D7.1

CCAM use cases validation requirements

Project short name
SUNRISE

Project full name
Safety assUraNce fRamework for connected, automated mobIlity SystEms

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADS	Automated Driving System
AEB	Autonomous Emergency Braking
ALKS	Automated Lane Keeping System
AV	Automated Vehicle
C-ACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CARLA	Car Learning to Act (simulation tool)
CCAM	Cooperative Connected Automated Mobility
CDA	Cooperative Driving Automation
CoSim	Co-simulation
CP	Collective Perception
CPM	Collective Perception Message
DDT	Dynamic Driving Task
DENM	Decentralized Environmental Notification Message
DSRC	Dedicated Short Range Communication
EEBL	Emergency Electronic Brake Light
ERTRAC	European Road Transport Research Advisory Council
ESC	Electronic Stability Control
ESMINI	Environment Simulator MINImalistic
FCW	Front Collision Warning

FOT	Field Operational Test
FoV	Field-of-View
GA	Grant Agreement
GLOSA	Green Light Optimal Speed Advisory
GPS	Global Positioning System
HD	High Definition (high resolution)
HiL	Hardware in the Loop
HW	HardWare
HWP	Highway Pilot
IMA	Intersection Movement Assist
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
ITS	Intelligent Transport System
ITS-G5	Access technology to be used in frequency bands dedicated for European ITS
KPI	Key Performance Indicator
LD	Lane Detection
LRR	Long-Range Radar
MiL	Model in the Loop
MIMO	Multiple-Input / Multiple-Output
MRC	Minimum Risk Condition
MRM	Minimum Risk Manoeuvre
MRR	Mid-Range Radar
MuCCA	Multi-Car Collision Avoidance (Project)
NLOS	Non-Line Of Sight
OBU	On-Board Unit
OD	Object Detection
ODD	Operational Design Domain

OEDR	Object and Event Detection and Response
OEM	Original Equipment Manufacturer
PAS	Publicly Available Specification
PG	Proving Ground
PoC	Proof of Concept
ROS	Robot Operating System
RSU	Road Side Unit
RWW	Road Works Warning
SA	Safety Assurance
SAE	Society for Automotive Engineers
SAF	Safety Assurance Framework
SciL	Scenario in the Loop
SiL	Software in the Loop
SotA	State of the Art
SPaT	Signal Phase and Timing
SW	SoftWare
SUMO	Simulation of Urban MObility
SuT	System under Test
TBD	To be defined
TJC	Traffic Jam Chauffeur
TL	Traffic Light
TS	Traffic Sign
TTC	Time To Collision
UC	Use Case
UN-R	United Nations Regulation
V2I	Vehicle to infrastructure communication
V2V	Vehicle to vehicle communication

V2X	Vehicle to X communication
VRU	Vulnerable Road User
Wi-Fi	Wireless Fidelity
WP	Work Package

EXECUTIVE SUMMARY

Safety assurance of Cooperative, Connected and Automated Mobility (CCAM) technologies and systems is a crucial factor for their successful adoption in society, yet it remains to be a significant challenge. CCAM must prove to be safe and reliable in every possible driving scenario. It is generally acknowledged that for higher levels of automation, the validation of these systems by real test-driving would be infeasible by conventional methods. Furthermore, certification initiatives worldwide struggle to define a harmonized approach to enable massive deployment of CCAM systems.

In the light of the above, the SUNRISE project aims to develop and demonstrate a commonly accepted, extensible Safety Assurance Framework (SAF) for the test and safety validation of a varied scope of CCAM systems. The overall objective of the SUNRISE project is to accelerate the safe deployment of innovative CCAM technologies and systems for passengers and goods by creating demonstrable and positive impact towards safety, specifically the EU's long-term goal of moving close to zero fatalities and serious injuries by 2050 (Vision Zero), and the resilience of (road) transport systems. SUNRISE aims to achieve this, by creating and sharing a European federated database framework centralising detailed scenarios for testing of CCAM functions and systems in a multitude of relevant test cases, including a virtual harmonised simulation environment with standardised, open interfaces and quality-controlled data exchange. SUNRISE will work closely with CCAM stakeholders such as policy makers, regulators, consumer testing agencies, user associations and other relevant stakeholders.

Following the above, the main goals of the deliverable D7.1 are:

a. to define a set of CCAM validation Use Cases (UCs), based on a broad range of existing automated driving systems (ADS);

b. to define the high-level validation requirements of the selected UCs, by covering the ADS under test behavioural capabilities, the Operational Design Domain (ODD), the scenario testing, the metrics for assessment, the testing methods and tools, and the required data.

The aforementioned goals are quite important due to the fact that the UCs constitute the backbone of all the technical WPs within the SUNRISE project. Additionally, UCs feed the SAF conception, and ultimately, they guide the project's final Proofs of Concepts (PoCs) creation. Furthermore, SUNRISE UCs take into consideration a strong variability of scenarios, tools and types of data needed for validating different ADS while ensuring that the main operational domains present in ERTRAC's CCAM use cases clustering are covered (urban, highway, traffic jam, hub-to-hub freight operation). Connectivity and cybersecurity non-functional aspects are also included explicitly in dedicated sub-UCs since implication of their consideration in a harmonized V&V framework is part of the SUNRISE activities.

Based on the above, SUNRISE UCs aim to cover both:

a. functional aspects (connectivity, traffic context, supported manoeuvres);

b. non-functional aspects (safety, cybersecurity)

Despite their discrete targeting, all defined SUNRISE UCs are traversed by common goals related to scenario-based testing coverage, aspects of virtual testing fidelity and automation as well as scenario description extensibility to incorporate elements coming from CCAM testing using co-simulation (integrating environment, traffic, driver, sensor, vehicle and controls models) or new hybrid types of closed-loop simulation like ViL and SciL.

1. INTRODUCTION

1.1. Project intro

CCAM systems must prove to be reliable in every possible driving scenario, which requires a strong safety argumentation. In this direction, safety assurance of CCAM technologies is a crucial factor for their successful adoption in society, yet it remains to be a significant challenge.

It is already acknowledged that for higher levels of automation, the validation of these systems by means of real test-drives would be infeasible. In consequence, a carefully designed mixture of physical and virtual testing has emerged as a promising approach, with the virtual part bearing more significant weight in this mixture for cost efficiency reasons. Several worldwide initiatives have started to develop test and assessment methods for ADS. These initiatives have already moved from conventional validation to a scenario-based data-driven approach and combine different test instances (physical and virtual testing).

The initiatives mentioned above provide new approaches to CCAM validation, and many expert groups formed by different stakeholders are already working on CCAM systems' testing and quality assurance. Nevertheless, the fact that there is a lack of a common European validation framework and homogeneity regarding validation procedures to ensure safety of these complex systems hampers the deployment of CCAM solutions. In this landscape, the role of standards is paramount in establishing common ground and providing technical guidance. However, standardising the whole pipeline of CCAM validation and assurance is in its infancy, as many of the standards are under development or have been very recently published and still need time to be synchronised and established as common practice.

Scenario databases (SCDBs) are another issue tackled by several initiatives and projects, providing silo solutions. A single concrete approach should be used (at least at the European level), dealing with scenarios of any possible variations, including the creation, editing, parameterisation, storing, exporting, importing, etc. in a universally agreed manner.

Furthermore, validation methods and testing procedures still lack appropriate safety assessment criteria in order to build a robust safety case. These must be set and be valid for the whole parameter space of scenarios. Another level of complexity is added, due to regional differences in traffic rules, signs, actors, and situations.

In the light of the aforementioned statements, SUNRISE aims to develop and demonstrate a commonly accepted, extensible SAF for the testing and safety validation of a varied scope of CCAM systems. SUNRISE aims to achieve this by creating and sharing a European federated database framework centralising detailed scenarios for testing of CCAM functions and systems in a multitude of relevant test cases, including a virtual harmonised simulation environment with standardised, open interfaces and quality-controlled data exchange.

An overview of the SUNRISE SAF considers the following: specific software tools convert (raw) driving data into a SCDB content and abstracts the data, and thereby, structure the driving environment. In this context, a comprehensive scenario concept will be developed in the SUNRISE project, which ensures that the collected scenarios can be converted into a standardized representation that can be easily stored in a SCDB. In addition, a method is to be developed that allows for the selection of relevant scenarios, when extracting from the database for testing. This is a task which needs to be researched in more detail and is one of the goals in SUNRISE. The idea is to structure the parameter space by combining big-data clustering with expert knowledge of ADS and thereby derive subspaces. These subspaces are a collection of similar scenarios which can be tested by selecting specific representatives taking the individual distribution within the subspace into account. This allows an identification of areas of interest in the parameter space that can be tested more systematically.

After extracting the relevant scenarios from the SCDB they can be used for testing. For the sake of efficiency, a large number of scenarios need to be tested in virtual simulation environments with high parallelization. Finally, the test results are used to contribute to a safety argumentation, e.g., via positive risk balance considerations. In addition, human driver reference models can be considered within the developed methodology to be able to compare the safety level of a CCAM system with the human driver performance.

1.2. Purpose of the deliverable

As mentioned previously, one of the basic specific objectives of the SUNRISE project is to demonstrate the SAF in a representative set of UCs in order to prove the robustness, repeatability and versatility of the developed framework when it is applied to different real world and virtual testing environments, by using the V&V toolchain developed in WP4.

