 0.5 cm/h	Light	vis > 1.6 km
Moderate Snow	0.5 km > vis > 1 km	Moderate	0.5 – 4.0 cm/h	Moderate	1.6 km < vis < 0.6 km

Heavy Snow	vis < 0.5 km	Heavy	> 4.0 cm/h	Heavy	vis < 0.6 km

5.1.3.2 Snow in ODD Definition

Since the reference for visibility is based on human vision, it is not necessarily applicable for, or easily converted to, performance for all types of sensors. However, as it is an open question at this point if there are better ways to characterize snow in an ODD definition, visibility is used as a starting point for the project. Other metrics such as flake size distribution or intensity can be added later if deemed useful.

The snow visibility classifications from ISO 34503 are used. However, based on the experience of real snow conditions from the Nordic partners, an additional class is added, very heavy snow with visibility < 0.1 km.

The effect of circulating snow from the ground is also discussed in Sec. 5.1.4.

5.1.3.3 Test capabilities

There are no test facilities in the project for controlled snow tests. Physical testing is largely dependent on such conditions occurring in test tracks or open-road tests.

5.1.4 Road Weather

Some environment phenomena, such as swirling snow on the road, may be described as secondary phenomena, appearing as a consequence of the interaction between several primary attributes already described in the ODD definition. There are several potential ways to handle such phenomena. One option would be not to describe it in the ODD definition at all, but to rely on the users to infer such dependencies and their consequences. However, the risk is that they are inadvertently overlooked. Another option is to state is as a dependency between parameters. ISO 34503 has a construct called conditional to describe ODD limitations where one attribute is dependent on another. However, this construct does not appear to explicitly express the nature of the emergent phenomena due to this dependency. To explicitly express the phenomena another form of dependency statement would be needed, or one can simply add new attributes to the ODD definition even if they are due to such dependencies.

In ROADVIEW, we have opted to add a new attribute called “road weather” as a sub-attribute to weather to explicitly include some types of weather phenomena of particular interest when investigating harsh weather. The phenomena included in the road weather attribute are listed in Table 10. We do not, at this point, include a metric specifying different magnitudes of the phenomena. It might be useful in the future, but for now, it is simply a binary classification if these phenomena are included or excluded from the ODD.

Table 10 The “road weather” ODD attribute.

Attribute	Cause
Water spray	Water on the drivable area combined with moving road vehicles causing water spray. This can occur during rain and after rain as long as there is still water on the road.
Swirling snow	Snow on the drivable area or at the side of the road combined with moving road vehicles or winds causing snowflakes to swirl around in the air over the road. This can occur as long as there is loose snow present. At colder temperatures the snow is less sticky and thus more likely to swirl compared to near zero temperatures.
Swirling leaves	Leaves on the drivable area combined with other moving road vehicles or strong winds causing fallen leaves to swirl in the air above the road. This is most prevalent in the autumns, when the leaves fall, in areas with trees and bushes. Note that leaves on road (which can e.g. cause slippery road and cover road markings) is in another category, “road surface contaminants”.

5.2 Illumination

5.2.1 Ambient and Artificial Illumination

Illumination is typically specified in the unit lux, which is the unit of illuminance in the SI system. One lux equals one lumen per square metre, where lumen is a measure of visible light emitted from a source per time unit. For road traffic, the sources of illumination are natural light (i.e., sunlight) or artificial light from streetlights, lights from other vehicles or indoor lights in e.g., parking facilities.

Low sun or glares blinding the sensor is another condition that can affect the sensors. These conditions vary with time-of-day, season and geographic location (and is also affecting human drivers). ISO 34503 notes that position and elevation can be used as parameters for daytime light conditions. Artificial light from oncoming vehicles can similarly create blinding glares. However, these kinds of phenomena are not a focus area for the ROADVIEW project and, therefore, not elaborated on in the ODD definitions. Thus, the definitions only contain illumination ranges in lux.

5.2.1.1 Test capabilities

- The Carissma test facility for rain and fog can change illumination levels between ~10 to 150 lux.
- The Cerema test facility for rain and fog can provide daylight or night-time conditions (by covering or uncovering the greenhouse).