There are two main objectives of UCs definition:

a. To be used with WP7 work since these will be the basis for the PoC design leading to the final SUNRISE demos.

b. To be an early input to the SUNRISE SAF, since apart from UC definition the UCs are analysed by the WP7 team in order to also provide preliminary high level validation requirements which will guide the work on project methodology (WP3) and toolchain (WP4).

The present deliverable (D7.1) defines a set of four (4) heterogeneous CCAM UCs with different automation levels and types of operational domains in various mixed traffic situations, as follows:

- UC ID 1: urban AD perception validation

- UC ID 2: traffic jam AD validation

- UC ID 3: highway (co-operative) AD validation
- UC ID 4: freight vehicle automated parking validation

The aforementioned UCs are the ODD-related cases that were initially defined in the Grant Agreement (GA) and are described with refinements in the next chapters. The main aim is to define the high-level validation requirements for testing a broad range of ADS covering both their functional and non-functional aspects. Roles and contributions of the partners participating in the deliverable D7.1 are depicted in detail in Table 1.

Table 1: Partner contribution to D7.1

Role	Who	UC ID
Defining the validation requirements for the urban pilot perception use case	VIF	1
Defining the UC requirements in controlled environments from the vehicle guidance and interaction point of view, with focus in physical testing for perception systems in urban environments	RESA	1
Defining the validation process of the ViL in the case of urban situations	VED	1
Defining the validation requirements for the urban pilot perception use case from the perspective of a TIER-2 manufacturer, focusing on necessary sensor and perception requirements	IFAG	1
Supporting the validation testing with virtual simulations to the perception testing urban pilot use case	CVC	1
Providing a controlled urban scenario description, including all elements of the corresponding environment	RSA	1
Defining validation requirements for the ALKS use case including CCAM functions, scenarios, test case generation methods, tools and methods for execution and KPI assessment	AVL	2
Defining validation requirements for the ALKS use case including CCAM functions, scenarios, test case generation methods, tools and methods for execution and KPI assessment	AVL TR	2
Defining a test strategy for the cooperative driving highway pilot use case	IDI	3
Defining a test strategy for the cooperative driving highway pilot use case	IDI DE	3
Defining relevant validation criteria for the heavy vehicle use case	RISE	4
Defining validation requirements on the L3+ system level, as well as providing relevant testing use cases and expected issues	CAF	1 & 2
Defining requirements for validation of methodology on specific UCs, identification of KPIs and metrics for validation of full chain from SiL to	CRF	1 & 3

real tests		
Supporting UCs selection and description with main focus to the cooperative perception testing urban pilot use case and the truck low-speed connected perception cyber-security pilot use case	ICCS	1 & 4
Supporting the validation with virtual simulations	IKA	ALL
Defining ODDs for the use cases using a standard machine readable ODD definition language	UoW	ALL

It is important to note that the main objectives of UCs are not to develop flawless technological functions ready for the streets. Rather, the aim is to investigate and develop effective and efficient methods for third-party assessment of assurance cases based on evidence gathered through a scenario-based testing approach relevant to the ADS. Further investigation topics within the UCs explore how evidence provided by accelerated tests can be confined within the area of validity for the claims they are intended to support. Also, termination conditions for the tests are of interest, e.g., how can safety criteria be defined in relation to a test scenario, scenario space and the ODD.

Advancement within the assessment and audit area is essential for ensuring the ADS meets the necessary safety standards and can be certified for use on public roads. Thus, the purpose of developing UCs is to create sample use-cases that can be used as a basis for drawing broader conclusions about the assessment procedure's effectiveness. These UCs serve as a tool for validating the SUNRISE SAF, by refining the assessment procedure to ensure that they can efficiently and effectively provide evidence of the ADS's safety and efficacy, based on the novel scenario-based testing approach.

1.3. Intended audience

The intended audience of the deliverable will include the entire project consortium as this will be used as a basis for the whole work on technical tasks and work packages of the project. More in detail, this document aims to provide a clear and helpful roadmap for the consortium partners on what targets to achieve, and what requirements to fulfill with respect to the presented UCs.

1.4. Structure of deliverable and its relationship with other work packages/deliverables

The contents of this deliverable are divided in the following chapters:

Chapter 2: Background work. This chapter refers to the scenario-based testing evaluation process as part of the safety validation for ADS with the aim to ensure safe operation of a CCAM system inside a pre-defined ODD.

Chapter 3: UCs methodology. This chapter refers to the methodology that was followed for structuring the selected UCs.

Chapter 4: UC ID 1 – urban AD perception validation. This chapter provides a detailed description of the urban AD perception validation use case with three well-defined sub-UCs (perception testing, connected perception testing, and collaborative perception testing). The high-level validation requirements for the aforementioned sub-UCs are defined by covering the ADS under test behavioural capabilities, the ODD, the scenario testing, the metrics for assessment, the testing methods and tools, and the required data.

Chapter 5: UC ID 2 – traffic jam AD validation. This chapter provides a detailed description of the traffic jam AD validation use case. The high-level validation requirements for the aforementioned UC are defined by covering the ADS under test behavioural capabilities, the ODD, the scenario testing, the metrics for assessment, the testing methods and tools, and the required data.

Chapter 6: UC ID 3 – highway (co-operative) AD validation. This chapter provides a detailed description of the highway AD validation use case with two well-defined sub-UCs (map-based perception & decision-making & control testing, cooperative perception & decision making & control testing). The high-level validation requirements for the aforementioned sub-UCs are defined by covering the ADS under test behavioural capabilities, the ODD, the scenario testing, the metrics for assessment, the testing methods and tools, and the required data.

Chapter 7: UC ID 4 – freight vehicle automated parking validation. This chapter provides a detailed description of the hub-to-hub freight operation use case with two well-defined sub-UCs (truck low-speed perception & decision-making testing, truck low-speed connected perception cyber-security testing). The high-level validation requirements for aforementioned sub-UCs are defined by covering the ADS under test behavioural capabilities, the ODD, the scenario testing, the metrics for assessment, the testing methods and tools, and the required data.

Chapter 8: Overview of validation requirements and relation to SAF. This chapter provides a summary of the validation requirements that were described previously for all the selected UCs (urban, highway, traffic jam, hub-to-hub freight operation). The above will be used as a basis for the development of the harmonized and scalable CCAM SAF, which aims to fulfil the needs of different automotive stakeholders for a continuously evolving number of UCs and sub-UCs.

Chapter 9: Conclusion. This chapter provides evidence with respect to the strong variability of scenarios, tools and types of data needed for validating different ADS under test.

Deliverable D7.1 has not received input from any SUNRISE deliverable. However, D7.1 output will be used for the future work in the deliverables D7.2 and D7.3. Furthermore, the D7.1 guides the conception and design of the generic SAF in WP2 and can be also used as a technical input for the rest of the other technical WPs (WP3 – Method, WP4 - Toolchain, WP5 – Ontology, and WP6 – Data framework).

2. BACKGROUND WORK

CCAM systems must prove to be reliable in every possible driving scenario. It is already acknowledged that for higher levels of automation the validation of these systems by real field driving would be infeasible by conventional methods. Thus, a carefully designed mixture of physical and virtual testing has emerged as a promising approach with the virtual part bearing more significant weight in this mixture (quality of scenario-based coverage versus quantity of miles) for cost efficiency reasons.

Several worldwide initiatives have started to develop test and assessment methods for ADSs, i.e., the EU-funded research projects HEADSTART, PEGASUS, StreetWise, ArchitectECA2030, etc.). These initiatives have already moved from conventional validation approaches to a scenario-based approach to avoid the million-mile issue. Extensive SotA review will be provided in the deliverable D2.1 of the SUNRISE project. Moreover, as stated in the draft EU regulation (Ares 2667391, 2022), "*the combination of objects, events and their potential interaction, as a function of the ODD, constitute the set of nominal scenarios pertinent to the ADS under analysis. The identification of nominal scenarios is not limited to traffic conditions but also covers environmental conditions, human factors, connectivity*."

In the light of the above, scenario-based testing can be an effective solution to the problem of testing ADS, as it allows for the compression of many miles of driving into only the most relevant parts. By identifying and focusing on only the critical aspects of a driving scenario, non-relevant situations can be disregarded, thereby enabling a more efficient and effective testing process. This approach ensures that the focus is placed on testing the parts of the drive that are actually critical for evaluating the ADS's performance, while minimizing the need for excessive and time-consuming testing of non-critical scenarios. The main focus is the selection of UCs for scenario-based testing covering different ODDs and testing environments.

2.1. ERTRAC roadmap

Realizing the importance of the transportation sector for the European economy and public at large, the European Road Transport Advisory Council (ERTRAC) formulates a Strategic Research Agenda to further research activities in the sector mainly around enhanced safety, but also easier mobility, more efficient energy use and improvements to air quality and the environment are included. An additional focus is placed on the competitiveness of the European road transport industry. The council is made up of different stakeholders, representing every part of the industry [2].

The stakeholders involved in ERTRAC share the vision of a progressive step-wise increase of automation levels during the upcoming decade. Since road transport includes various types of vehicles, it is important to detail the development paths into specific roadmaps reflecting the different opportunities of each vehicle category. Passenger cars are the main driver of the development towards automated driving, as with their high volume in the market, they can afford to develop the necessary technologies. They evolve level by level with more sensors, connectivity and computing power on- and off-board and can be distinguished by parking and driving use cases.