5.2.2 Clouds

Clouds are in ISO 34503 measured in oktas, which is also the typical metrics used in meteorology. This metric estimates how large part of the sky over a given location is covered in clouds (as measured in 1/8 to 8/8, hence oktas). Cloudiness affects overall illumination and can also cause variance in illumination/sunlight. To assess this, it would be useful to know cloudiness and probably especially the number of low and middle clouds, as well as the direction in which they cover the sun. This can be visualized remotely using satellite data. Since it is not readily measured and not a measure that considers the thickness or cloud type, it does not directly translate to visibility or sensor performance. Hence, we have currently opted not use this cloud metric in our ODD definitions.

5.3 Other ODD Attributes

5.3.1 Dynamic Elements

Traffic is defined in the ODD attribute dynamic elements – traffic, and divided into different types of agents (car, truck, pedestrian, bicycle, two-wheeler, animal, as well as special vehicles such as an ambulance) and whether they are stationary or moving.

ISO 34503 suggests the density of traffic is specified as the density of agents (e.g., agents/km of road), volume (e.g., agents passing a reference point during a specific time period) or flow rate (e.g., agents/h). Another measure often used by traffic authorities is annual average daily traffic flow (AADF), which is the average volume of vehicles on a specific road as measured over a year, i.e., agents/day. This gives a simple measure of how busy a road is and averages out differences over time-of-day, day-of-week, and seasons.

The appropriate metric for traffic density should be considered in relation to the intended use. For instance, in D2.2 some of the scenarios include pedestrians and many include other vehicles. Thus, specifying which types of agents are considered by each demonstrator is an important part of the ADS specification. Hence, for the ROADVIEW project, it is relevant to include in the OD definitions which types of agents are within or outside the ODD.

When it comes to density or flow rate, this information can be used for instance to determine the complexity (in terms of the number of agents) of test scenarios that are necessary and how many other agents an ADS must be able to handle. It can also be necessary for the risk assessment. E.g., a certain detection capability of different agent types may translate to a maximum density/rate of traffic allowed before the risk of accidents becomes too high. This can result in an ADS being designed with an ODD limitation setting a threshold for allowed density or rate that must be measured and monitored to determine if the vehicle is within its ODD. For this project, however, the selected test scenarios (see D2.2) are simpler with a fixed number of agents as the project focus is harsh weather and not stretching the limits in terms of the complexity of scenarios. For this reason, we have not specified traffic in terms of density or flow rates, only in terms of which types of agents are in the ODD and if they can be stationary or moving. Density or rate can be added to each agent type or as a total for all agents if needed.

5.3.2 Drivable Area

Some other attributes to note that have been added since they may become relevant are:

- The slip roads attribute has been refined to on-ramp and off-ramp as they appear in some highway scenarios.
- Divided drivable area (i.e., no oncoming traffic) has been refined to distance separated or separated by a solid barrier, as this may have an effect on how sensors perceive the edge-of-road.
- The ice road surface condition has been refined to black ice or just ice, where black ice is transparent, often patchy, and more difficult to detect.
- Snow-on-road has been refined to thin (< 1 cm) or thick snow to indicate there is likely differences depending on the amount of snow and not just a binary no snow or unlimited snow. However, the two classes are somewhat arbitrary chosen as what are reasonable is an open question.
- Snow poles (see Figure 13) have been added as a potential drivable area edge marker.

Figure 13 Snow pole marking the edge of the road (poles are located some distance outside the drivable area).

5.3.3 Connectivity

Connectivity in ISO 34503 is divided into communication and positioning attributes, where communication includes V2X (vehicle to anything, e.g., infrastructure or other vehicles). In ROADVIEW, positioning is used by the demonstrators, but it is not a focus of the project to test or improve the positioning functionality, so no metrics are used for the positioning attribute.

There are scenarios with vehicle to infrastructure communication in the project (see D2.2), where roadside sensors are used to improve the perception of the automated vehicles. Signal strength and interference are suggested as possible metrics for the communication between CAV and infrastructure, but again the focus of the project is on performance of the sensors, not the communication link, even if this is an important issue on its own.

6 ODD Definitions for ROADVIEW

In the subsections below, the ODD definitions for three types of drivable areas (defined in D2.2) are listed. Each ODD is divided into three tables for each of the top-attributes in the ODD taxonomy illustrated in Figure 2; scenery, environmental conditions, and dynamic elements.

The qualifier (Q) column can be one of include (I), which means the attribute is within this ODD, exclude (E), which means it is not in the ODD, and conditional (C), which means it is inside but given some condition, e.g., a maximum value on some metric. The qualifiers in each section reflect the capabilities of the demonstration vehicles and expected environmental conditions for the different use cases.