Furthermore, CCAM driving is the opportunity to address several important societal challenges of road transport like safety, energy efficiency, congestion, urban accessibility and social inclusion, in-line with the 2050 vision outlined in the ERTRAC Strategic Research Agenda [1]. New automated solutions for shared mobility and public transport could have very positive impacts on future urban and inter-urban environments, making CCAM systems more accessible for elderly and people with disabilities. New automated logistics solutions will contribute to meeting the increased goods transport demands, improving resource utilization and environmental impact. Additionally, ERTRAC ensures proper user information and acceptance, by addressing policy and societal aspects, and triggering the necessary regulatory adaptations.

2.2. ODD specifications inputs

According to the maturity of the AD technology and the AD business use case, each ADS is designed to operate safely in a specified Operation Design Domain (ODD). The ODD represents the operating environment and specific conditions under which the AD system is designed to operate safely. ODD includes, but not limits to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.
Two available standards for ODD representation that were used also in this work are briefly described herafter:

- **ISO 34503 - Road vehicles - Taxonomy for operational design domain for automated driving systems [42]:** *This standard aims to specify the basic requirements for a hierarchical taxonomy for defining the ODD of an ADS. This standard also aims to define basic test procedures for attributes of the ODD and it is applicable to ADSs of Level 3 and higher as defined in ISO/SAE 22736. It should be stated that this document is currently in the Preparatory Stage (under development) at ISO.*

- **PAS 1883:2020 Operational Design Domain (ODD) taxonomy for an automated driving system (ADS) – Specification [28]:** *This document is one in a series commissioned by the Centre for Connected and Autonomous Vehicles (CCAV) to support the development of CAVs in the UK and help shape the future of international CAV standards. PAS 1883:2020 deals with requirements for an ODD taxonomy. It provides requirements for the minimum hierarchical taxonomy for specifying an ODD to enable the safe deployment of an ADS. This PAS is applicable to Level 3 and Level 4 ADS.*

In the aforementioned standards ISO 34503 and PAS 1883:2020, the ODD comprises the static and dynamic attributes within which an ADS is designed to function safely. At the top level, this analysis can be classified into the following three attributes:

- "scenery"
- "environmental conditions"
- "dynamic elements"

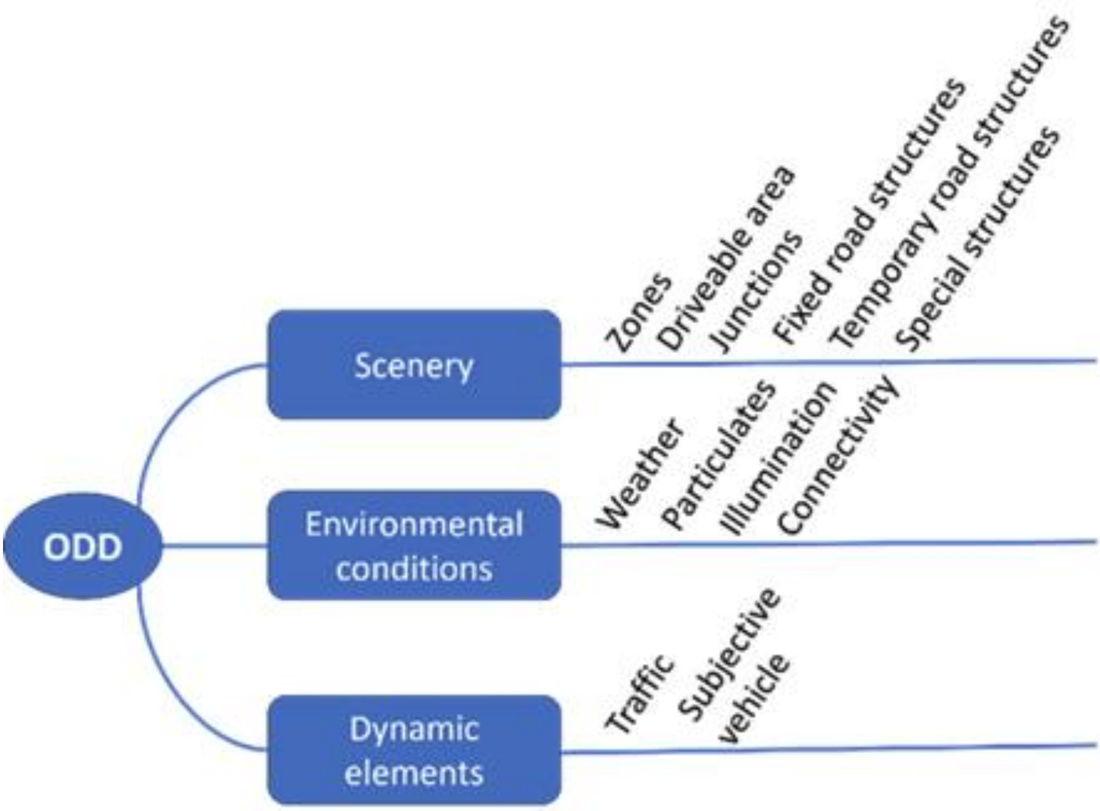

Figure 1: Top-level ODD taxonomy according to the PAS 1883:2020.

The "scenery" attribute shall consist of the non-movable elements of the operating environment, e.g., roads or traffic lights. The "environmental conditions" attribute shall consist of weather conditions, atmospheric conditions, and (if any) V2X communications, whereas the "dynamic elements" attribute shall consist of the movable elements of the ODD, e.g., traffic or subject vehicle. ISO 34503 takes the framework established in PAS1883 and exemplifies its use for creating an ODD description. The standard covers key topics for establishing an ODD format including the nuances between a 'restrictive' or 'permissive' description. Figure 1 shows the top-level ODD taxonomy according to the PAS 1883:2020.

3. USE CASES SELECTION AND METHODOLOGY

This section outlines the methodology that was followed for structuring the selected UCs and the key card template (this is provided in Annex I) used for collecting UC description information from the partners participating in SUNRISE Task 7.1 activities.

3.1. Selected SUNRISE use cases

SUNRISE UCs describe a set of application-specific CCAM systems based on which validation requirements can be derived for testing a broad range of existing ADS covering both their functional (target operational domain including connectivity, traffic context and supported manoeuvres, driver in-the-loop considerations, etc.) and non-functional aspects (safety, cybersecurity, etc.). As mentioned previously in Chapter 1, these UCs affect the development and analysis of all the technical WPs within the SUNRISE project as they feed the SAF conception. Additionally, these UCs aim to guide the project's final Proofs of Concepts (PoCs) in Task 7.2 and the associated demonstration activities in Task 7.3.

Each SUNRISE UC is built upon a specific application-based CCAM use case narrative, as defined by the "ERTRAC Connected, Cooperative and Automated Mobility Roadmap (2022)" [3] (e.g. urban and sub-urban pilot), but its formal description is extended to also include the associated scenario space and validation profile assumed to be required for the particular UC. A set of four SUNRISE UCs and eight sub-UCs (corresponding to a specific ADS under test each time) are presented in Table 2. More details for the selected UCs and sub-UCs are provided in Chapters 4, 5, 6 and 7.

Table 2: Selected SUNRISE UCs and sub-UCs.

UC	sub-UC
1 urban AD perception validation	1.1: Perception testing 1.2: Connected perception testing 1.3: Cooperative perception testing
2: traffic jam AD validation	2.1: Safety assessment & decision-making testing
3: highway (co-operative) AD validation	3.1: Map-based perception & decision-making & control testing 3.2: Cooperative perception & decision making & control testing
4: freight vehicle automated parking validation	4.1: Truck low-speed perception & decision-making testing 4.2: Truck low-speed connected perception cyber-security testing

3.2. Methodology

Within the SUNRISE project a methodology for constructing the main elements for each UC or/and sub-UC was adopted based on the following:

(System safety* assessment *UC description)

- **Short description and objectives**: main aim, problem statement, vision, state-of-the-art and beyond SotA / Innovation, etc. Setup: block diagram, partner roles, etc.
- **ADS under test** which includes:
    - **SuT**: which system or subsystem of the ADS is the SuT of this UC (sensor, perception, decision making, control sub-system)
    - **ODD**: The ODD of the specific ADS
    - **OEDR/MRM**: The ADS OEDR and MRM (when applicable)
- **Indicative set of test scenarios:** description of the scenario space (supported manoeuvres, other road users' behaviour etc.)

(UC validation requirements based on system safety assessment UC analysis)

- **Preliminary test plan for Safety Assurance (SA) assessment**: short description of evaluation platforms - simulation/driving simulators, etc. Virtual simulation testing (MiL, SiL, HiL, Cosim, ViF, SciL), Proving ground testings in specific controlled driving environments. Field testing in public roads, open areas, confined areas, etc.
- **Preliminary metrics for Safety Assurance (SA) assessment**: KPIs and metrics which evaluate the success of the validation process in line with the stated requirements
- **Preliminary input data requirements for Safety Assurance (SA) assessment**

UC high-level validation requirements summary clustered into:

- **ADS functional safety assessment**
- **Scenario description**
- **Test framework, methods and input data**
- **User perspective**

HINT: The UC high-level validation requirements summary is the condensed output of D7.1 towards all other WPs of the SUNRISE project responsible for SAF design and development.