6.1 ODD for Highway

6.1.1 Scenery

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Zones					
Geo-fenced areas				I	Highway section
Zone type	Traffic mgmt. zones			E	
	School zones			E	
	Interference zones			E	
	Port zone			E	
	Freight distr. centre			E	
Regions or states				I	Turkey
Drivable Area					
Drivable area type	Motorways or highways	Active traffic mgmt.		C	<= 60 km/h
		No active traffic mgmt.		C	<= 60 km/h
	Primary roads	No active traffic mgmt.		E	
	Radial roads	No active traffic mgmt.		E	
	Distributor roads	No active traffic mgmt.		E	
	Minor/local roads	No active traffic mgmt.		E	
	Slip roads	No active traffic mgmt.	Highway on-ramp	I	
		No active traffic mgmt.	Highway off-ramp	I	
	Parking	No active traffic mgmt.		E	
	Shared space	No active traffic mgmt.		E	
Drivable area geometry	Horizontal plane	Straight lines		I	
		Curves		C	Rad > 500 m
	Transverse plane	Divided	Separated	E	
			Solid barrier	I	
		Undivided		E	
		Pavements		E	
		Barrier on the edges		E	
		Types of lanes together	Traffic/on-ramp	I	
			Traffic/traffic	I	
			Traffic/off-ramp	I	
		Superelevation/banking		E	
	Longitudinal plane	Up-slope		C	<= 12%
		Down-slope		C	<= 12%
		Level plane		I	
Drivable area lane specification	Lane dimensions	Lane width		C	3.75 m
	Lane marking			I	
	Lane Type	Bus lane		E	
		Traffic lane		I	
		Cyclists' lane		E	
		Tram lane		E	
		Emergency lane		E	MRC only

		Shared lane		E	
		Other special purpose lane		E	
	Number of lanes			I	2
	Direction of travel	Right-hand travel		I	
		Left-hand travel		E	
Drivable area signs	Information	Variable		E	
		Uniform		E	
	Regulatory	Variable		E	
		Uniform		I	
	Warning	Variable		E	
		Uniform		I	
Drivable area edge	Line markers			I	
	Shoulder	paved		I	
		gravel		I	
		grass		I	
	Snowbanks			I	
	Solid barriers			I	
	Temporary lines			E	
	Snow plow markers			E	
	none			E	
Drivable area surface	Induced road surface conditions	Icy roads	Black ice	E	
			Ice	E	
		Mirage		I	
		Snow on road	thin snow (<1 cm)	I	
			thick snow (>1 cm)	E	
		Water on road	Wet road	I	
			Standing water	I	
			Flooded roadways	E	
		Surface contamination	Sand	I	
			Leaves	I	
			larger debris	I	
			Oil spill	E	
	Road surface features	cracks		I	
		potholes		I	
		ruts		I	
		swells		I	
		Speed bump		E	
		Other speed obstacle		E	
	Road surface types	Loose (e.g., gravel, earth, sand)		E	
		Segmented (e.g., concrete slabs)		E	
		Uniform (e.g., asphalt)		C	Only asphalt
Junctions					
Roundabout	Normal	Signalised		E	
		Non-signalised		E	
	Compact	Signalised		E	
		Non-signalised		E	
	Double	Signalised		E	
		Non-signalised		E	
	Large	Signalised		E	
		Non-signalised		E	
	Mini	Signalised		E	
		Non-signalised		E	
Intersection	T-junctions	Signalised		E	
		Non-signalised		E	
	Staggered	Signalised		E	
		Non-signalised		E	

	Y junction	Signalised		E	
		Non-signalised		E	
	Crossroads	Signalised		E	
		Non-signalised		E	
	Grade separated	Signalised		E	
		Non-signalised		E	
Special Structures					
Automatic access control				I	
Bridges				E	
Pedestrian crossings				E	
Rail crossings				E	
Tunnels				E	
Toll plaza				E	
Basic Road Structures					
Buildings				I	
Streetlights				I	
Street furniture				E	
Vegetation				I	
Temporary Road Structures					
Construction site detours				I	
Refuse collection				E	
Road works				I	
Road signage				E	