Schematic representation of the UC construction methodology is depicted in Figure 2.

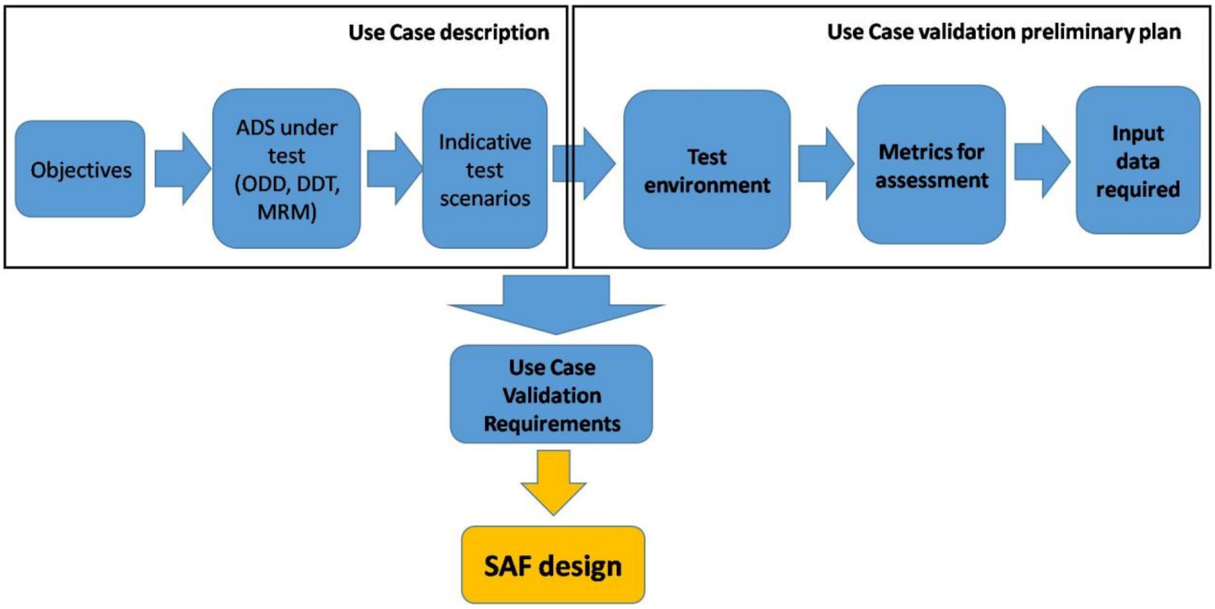

Figure 2: Schematic representation of the UC construction methodology.

4. UC ID 1 – URBAN AD PERCEPTION VALIDATION

The scope of **“UC ID 1 - Urban AD perception validation”** is to validate the environment perception for SAE L3+ vehicles in urban or/and suburban areas via the implementation of a hybrid validation testing, by combining virtual simulations and physical tests and by also considering aspects of connected driving and collective perception. In SUNRISE project, UC ID 1 includes three main sub-UCs, as follows:

- sub-UC 1.1 «Perception testing»

  covers sensor models used in simulation and perception subsystem validation methods and metrics

- sub-UC 1.2 «Connected perception testing»

  builds upon sub-UC 1.1 and covers the integration of other vehicles/VRUs' information coming from external sources via V2X and the usage of C-ITS services (CAM, DENM, etc.)

- sub-UC 1.3 «Cooperative perception testing»

  builds upon sub-UC 1.2 and also covers the integration of other vehicles/VRUs' information coming from external sources via V2X and the usage of C-ITS services (CPMs).

With respect to the multi-modal perception sub-system safety assessment framework, the need for accurate sensor models as well as the different co-simulation architectures needed (combination of driving and traffic simulation environments) in order to integrate connectivity among road agents and infrastructure will be analysed. With respect to ADS under test, which in this case is an urban chauffer ADS, UC ID 1 mainly focus on all longitudinal manoeuvres except reversing in contexts of mixed traffic and interactions with other users and with infrastructure, with KPIs mostly related to safety. Types of data coming from other vehicles and infrastructures are described in order to be used for the validation testing.

4.1 Sub-UC 1.1 "Perception testing”

4.1.1 Short description and objectives

Sub-UC 1.1 aims to cover the testing and safety validation of the different elements of the perception layer when the ADS operational design domain includes complex urban intersections and the inclusion of adverse weather conditions. The scope is to extend the current possibilities of test and validation of CCAM functions in urban environments focusing on intersections where the majority of accidents occur due to distracted pedestrians or traffic lights violations.

In this context, a representative perception AD subsystem is addressed which is based on three different sensors (Lidar, camera and radar).

4.1.2 ADS under test

- **SuT**

In this sub-UC the assumed ADS under test is the perception AD subsystem of an urban chauffer ADS.

Brief background on LiDAR-based perception

A perception system based on LiDAR uses a pulsed laser to emit beams of light towards an object and then measures the time it takes for the light to bounce back to the LiDAR sensor. This allows for precise distance measurement of the object to the sensor. The ability of LiDAR to measure distance with high precision makes it a valuable tool for environment perception and real-time decision-making in many autonomous driving applications.

LiDAR technology principally consists of a laser, a scanner, and a receiver. The laser emits pulses of light towards the object being measured, and the scanner directs the beam of light in different directions to cover a wider area. The receiver detects the reflected light and measures the time it takes to return to the sensor.

The information collected by the LiDAR is used to create a three-dimensional model of the environment. The data can be processed using object detection and segmentation algorithms to identify and classify different objects, such as vehicles, pedestrians, and other obstacles.

Detecting these obstacles on the road from a LiDAR point cloud involves segmenting the point cloud to identify groups of points that correspond to specific objects. The following are the general steps that are followed to detect objects on the road from a LiDAR point cloud:

This 3D map is called a Point Cloud, which combines map-based prior information of the environment and real-time occupancy grid map-based object detection.

- Filtering and cleaning the point cloud: The point cloud received by the LiDAR sensor can be filtered and cleaned to remove any noise or unwanted points. A 3D map with prior information of the environment can be used to filter unwanted obstacles, buildings, trees, etc.

- Segmentation: The point cloud can be segmented into different objects using clustering algorithms. This groups the points that belong to the same object together.

- Classification: Once the point groups have been identified, classification algorithms can be used to identify what objects the groups represent. This may involve extracting features from the points, such as shape, size, and position, and then comparing those features to the features of known objects, such as vehicles or pedestrians.

- Tracking: After the initial detection of objects, objects can be tracked over time using information from the point cloud of previous and current frames. This allows to know obstacle speed and distance. Output: Finally, the detected objects can be presented in a graphical visualization or used for real-time decision making, such as a navigation algorithm telling the vehicle to brake.

In summary, detecting objects on the road from a LiDAR point cloud involves segmenting and classifying the point cloud to identify specific objects, followed by tracking and presentation/sending of the detected objects.

Brief background on camera-based perception

Another important sensor involved in mostly all of the AD functionalities is a camera. A camera today mainly consists of an appropriate optics, a sensor, an ISP image pre-processing, functional chain including different features, like object detection (OD), lane detection (LD), traffic sign and traffic light recognitions (TLR, TSR). A smart camera also includes a dedicated ECU for functional processing and a standalone camera is connected to a central ECU for the processing.

A camera sensor permits mostly to detect different objects of interest in the scene and classify them according to their types. It is usually used in a combination with another sensor (like radar or lidar) to associate a spatial objects disposition. It is also rather sensitive to the environment conditions and occlusions.

In the scope of the sub-UC 1.1, a frontal multi-functional camera will be studied, in the situations mainly oriented to VRU protection, like emergency braking or collision avoidance. As an indication, main characteristics of such camera functions are presented on Figure 3.

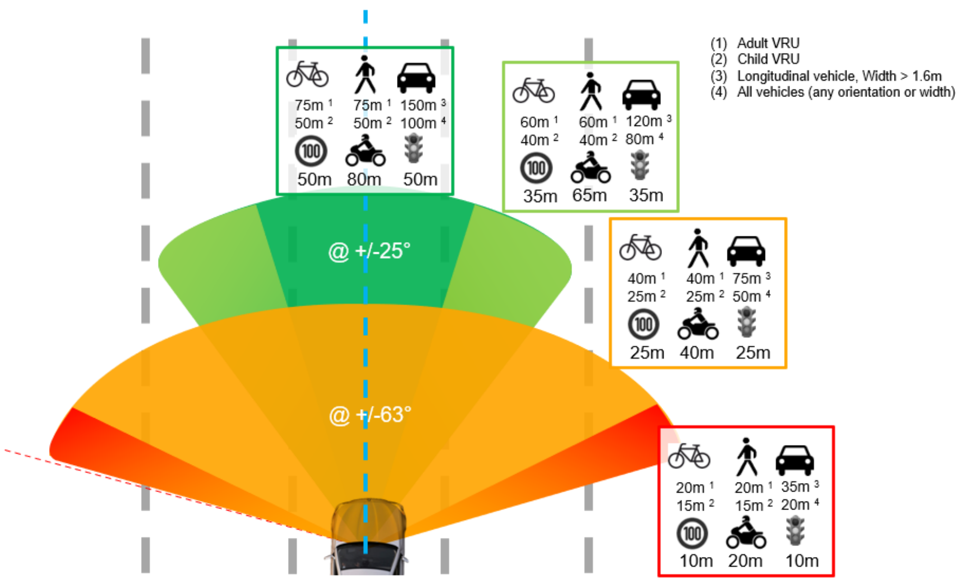

Figure 3: Camera detection ranges.