6.1.2 Environmental Conditions

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Weather					
Wind	Calm	0–0.2 m/s		I	
	Light air	0.3–1.5 m/s		I	
	Light breeze	1.6–3.3 m/s		I	
	Gentle breeze	3.4–5.4 m/s		I	
	Moderate breeze	5.5–7.9 m/s		I	
	Fresh breeze	8.0–10.7 m/s		I	
	Strong breeze	10.8–13.8 m/s		I	
	Near gale	13.9–17.1 m/s		E	
	Gale	17.2–20.7 m/s		E	
	Strong gale	20.8–24.4 m/s		E	
	Storm	24.5–28.4 m/s		E	
	Violent storm	28.5–32.6 m/s		E	
	Hurricane force	>= 32.7 m/s		E	
Rainfall	Light rain	rain rate <2.5 mm/h	Droplet Ø < 0.5 mm	I	
			0.5 <= Droplet Ø <= 5 mm	I	
			Droplet Ø > 5 mm	I	
	Moderate rain	between 2.5 and 7.6 mm/h		I	
	Heavy rain	between 7.6 and 50 mm/h		I	
	Violent rain	between 50 and 100 mm/h		E	
	Cloudburst	rain rate is > 100 mm/h.		E	
Snowfall	Light snow	visibility > 1 km.		I	
	Moderate snow	visibility between 0.5 and 1 km		I	
	Heavy snow	visibility between 0.1 and 0.5 km		E	
	Very heavy snow	Visibility < 100m		E	

Freezing rain				E	
Hail				E	
Temperature				C	-10 to +40 °C
Particulates	Non-precipitating water droplets	Sea fog	Dense (10 < MOR < 20 m)	E	
			Med. (30 < MOR < 60 m)	E	
			Light (MOR > 60 m)	E	
		Continental fog	Dense (10 < MOR < 20 m)	E	
			Med. (30 < MOR < 60 m)	E	
			Light (MOR > 60 m)	I	
	Sand and dust			I	
	Smoke and pollution			I	
	Volcanic ash			E	
	Blowing debris			I	
Road weather	Water spray			I	
	Swirling leaves			I	
	Swirling snow			E	
Illumination					
Daytime	> 2000 lx			I	
Night	< 1 lx			E	
Low ambient lighting	> 1 lx and <2000 lx			I	
Artificial illumination	streetlights, oncoming vehicle lights, indoor lights (e.g. parking facilities)			I	
Solar flares				E	
Cloudiness	Clear or partly cloudy			I	
	Full overcast			E	
Connectivity					
Communication	Vehicle to Vehicle	Cellular		E	
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to Infrastructure	Cellular		I	
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to pedestrian			E	
	Vehicle to network			E	
Positioning	GNSS	Galileo		I	
		GLONASS		E	
		GPS		I	
		RTK		E	
	Local positioning			E	

6.1.3 Dynamic Elements

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Traffic					
Agent type	motor vehicle	car	Moving	I	
			Stationary	I	
		truck	Moving	I	
			Stationary	I	
		bus	Moving	I	
			Stationary	I	
		other motor vehicle	Moving	I	
			Stationary	I	
	vulnerable road users	pedestrian	Moving	I	
			Stationary	I	
		bicycle	Moving	I	
			Stationary	I	
		two-wheeler	Moving	I	
			Stationary	I	
		e-scooter	Moving	I	
			Stationary	I	
		other VRU	Moving	I	
			Stationary	I	
	animals	horse rider	Moving	I	
			Stationary	I	
		wild animals	Moving	I	
			Stationary	I	
Presence of special vehicles	ambulances			I	
	police vehicles			I	
	Work vehicles			I	
Subject Vehicle					
speed				C	<= 60 km/h
pre-defined route				I	

6.2 ODD for Urban Traffic

For the urban traffic case, the qualifier section reflects the expected capability of a typical urban traffic ADS feature, and restrictions in the demonstrator vehicle used in the ROADVIEW project are indicated in parenthesis, e.g., I (E) would mean a typical urban feature would include the attribute, but the demonstrator has a limitation and does not include the attribute.