Radar sensors and their simulation models

Radar sensors are an essential sensor modality to cope with the requirements of a surround perception, which is required to deploy higher levels of automation.

Radar sensors specifically deliver information about location (distance and angle) of obstacles, as well as the relative speed within the same measurement cycle. Moreover, radar sensors still perform well in environment conditions under which optical sensors like camera or lidar fail – e.g., dense fog.

A radar sensor is characterized by its:

- field of view (FoV) in the horizontal plane (azimuth) and the vertical plane (elevation), which is mostly determined by the antenna design
- maximum range in which obstacles can be detected, again mostly determined by antenna design, but also maximal transmit power and digital beam forming techniques
- maximum measurable velocity, which is mostly determined by the chirp repetition time within the radar sequence
- range resolution, which is mostly determined by the Bandwidth of the radar sweep as defined thru the radar sequence
- angular resolution, which is mostly defined by the number of (MIMO) channels

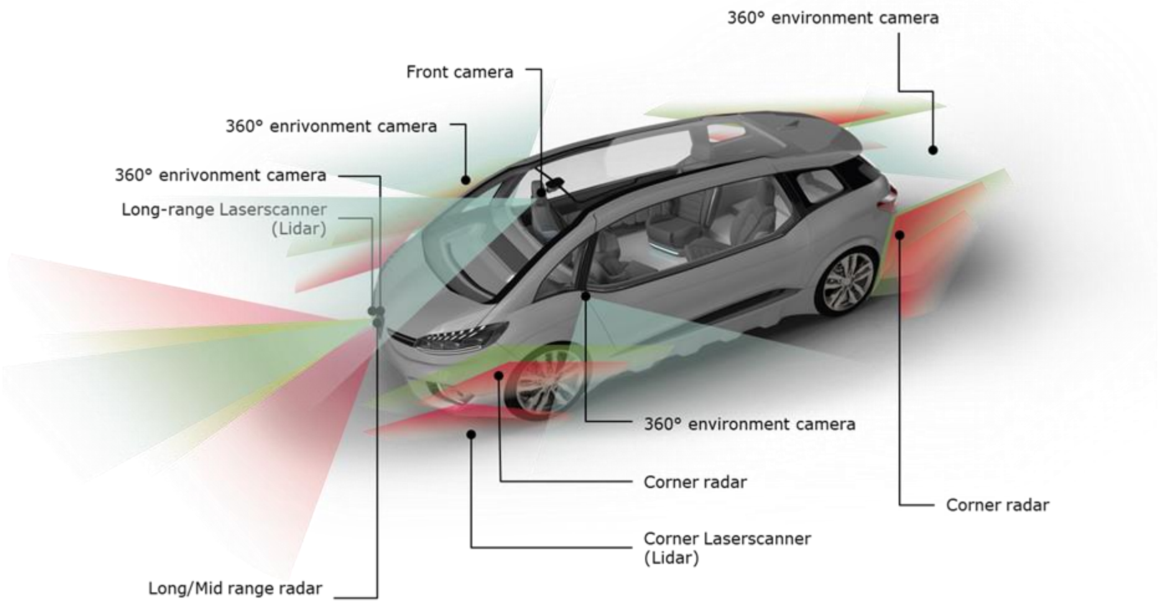

Figure 4: Radar sensors as integral part of the perception cocoon of a potentially highly AV.

As a matter of fact, an increase of the number of receive and transmit channels leads to improved performance parameters as listed, while this comes to the cost of a higher complexity (cost) and power consumption and always needs to be balanced with the target application. For highly automated vehicles it is foreseeable that higher channel numbers than today can be expected. This is especially needed, as the angular resolution is critical to achieve a separation of objects and a reasonable coverage of the vertical plane (elevation) requires more channels than today, as it can be seen with the characteristic parameters of today's systems below. Typical radar sensors of a potentially highly AV are presented on Figure 3.

Today the quasi-standard radar sensor device comes with 4 transmit and 4 receive channels and can be characterized with the following parameters - given according antenna designs for a mid-range radar (MRR) and long-range radar (LRR) application:

- FoV in the horizontal plane (azimuth) and the vertical plane (elevation): *Azimuth/Elevation MRR: +/- 60°/15°, LRR: +/- 15°/15°*

- maximum range: *MRR:~100m, LRR:~200m*

- maximum measurable velocity, which is mostly determined by the chirp repetition time within the radar sequence

- range resolution: *MRR:~0,25m LRR:~0,5m*

- angular resolution (azimuth): *MRR ~12°, LRR ~4*°, (elevation) just rough estimate in the range of the elevation FoV

The simulation model will focus on the characteristic of today's systems, as given above but shall allow the modification of essential parameters, like the channel number and max. bandwidth, as well as chirp repetition times (ramp speed).

- **ODD**

Using the ODD definition provided by the sub-UC 1.1 working group, an ISO 34503 compliant ODD representation is given below:

Base state: Restrictive
#Composition statements

Scenery
Included drivable area type is [minor roads, outdoor parking]
Excluded drivable area type is [motorways, radial roads, distributor roads]
Included lane type is [traffic lane]
Excluded lane type is [bus lane, cycle lane, tram lane, emergency lane]
Included direction of travel is [right-hand travel]
Excluded direction of travel is [left-hand travel]

Included drivable area surface conditions are [dry, wet road]
Excluded drivable area surface features are [cracks, swells]
Included road surface type is [segmented, uniform]
Included horizontal plane is [straight roads, curved roads]
Included vertical plane is [up-slope, down-slope, level plane]
Included transverse plane is [undivided, pavements]
Excluded transverse plane is [barriers on the edges]
Included types of lanes together are [traffic lanes]
Included drivable area surface type is [asphalt, concrete]
Excluded drivable area surface type is [cobblestone, gravel, granite setts]
Included drivable area signs are [regulatory, warning, information]
Included traffic information signs are [traffic lights full-time]
Included intersections are [T-junctions, Y-junctions, crossroads, roundabouts]
Included special structures are [tunnels, bridges, toll plazas, pedestrian crossings]

Environmental conditions
Included wind is [no wind, calm, light air, light breeze, gentle breeze]
Excluded rainfall is [violent rain, cloudburst]
Included particulates are [non-precipitating water droplets]
Included illumination is [day, night, cloudiness, fog, artificial illumination]

Dynamic elements
Included agent type is [vulnerable road users, trucks, vehicles]
Excluded special agents are [ambulances, police vehicles]

- **OEDR + MRM (when applicable)**

The behaviour competencies of the ADS are described in the following. The OEDR (object & event detection and response) behaviour capabilities are defined by identifying what the ADS should detect and respond to:

[ODD boundary transition, relevant static obstacles in the lane, relevant cyclists, relevant pedestrians, oncoming vehicles, speed limit changes, relevant stopped vehicles]

Furthermore, the ADS' features and tactical and operational manoeuvres are defined as:

[maintain speed, car following, lane centring, follow driving laws, navigate roundabouts, navigate intersections, route planning, collision avoidance, emergency braking]

The respective failure modes of the ADS are:

- ODD Boundary: *Detect and respond to ODD boundary transition with MRM (braking) until MRC is reached.*

- Detect degraded performance and respond with appropriate fail-safe/fail-operational mechanisms.

The following describes in more detail how the AV should behave with a focus on the perceptions system. Perception system should behave the same in sun, rain or fog conditions.

- When starting the AV, the perception system should check if there is any obstacle before moving forward, e.g. pedestrian, vehicles, trucks – If an obstacle is present, the vehicle should wait until it is gone.
- AV must follow speed limits in the area and reduce speed when approaching any intersection.
- When arriving to a stop, the AV should recognise it and stop. Before moving forward, the perception system must check the presence of any other obstacles in any direction. Distance and speed to obstacles are needed to check if there is time/space to move on safety.
- When arriving to a giveaway, the AV should recognise it and reduce its speed. Before moving forward, the perception system must check the presence of any other obstacles in any direction. Distance and speed to obstacles are needed to check if there is time/space to move on safety.
- When approaching a pedestrian crossing, vehicle must detect it and reduce its speed. Before moving forward, perception system should check if there is any pedestrian.
- When driving, the perception system should check if there is any other vehicle in front of as, adapting the AV's speed in order to avoid any unsafe situation.
- When arriving to a roundabout, the AV should detect it and reduce its speed. The perception system should check if there is any obstacle within the roundabout and stop or not accordingly. The AV should use turning light to indicate what it is going to do.
- When arriving to a parking area, the perception system should check for other vehicles, always stopping the vehicle to avoid any kind of collision. Vehicle speed should be reduced in those areas.

4.1.3 Indicative test scenarios

The preliminary test scenarios discussed in this work are based on the chosen physical test environment and are listed under section 4.1.4.2.

4.1.4 Preliminary test plan

In the urban environment conditions, a particular attention must be given to the perception sub-system detection rate, to avoid any misdetection, and to the unknown objects that could appear more frequently, compared to the highway environment. The misdetection risk from the perception side must be mitigated by the vehicle behaviour on the ADS level.

4.1.4.1 Virtual testing

In this subsection the type of virtual testing that is going to be executed in the sub-UC 1.1 is presented. Also, the basic capabilities of the planned testing are clarified and briefly described.

Table 3: Main subsystems of the virtual testing framework for the sub-UC 1.1.

Subsystem	Role
ADS	The automated driving system to be validated (prototype)
Environment Simulation	Certain environment simulations, ranging from low-fidelity (for example, ESMINI [43]) to medium- and high-fidelity (for example, CARLA [39]), will be used to showcase the individual aspects.
Sensor Models	Various sensor models with different model fidelities will be available and integrated to cover as much as possible of the defined target ODD with virtual testing.
Vehicle Dynamics	Python-based vehicle dynamics

The main subsystems presented in Table 3 will be integrated into a co-simulation architecture that can be extended if necessary. Considering different model fidelities for certain subsystems enables multiple architecture configurations for certain test cases, providing a flexible approach towards virtual testing.

More in detail, virtual perception testing is conducted with sensors models (radar sensor models) as part of a scenario simulation, using simulation environments like IPG CarMaker, Aurelion, Tronis or similar. Preferably a simulation environment which follows the ASAM OSI [44] and ASAM OpenSCENARIO [45] definitions. In that sense, the environment simulation and vehicle dynamics part will be covered by for example the IPG CarMaker simulator while the radar sensor models will be the core elements to be developed within the SUNRISE project and embedded (linked) to the chosen simulation environment.

The evaluation of perception models using virtual tests is a hard problem due to the fidelity of simulation with the data provided by the physical sensor in vehicles. Thus, the medium-high fidelity testing is done in two steps: behaviour and temporal evaluation, and perception model evaluation. The behaviour of the AD stack is done using the CARLA simulator including detection failures to define the affordable miss detection and the critical failures that could lead to possible accidents. The evaluation of the perception model with virtual testing is done with photo-realistic render as it requires much higher fidelity to be acceptable. The photo-realistic render does not include any type of temporal sequence, thus, any aspect related to temporal sequence evaluation is done by the CARLA simulator.

CARLA is an open-source simulator environment compatible with OpenSCENARIO, where any feature related to maps, actors, actor's behaviours, actor's traffic and sensors can be modified. Furthermore, for every actor, the simulator can provide information regarding:

- Accidents and illegal maneuvers
- Intrinsic and extrinsic sensor parameters
- Actor's position, orientation and speed
- Sensors data (LIDAR and cameras)
- Sensors perception data (eg.: segmentation, depth, bounding boxes, etc)

The cases to evaluate in CARLA are selected from the current CARLA leaderboard using Scenario Runner, where many come from NHTSA. The tests are done by bypassing the perception models using the sensors ground truth (Bounding boxes, Semantic Segmentation, etc) already implemented in CARLA, and they use ROS2 to communicate the AD stack with the simulated vehicle. In Table 4 the properties of the CARLA simulation can be seen.

Table 4: Carla simulation properties

	Values	Comments
Area of operation	Carla Maps	Urban-like, Highway, multi-lanes, etc
Road users	Vehicles, pedestrian	---
Environmental conditions	Sun, rain, fog	---
Vehicle configuration	GPS Cameras Lidar	Camera-sensor lenses cannot be modified. Lidar sensor only provides geometric position. It is not affected by weather conditions.

The photo-realistic simulator can simulate urban-like areas with randomized scenes on any demanded illumination and weather (sun, rain, fog), but they do not have a continuous temporal space to evaluate the vehicle driving. This test will provide classification and detection metrics to show the perception model performance on different weather and/or illuminations. The scenes include the configuration shown on the Table 5.

Table 5: Photo-realistic simulation properties

	Values
Area of operation	Urban-like areas
Road users	Vehicles, pedestrian
Environmental conditions	Sun, rain, fog
Vehicle configuration	Cameras

4.1.4.2 Physical testing

An electric Renault Megane is robotized for developing an AD level 4 vehicle with a lidar-based perception system. Vehicles' architecture is slightly modified to turn the vehicle into an AV, adding sensors, computers, and some redundancy to critical systems (braking). The original autonomous emergency braking (AEB) system is kept as a possible redundancy to the perception system. A MicroAutoBox is added as the bridge between vehicle actuators and the AD world living in a different computer. Table 6 summarizes the hardware and software that are present in the prototype.

Table 6: Summary of hardware and software needs in the prototype vehicle for the sub-UC 1.1.

AD component	Description	Software/Hardware needs
Localization	Determines position and orientation of the vehicle within its environment.	AD computer GPS / IMU / Lidar Vehicle odometry
Perception	Detects and tracks obstacles surrounding the vehicle	AD computer Lidar / GPS
High-definition map	Database with information about roads, path, intersections, speed limits and driving priorities	AD computer
Navigation	It uses localization and perception information to determine a safe and efficient route (path and vehicle speed)	AD computer
Control	It controls vehicles actuators (steering, brake and throttle) to follow the trajectory planned by navigation	MicroAutoBox GPS Vehicle actuators

As an AD level 4, this prototype is meant to drive in autonomous mode and without a driver within a specific ODD in an urban-like environment within Renault facilities in Valladolid (Spain). Table 7 summarizes the proposed scenario used in sub-UC 1.1.

Table 7: Summary of the proposed scenario (area of operation and urban-like areas) used in sub-UC 1.1.

Area of operation	Urban-like areas
Area of operation	Renault Facilities Non segregated lanes
Road users	Vehicles, pedestrian, trucks,
Road infrastructure	Intersections, giveaways, parking area, pedestrian crossing, roundabout
Traffic density	From Renaults' office to ADAS parking
Speed range	< 30 Kph
Environmental conditions	Sun, rain, fog

The proposed scenario includes an area of operation where the AD level 4 vehicle goes from Renault office to ADAS Parking passing next to Text Track area as depicted in the Figure 5.

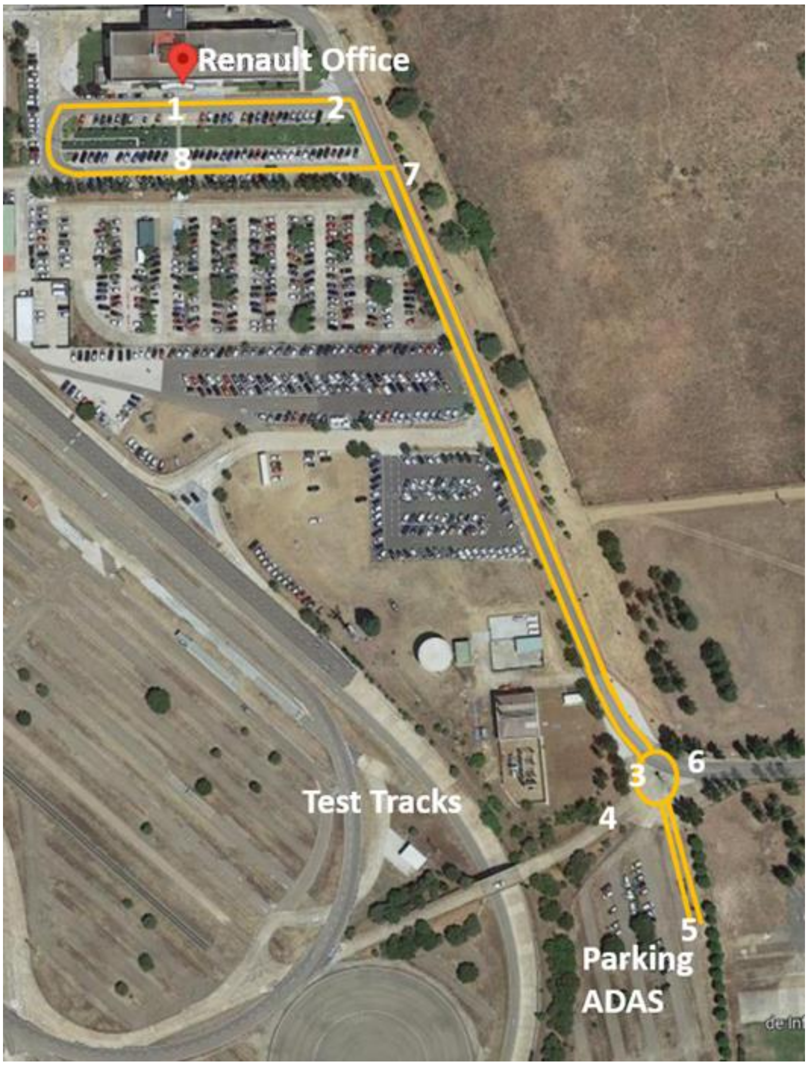

Figure 5: Proposed scenario used in sub-UC 1.1.