6.2.1 Scenery

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Zones					
Geo-fenced areas				E	
Zone type	Traffic mgmt. zones			I (E)	
	School zones			I (E)	
	Interference zones			I (E)	
	Port zone			E	
	Freight distr. centre			E	
Regions or states				I	Germany (test track)
Drivable Area					
Drivable area type	Motorways or highways	Active traffic mgmt.		E	
		No active traffic mgmt.		E	

	Primary roads	No active traffic mgmt.		C	30-50 km/h
	Radial roads	No active traffic mgmt.		E	
	Distributor roads	No active traffic mgmt.		C (E)	50 km/h
	Minor/local roads	No active traffic mgmt.		C	50 km/h
	Slip roads	No active traffic mgmt.	Highway on-ramp	E	
		No active traffic mgmt.	Highway off-ramp	E	
	Parking	No active traffic mgmt.		I	
	Shared space	No active traffic mgmt.	Cyclist on road	C	7-30 km/h
Drivable area geometry	Horizontal plane	Straight lines		I	
		Curves		I	
	Transverse plane	Divided	Separated	E	
			Solid barrier	E	
		Undivided		I	
		Pavements		I (E)	
		Barrier on the edges		I (E)	
		Types of lanes together		E	
		Superelevation/banking		E	
	Longitudinal plane	Up-slope		C (E)	<= 5%
		Down-slope		C (E)	<= 5%
		Level plane		I	
Drivable area lane specification	Lane dimensions	Lane width		C	>3.75m
	Lane marking			I	
	Lane Type	Bus lane		I (E)	
		Traffic lane		I	
		Cyclists' lane		I (E)	
		Tram lane		I (E)	
		Emergency lane		E	
		Shared lane		I	
		Other special purpose lane		E	
	Number of lanes			C	1
	Direction of travel	Right-hand travel		I	
		Left-hand travel		I (E)	
Drivable area signs	Information	Variable		E	
		Uniform		E	
	Regulatory	Variable		E	
		Uniform		I	Full-time, temporary
	Warning	Variable		E	
		Uniform		I	Full-time, temporary
Drivable area edge	Line markers			I	
	Shoulder	paved		I	
		gravel		E	
		grass		E	
	Snowbanks			I (E)	
	Solid barriers			I (E)	
	Temporary lines			I (E)	
	Snow plow markers			E	
	none			E	
Drivable area surface	Induced road surface conditions	Icy roads	Black ice	I (E)	
			Ice	I (E)	
		Mirage		I	
		Snow on road	thin snow (<1 cm)	I (E)	
			thick snow (>1 cm)	I (E)	
		Water on road	Wet road	I	
			Standing water	I	
			Flooded roadways	E	
		Surface contamination	Sand	E	

			Leaves	I	
			larger debris	E	
			Oil spill	E	
	Road surface features	cracks		I (E)	
		potholes		I (E)	
		ruts		I (E)	
		swells		I (E)	
		Speed bump		E	
		Other speed obstacle		E	
	Road surface types	Loose (e.g., gravel, earth, sand)		E	
		Segmented (e.g., concrete slabs)		E	
		Uniform (e.g., asphalt)		C	asphalt
Junctions					
Roundabout	Normal	Signalised		E	
		Non-signalised		I (E)	
	Compact	Signalised		E	
		Non-signalised		I (E)	
	Double	Signalised		E	
		Non-signalised		E	
	Large	Signalised		E	
		Non-signalised		E	
	Mini	Signalised		E	
		Non-signalised		I (E)	
Intersection	T-junctions	Signalised		I (E)	
		Non-signalised		I (E)	
	Staggered	Signalised		E	
		Non-signalised		E	
	Y junction	Signalised		E	
		Non-signalised		E	
	Crossroads	Signalised		I	
		Non-signalised		I	
	Grade separated	Signalised		E	
		Non-signalised		E	
Special Structures					
Automatic access control				E	
Bridges				I (E)	
Pedestrian crossings				I	
Rail crossings				E	
Tunnels				E	
Toll plaza				E	
Basic Road Structures					
Buildings				I	
Streetlights				I (E)	
Street furniture				I (E)	
Vegetation				I (E)	
Temporary Road Structures					
Construction site detours				I (E)	
Refuse collection				I (E)	
Road works				I (E)	
Road signage				I (E)	

6.2.2 Environmental Conditions

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
		Weather			
Wind	Calm	0–0.2 m/s		I	
	Light air	0.3–1.5 m/s		I	
	Light breeze	1.6–3.3 m/s		I	
	Gentle breeze	3.4–5.4 m/s		I	
	Moderate breeze	5.5–7.9 m/s		I	
	Fresh breeze	8.0–10.7 m/s		I	
	Strong breeze	10.8–13.8 m/s		I	
	Near gale	13.9–17.1 m/s		E	
	Gale	17.2–20.7 m/s		E	
	Strong gale	20.8–24.4 m/s		E	
	Storm	24.5–28.4 m/s		E	
	Violent storm	28.5–32.6 m/s		E	
	Hurricane force	>= 32.7 m/s		E	
Rainfall	Light rain	rain rate <2.5 mm/h	Droplet Ø < 0.5 mm	I	
			0.5 <= Droplet Ø <= 5 mm	I	
			Droplet Ø > 5 mm	I	
	Moderate rain	between 2.5 and 7.6 mm/h		I	
	Heavy rain	between 7.6 and 50 mm/h		I	
	Violent rain	between 50 and 100 mm/h		E (I)	
	Cloudburst	rain rate is > 100 mm/h.		E (I)	
Snowfall	Light snow	visibility > 1 km.		I (E)	
	Moderate snow	visibility between 0.5 and 1 km		I (E)	
	Heavy snow	visibility between 0.1 and 0.5 km		I (E)	
	Very heavy snow	Visibility < 100m		I (E)	
Freezing rain				E	
Hail				E	
Temperature				C	-40 - 85 °C (0 - 25 °C)
Particulates	Non-precipitating water droplets	Sea fog	Dense (10 < MOR < 20 m)	I (E)	
			Med. (30 < MOR < 60 m)	I (E)	
			Light (MOR > 60 m)	I (E)	
		Continental fog	Dense (10 < MOR < 20 m)	I (E)	
			Med. (30 < MOR < 60 m)	I (E)	
			Light (MOR > 60 m)	I (E)	
	Sand and dust			E	
	Smoke and pollution			E	
	Volcanic ash			E	
	Blowing debris			E	
Road weather	Water spray			I	
	Swirling leaves			I	
	Swirling snow			I (E)	
		Illumination			
Daytime	> 2000 lx			I	
Night	< 1 lx			I (E)	
Low ambient lighting	> 1 lx and <2000 lx			I (E)	
Artificial illumination	streetlights, oncoming vehicle lights, indoor lights (e.g. parking facilities)			I (E)	
Solar flares				E	
Cloudiness	Clear or partly cloudy			I	

	Full overcast			E	
		Connectivity			
Communication	Vehicle to Vehicle	Cellular		E	
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to Infrastructure	Cellular		I	
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to pedestrian			E	
	Vehicle to network			E	
Positioning	GNSS	Galileo		E (I)	
		GLONASS		E	
		GPS		E (I)	
		RTK		E (I)	
	Local positioning			I (E)	

6.2.3 Dynamic Elements

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
		Traffic			
Agent type	motor vehicle	car	Moving	I (E)	
			Stationary	I	
		truck	Moving	I (E)	
			Stationary	I (E)	
		bus	Moving	I (E)	
			Stationary	I (E)	
		other motor vehicle	Moving	I (E)	
			Stationary	I (E)	
	vulnerable road users	pedestrian	Moving	I	
			Stationary	I (E)	
		bicycle	Moving	I	
			Stationary	I	
		two-wheeler	Moving	I (E)	
			Stationary	I (E)	
		e-scooter	Moving	I (E)	
			Stationary	I (E)	
		other VRU	Moving	I (E)	
			Stationary	I (E)	
	animals	horse rider	Moving	I (E)	
			Stationary	I (E)	
		wild animals	Moving	I (E)	
			Stationary	I (E)	
Presence of special vehicles	ambulances			I (E)	
	police vehicles			I (E)	
	Work vehicles			I (E)	
		Subject Vehicle			
speed				C	<= 50 km/h
pre-defined route				I	