Indicative set of tests are presented hereafter based on the targeted real-world environment of the area of operation. A detailed description follows:

- The starting point is the main entrance of the office (see Figure 6). As can be seen, there is a pedestrian crossing.
- About 60m (Figure 7), a first giveway appears on the left side.
- Then the proposed route continues to the right, where there is a straight line with a speed limit of 30 kph with 2 pedestrian crossings (Figure 8 and Figure 9, about 100m and 190m distance from the starting point).
- Later on, there is a roundabout (Figure 10), that will be left to the right-side to the entrance to test tracks (Figure 11), and moving forward to a narrow road that enters the ADAS Parking (Figure 12).
- It takes about 200m to enter the ADAS Parking (Figure 13).
- When leaving the ADAS parking there is another giveway (Figure 14).
- After that, the route returns to the roundabout (Figure 15).
- The roundabout will be exited with a left turn with no priority in the two-way road (Figure 16).
- The route continues through the main road, were there is again the same pedestrian crossing (Figure 17).
- 60m later, there is the left turn give way (Figure 18), to get back to the starting parking area.
- There is another pedestrian crossing (Figure 19), before coming back to the initial point.

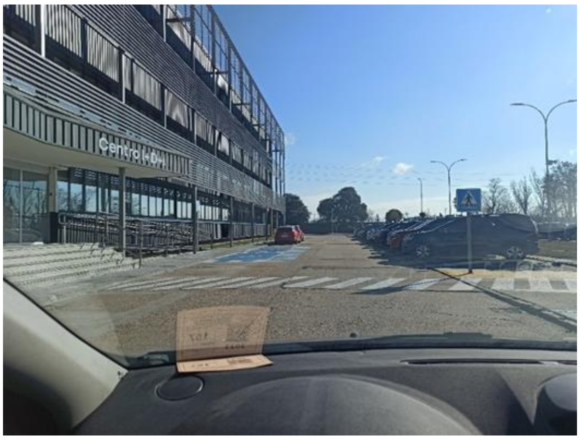

Figure 6: Main building entrance – Pedestrian crossing.

Figure 7: Turn right – Give way in our left.

Figure 8: Pedestrian crossing.

Figure 9: Second pedestrian crossing.

Figure 10: Roundabout.

Figure 11: Test tracks entrance – Access control with bars.

Figure 12: Narrow road to Parking ADAS.

Figure 13: Parking ADAS.

Figure 14: Exit giveway Parking ADAS

Figure 15: Roundabout

Figure 16: Turn left give way in both sides

Figure 17: Pedestrian crossing

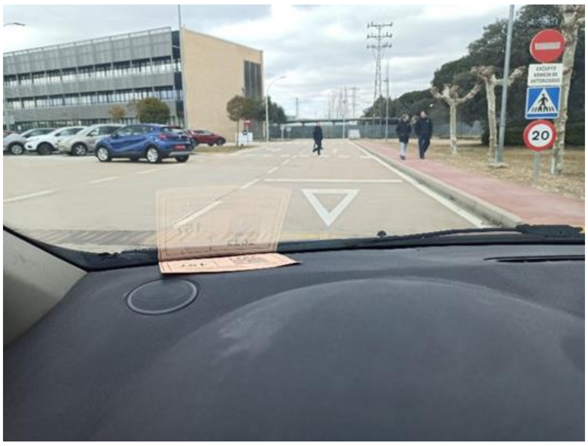

Figure 18: Turn left give way.

Figure 19: Parking area – Pedestrian crossing.

4.1.5 Preliminary metrics for SA validation

With respect to AD behaviour validation, as a starting point the KPIs which are given or can be derived from EURO NCAP intersection scenarios can be used. However, EURO NCAP uses the Time-to-collision (TTC) metric which is inadequate when dealing with intersection-related scenarios where the road agents may come in close distance leading to a safety hazard situation for the VRU (a vehicle with a bicyclist) without colliding.

With respect to the perception validation, the focus should be on the separability metrics in terms of the angular resolution of the RADAR sensor and its ability to distinguish weak object reflections next to strong reflections, like pedestrian or bicycle next to a truck [46].

Finally, new metrics to evaluate target ODD coverage from test cases are required.

4.1.6 Preliminary input data requirements

Physical testing – Real data

For testing the AD prototype, with a focus in a lidar-based perception system:

- Ground truth data. *Real data manually labelled and obstacles with GPS, so distance, position and speed can be known*
- Perception system output. *List of obstacles with corresponding classification, position, distance, and speed*
- Ego-vehicle position
- Data coming from ego-vehicle AEB system
- Perception system watchdog
- Driver intervention flag
- Lidar output
- Autonomous mode condition
- Steering, brake, throttle measurements
- Weather conditions

In general, high quality ground truth data is essential for the development and verification of the intended radar sensor models. In that aspect, mainly ground truth data extracted from simulation and available data sets will be used completed by real measurements to ensure correlation.

4.1.7 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- o UC1.1_REQ_SA_001: Apply ISO26262 and analyze possible hazards and risk assessment related to a lidar-based perception system
  - *Random HW Faults*

        - *Systematic SW Faults*
        - *Define safety goals depending on resulting ASILs*
    - UC1.1_REQ_SA_002: Apply ISO21448 and analyze safety in use (SOTIF)
        - *External factors: Environment and weather*
        - *User interaction*
    - UC1.1_REQ_SA_003: Apply ISO26262 and ISO21448 to AD prototype (All SW and HW):
        - *Vehicle should be considered safe enough to not have a driver.*
    - UC1.1_REQ_SA_004: Apply EU General Safety Regulation (EU) 2019/2144 and analyze compliance to the appliable safety regulations:
        - *Function fulfils the required behaviour in target scenarios and use cases.*
    - UC1.1_REQ_SA_005: Perception system shall detect and track vehicles and pedestrians.
    - UC1.1_REQ_SA_006: Perception system shall detect obstacles position, distance and speed should be perceived.
    - UC1.1_REQ_SA_007: Detection range shall be enough for a given speed.
    - UC1.1_REQ_SA_008: Obstacles detection confidence shall be high enough.
    - UC1.1_REQ_SA_009: Perception system accuracy
        - *Detection of semi-occluded pedestrian in front or aside of crossing vehicle.*
    - UC1.1_REQ_SA_010: Perception system acquisition speed
        - *Crossing traffic need to be detected fast enough to avoid collisions when entering/passing over the intersection.*
    - UC1.1_REQ_SA_011: Perception system robustness
        - *Crossing traffic shall be detected by the radar system in the presence of dense fog.*

- UC1.1_REQ_SA_012: Perception system sensitivity
    - *Bicycles as crossing traffic need to be detected as crossing traffic – at all and early enough, while early relates to the requirement of acquisition speed. In this case a sufficient sensitivity is a prerequisite to determine the required acquisition speed at all.*
- UC1.1_REQ_SA_013: Perception system shall run in real time.
- UC1.1_REQ_SA_014: Perception system shall work in adverse weather conditions – rain, fog – Performance could be reduced, but system limitations should be known adapting the vehicle behavior accordingly.
- UC1.1_REQ_SA_015: Safe fallback solution in case of failure in the perception system or any of the other AD components.

B. High level requirements with respect to scenario description/generation:

- UC1.1_REQ_SDG_001: ODD/Environment – adverse weather conditions affecting the perception system to be considered
- UC1.1_REQ_SDG_002: ODD/Road – Urban intersections, narrow roads, 2 lanes maximum to be considered.
- UC1.1_REQ_SDG_003: User interaction – VRUs and other vehicles to be considered including scenarios with occlusions that are not captured from specific perception system sensors (e.g. not captured by camera but captured by RADAR), e.g., right turn of ego vehicle, while pedestrian is crossing the lane, which is to be entered and crossing traffic is present.
- UC1.1_REQ_SDG_004: EURO NCAP intersection scenarios can be the basis for validation requirements imposed onto the perception system, while the requirements for the perception itself need to be derived out of these scenarios, as the perception performance is just one part of the scenario. Related to NCAP scenarios with crossing traffic by bicycles or cars to be detected.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC1.1_REQ_TTM_001: Combination of physical testing and virtual testing
- UC1.1_REQ_TTM_002: High quality ground truth data is essential for the development and verification of the intended perception system sensor models. In that aspect, mainly ground truth data extracted from simulation

and available data sets will be used completed by real measurements to ensure correlation.

- UC1.1_REQ_TTM_003: Comparison of the ADS behaviour between virtual and physical tests (Proving Ground) shall be performed to validate and confirm the robustness of the simulated approach.

4.2 Sub-UC 1.2 " Connected perception testing”

4.2.1 Short description and objectives

The goal of this sub-UC 1.2 is to demonstrate an overall safety argumentation for urban pilots with a focus on perception testing, concretely addressing current gaps with respect to:

- Extended virtual perception through V2X cooperation
- ODD and scenario coverage which include connectivity with vehicles in front and infrastructure (in this case, connected traffic lights).

4.2.2 ADS under test

- **SuT**

In this sub-UC the assumed ADS under test is both the perception AD subsystem and the Path Planning/Control AD subsystems of an urban chauffer ADS.

- **ODD**

The ODD related to sub-UC 1.2 concerns urban intersections with RSUs (Roadside Units) and has been specified using ISO 34503 compliant format.