6.3 ODD for Rural Road

6.3.1 Scenery

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Zones					
Geo-fenced areas				I	
Zone type	Traffic mgmt. zones			E	
	School zones			E	
	Interference zones			E	
	Port zone			E	
	Freight distr. centre			E	
Regions or states				C	Finland
Drivable Area					
Drivable area type	Motorways or highways	Active traffic mgmt.		E	
		No active traffic mgmt.		E	
	Primary roads	No active traffic mgmt.		E	
	Radial roads	No active traffic mgmt.		E	
	Distributor roads	No active traffic mgmt.		E	
	Minor/local roads	No active traffic mgmt.		C	<= 40 km/h
	Slip roads	No active traffic mgmt.	Highway on-ramp	E	
		No active traffic mgmt.	Highway off-ramp	E	
	Parking	No active traffic mgmt.		E	
	Shared space	No active traffic mgmt.		E	
Drivable area geometry	Horizontal plane	Straight lines		I	
		Curves		I	
	Transverse plane	Divided	Separated	E	
			Solid barrier	E	
		Undivided		I	
		Pavements		E	
		Barrier on the edges		E	
		Types of lanes together		E	
		Superelevation/banking		E	
	Longitudinal plane	Up-slope		I	
		Down-slope		I	
		Level plane		I	
Drivable area lane specification	Lane dimensions	Lane width		C	2.8 m
	Lane marking			E	
	Lane Type	Bus lane		E	
		Traffic lane		I	
		Cyclists' lane		E	
		Tram lane		E	
		Emergency lane		E	
		Shared lane		I	Single lane road
		Other special purpose lane		E	
	Number of lanes			I	1-2
	Direction of travel	Right-hand travel		I	
		Left-hand travel		E	
Drivable area signs	Information	Variable		E	
		Uniform		E	
	Regulatory	Variable		E	
		Uniform		E	
	Warning	Variable		E	
		Uniform		E	
Drivable area edge	Line markers			E	

	Shoulder	paved		I	
		gravel		I	
		grass		I	
	Snowbanks			I	
	Solid barriers			I	
	Temporary lines			E	
	Snow plow markers			I	
	none			I	
Drivable area surface	Induced road surface conditions	Icy roads	Black ice	I	
			Ice	I	
		Mirage		E	
		Snow on road	thin snow (<1 cm)	I	
			thick snow (>1 cm)	I	
		Water on road	Wet road	I	
			Standing water	I	
			Flooded roadways	E	
		Surface contamination	Sand	I	
			Leaves	I	
			larger debris	E	
			Oil spill	E	
	Road surface features	cracks		I	
		potholes		I	
		ruts		I	
		swells		I	
		Speed bump		E	
		Other speed obstacle		E	
	Road surface types	Loose (e.g., gravel, earth, sand)		C	gravel
		Segmented (e.g., concrete slabs)		E	
		Uniform (e.g., asphalt)		I	
Junctions					
Roundabout	Normal	Signalised		E	
		Non-signalised		E	
	Compact	Signalised		E	
		Non-signalised		E	
	Double	Signalised		E	
		Non-signalised		E	
	Large	Signalised		E	
		Non-signalised		E	
	Mini	Signalised		E	
		Non-signalised		E	
Intersection	T-junctions	Signalised		E	
		Non-signalised		E	
	Staggered	Signalised		E	
		Non-signalised		E	
	Y junction	Signalised		E	
		Non-signalised		E	
	Crossroads	Signalised		E	
		Non-signalised		E	
	Grade separated	Signalised		E	
		Non-signalised		E	
Special Structures					
Automatic access control				E	
Bridges				E	
Pedestrian crossings				E	
Rail crossings				E	
Tunnels				E	

Toll plaza				E	
Basic Road Structures					
Buildings				E	
Streetlights				I	
Street furniture				E	
Vegetation				I	
Temporary Road Structures					
Construction site detours				E	
Refuse collection				E	
Road works				E	
Road signage				E	

6.3.2 Environmental Conditions

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Weather					
Wind	Calm	0–0.2 m/s		I	
	Light air	0.3–1.5 m/s		I	
	Light breeze	1.6–3.3 m/s		I	
	Gentle breeze	3.4–5.4 m/s		I	
	Moderate breeze	5.5–7.9 m/s		I	
	Fresh breeze	8.0–10.7 m/s		I	
	Strong breeze	10.8–13.8 m/s		I	
	Near gale	13.9–17.1 m/s		E	
	Gale	17.2–20.7 m/s		E	
	Strong gale	20.8–24.4 m/s		E	
	Storm	24.5–28.4 m/s		E	
	Violent storm	28.5–32.6 m/s		E	
	Hurricane force	>= 32.7 m/s		E	
Rainfall	Light rain	rain rate <2.5 mm/h	Droplet Ø < 0.5 mm	I	
			0.5 <= Droplet Ø <= 5 mm	I	
			Droplet Ø > 5 mm	I	
	Moderate rain	between 2.5 and 7.6 mm/h		I	
	Heavy rain	between 7.6 and 50 mm/h		I	
	Violent rain	between 50 and 100 mm/h		I	
	Cloudburst	rain rate is > 100 mm/h.		E	
Snowfall	Light snow	visibility > 1 km.		I	
	Moderate snow	visibility between 0.5 and 1 km		I	
	Heavy snow	visibility between 0.1 and 0.5 km		I	
	Very heavy snow	Visibility < 100m		I	
Freezing rain				E	
Hail				E	
Temperature				C	-10 to 40 °C
Particulates	Non-precipitating water droplets	Sea fog	Dense (10 < MOR < 20 m)	E	
			Med. (30 < MOR < 60 m)	E	
			Light (MOR > 60 m)	E	
		Continental fog	Dense (10 < MOR < 20 m)	I	
			Med. (30 < MOR < 60 m)	I	
			Light (MOR > 60 m)	I	
	Sand and dust			E	
	Smoke and pollution			E	
	Volcanic ash			E	
	Blowing debris			E	
Road weather	Water spray			I	

	Swirling leaves			I	
	Swirling snow			I	
Illumination					
Daytime	> 2000 lx			I	
Night	< 1 lx			I	
Low ambient lighting	> 1 lx and <2000 lx			I	
Artificial illumination	streetlights, oncoming vehicle lights, indoor lights (e.g., parking facilities)			I	
Solar flares				E	
Cloudiness	Clear or partly cloudy			I	
	Full overcast			I	
Connectivity					
Communication	Vehicle to Vehicle	Cellular		E	
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to Infrastructure	Cellular		C	4G/5G
		Satellite		E	
		802.11p-based Wi-Fi		E	
	Vehicle to pedestrian			E	
	Vehicle to network			E	
Positioning	GNSS	Galileo		I	
		GLONASS		E	
		GPS		I	
		RTK		I	
	Local positioning			C	Map-based

6.3.3 Dynamic Elements

Attribute	Sub-attribute	Classification	Refinement	Q	Condition
Traffic					
Agent type	motor vehicle	car	Moving	I	
			Stationary	I	
		truck	Moving	I	
			Stationary	I	
		bus	Moving	I	
			Stationary	I	
		other motor vehicle	Moving	I	
			Stationary	I	
	vulnerable road users	pedestrian	Moving	I	
			Stationary	I	
		bicycle	Moving	I	
			Stationary	I	
		two-wheeler	Moving	I	
			Stationary	I	
		e-scooter	Moving	I	
			Stationary	I	
		other VRU	Moving	I	
			Stationary	I	
	animals	horse rider	Moving	I	
			Stationary	I	
		wild animals	Moving	I	
			Stationary	I	
Presence of special vehicles	ambulances			E	
	police vehicles			E	
	Work vehicles			E	
Subject Vehicle					
speed				I	
pre-defined route				I	

7 Conclusions

The expectations from this deliverable, according to the project application, is that "An extended ODD taxonomy will be reported considering harsh weather conditions and complex urban/rural environments." To that end, the deliverable has mapped: (i) characteristics of sensors, (ii) capabilities of test environments, (iii) goals of the project in terms of which types of harsh weather are targeted, (iv) other characteristics of the environments where the tests are to be conducted, (v) known and typical ways of quantifying harsh weather conditions. This input has been used to create three ODD definitions—based on the ODD taxonomy from the international standard ISO 34503—for three types of drivable areas that will be investigated in the project: highway, urban traffic, and rural road.

This deliverable is meant to be used in conjunction with D2.2—Use cases and scenarios, which defines specific use cases and scenarios of interest. In the other work packages, the project shall improve the performance of CAVs for the harsh weather conditions included in the ODD and perform tests in the different test environments used in the project, as well as demonstrations for some of the scenarios from D2.2.

The standard ISO 34503 has been developed since the project application was written, which means we had a good foundation for the ODD definitions and less need for extending taxonomies than initially planned, since this standard already captures weather conditions and the need for different environments quite extensively. Therefore, the developed ODD definitions follow the standard quite closely, with just some additional parameters for weather conditions. However, the deliverable also captures the rationale for which metrics to use and which attributes are less relevant to consider, given the project objectives.

In addition to the ODD definition, key terminology for automated driving, scenarios, and test that should be useful for the project has also been collected in this deliverable to harmonize the use of terminology in the project.

An issue to note is that there are open questions when it comes to the impact of weather on perception and decision-making systems, which is the reason behind this project. At the beginning of the project, it is not yet fully known which attributes and metrics are necessary and useful for characterization, implementation, and testing. While we have attempted to look at, e.g., knowledge of sensors and test environments, we expect a need to further refine the parameters as more knowledge is gained during the project.

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