Base state: Restrictive
#Composition statements

Scenery
Included drivable area type are [minor roads, parking]
Included lane type is [traffic lane]
Included direction of travel is [right- hand travel]
Included drivable area surface conditions is [dry, wet road]
Included drivable area surface features are [cracks, swells]
Included road surface type are [segmented, uniform]
Included horizontal plane is [straight roads, curved roads]
Included vertical plane are [up-slope, down-slope, level plane]
Included transverse plane are [undivided, pavements]
Included types of lanes together is [traffic lanes]
Included drivable area surface type is [asphalt, concrete]

Included drivable area signs are [regulatory, warning, information]
Included traffic information signs [traffic lights full-time]
Included intersections are [T-junctions, Y-junctions, Crossroads]
Included special structures are [tunnels, bridges, toll plazas]

Environmental conditions
Included wind is [no wind, calm, light air, light breeze, gentle breeze]
Excluded rainfall is [violent rain, cloudburst]
Included particulates is [non-precipitating water droplets]
Included illumination is [day, cloudiness]
Included communication is [V2I communication]

Dynamic elements
Excluded agent type is [vulnerable road users, animals, non-motor vehicles]
Included special agents are [ambulances, police vehicles]

- **OEDR/MRM**

The ADS will be capable of driving in proximity of urban intersections with RSUs and handle situations of traffic lights adaptation, car following, pedestrian crossing thanks to the combination of sensors and V2X information. Considered AV manoeuvres include all the longitudinal manoeuvres (speed keeping, braking, accelerating, etc.) except reversing.

Brief background on GLOSA and C-ACC

Sub-UC 1.2 aims at further improving and combining the GLOSA (Green Light Optimal Speed Advisory) and C-ACC (Cooperative Adaptive Cruise Control) features, within a predefined ODD context, to have enhanced key benefits, which are mainly related to safety, but also can cover other important issues like fuel consumption, speed optimization, waiting time reduction, and increased comfort.

GLOSA system [4] uses accurate information about traffic signal timing and locations to guide drivers (through V2I communication) with speed advice for a more uniform commute with less stopping time. This is done via connection to traffic light cloud services. Key benefits driving the GLOSA are reduction in traffic light waiting time and reduction in fuel consumption. Upgrades of GLOSA take VRUs (Vulnerable Road Users) and RWWs (Road Works Warnings) into account for an increased safety.

An application of GLOSA, which can be provided as a reference, has been described in detail by C2C Communication Consortium [47] and specifically in Use Case 4.2.1 Automated Green Light Optimum Speed Advisory (A-GLOSA). This latter extends the GLOSA ITS application by implementing automated functions at the application on the vehicle. This function tries to automatically adopt the GLOSA speed, which can be either suggested by the infrastructure or computed by the application on the vehicle. The specific goal is for cooperative vehicles to automatically adapt their speed to pass the intersection at the green light on their route, or to smoothly decelerate and stop at red light.

ACC (Adaptive Cruise Control) system [5] automatically adjusts the vehicle speed to maintain a safe distance from a vehicle ahead. V2V enables the extension to Cooperative ACC (C-ACC) concept thanks to additional information obtained from connected vehicles ahead. Key benefits driving the ACC are the reduction of fuel consumption, driving comfort, speed optimization. This feature may be combined with other functionalities such as GLOSA, FCW (Forward Collision Warning), EEBL (Emergency Electronic Brake Light) for an increased safety.

The state of the art of the abovementioned functionalities are presented in the public founded projects C-ROADS ITALY 2 for C-ACC and CONCORDA regarding GLOSA. C-ROADS ITALY 2 [6] demonstrates V2X connectivity to optimize vehicle energy consumption in hybrid vehicles gathering data from urban traffic scenario and applying V2X in urban and highways scenarios to extend vehicle's awareness about unexpected traffic events. On the other hand, CONCORDA [7] demonstrates the cooperative driving with GLOSA using features as C-ACC and lane change advice, in a set of use cases spanning traffic light advisory, road management information and hazard information.

4.2.3 Indicative test scenarios

The following test scenarios have been considered in the present sub-UC analysis:

- **<u>Test scenario sub-UC 1.2-A: ACC+GLOSA without car following</u>**

The ego vehicle is approaching an urban intersection with ACC+GLOSA (Adaptive Cruise Control + Green Light Optimised Speed Advisory) turned on without any obstacle in front, as depicted in Figure 20.

The ego vehicle adapts its speed based on the SPaT and MAP messages that includes Traffic Lights phases, timing and map information.

Parameters:

- *Vehicle speed range: 30-50 km/h*
- *Road type: Urban intersection*
- *Weather conditions: all*
- *Light conditions: all*

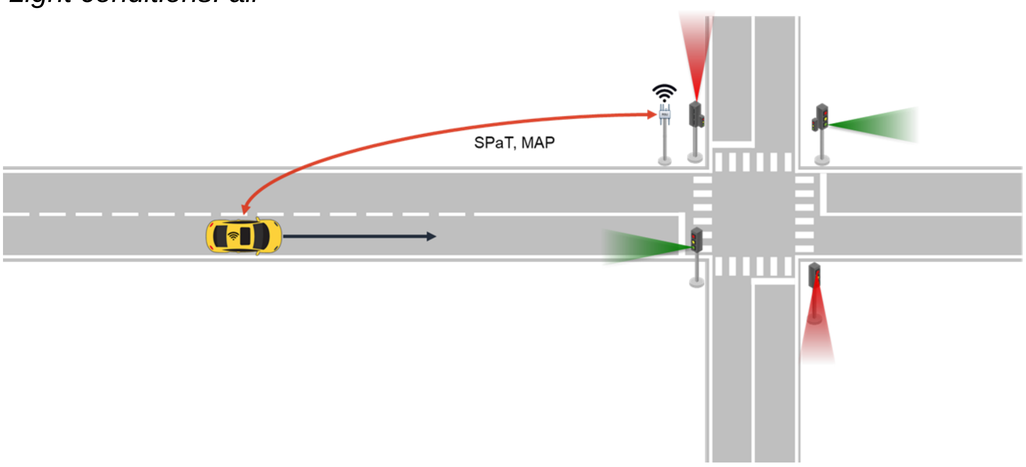

Figure 20: Schematic representation of sub-UC 1.2-A (ACC+GLOSA without car following scenario).

- **Test scenario sub-UC 1.2-B: GLOSA V2I without car following, red TL violation orthogonal by a pedestrian DENM**

The ego vehicle is approaching an urban intersection with ACC+GLOSA (Adaptive Cruise Control + Green Light Optimised Speed Advisory) turned on without any obstacle in front.

The ego vehicle adapts its speed based on the SPaT and MAP messages that includes Traffic Lights phases, timing and map information.

The vehicle receives randomly a DENM that informs about the presence of a distracted pedestrian (VRU) that is violating the redlight, as depicted in Figure 21.

Parameters:

- *Vehicle speed range: 30-50 km/h*
- *Road type: Urban intersection*
- *Weather conditions: all*
- *Light conditions: all*

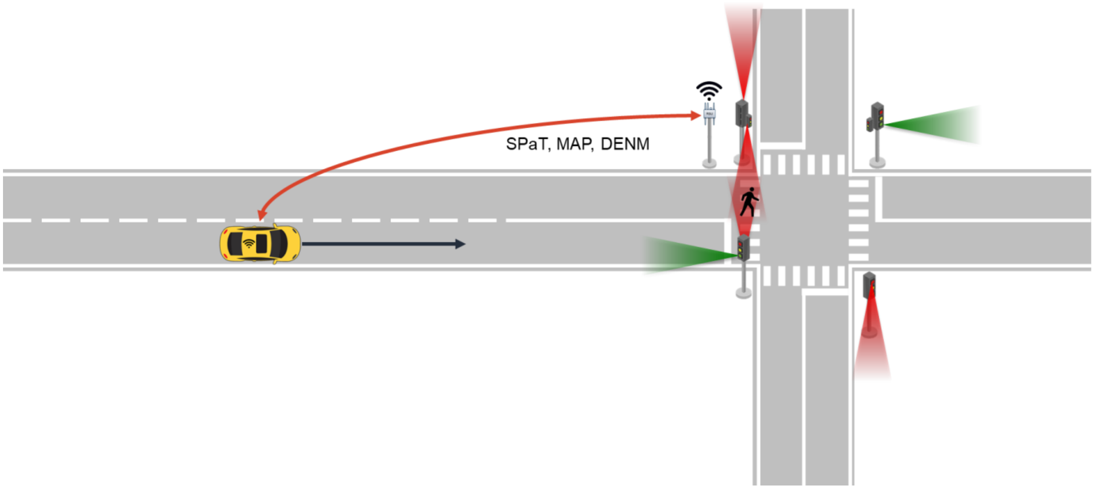

Figure 21: Schematic representation of sub-UC 1.2-B (GLOSA V2I without car following, red TL violation orthogonal by a pedestrian DENM scenario).

- **Test scenario sub-UC 1.2-C: ACC+GLOSA V2I without car following, TL reset countdown**

The ego vehicle is approaching an urban intersection with ACC+GLOSA (Adaptive Cruise Control + Green Light Optimised Speed Advisory) turned on without any obstacle in front.

The ego vehicle adapts its speed based on the SPaT and MAP messages that includes Traffic Lights phases, timing and map information.

The SPaT message contents are reset due to a VRU (pedestrian) crossing: the planned phase changes and the traffic light remains red, as depicted in Figure 22.

The ego vehicle needs to stop immediately.

Parameters:

- *Vehicle speed range: 30-50 km/h*
- *Road type: Urban intersection*
- *Weather conditions: all*
- *Light conditions: all*

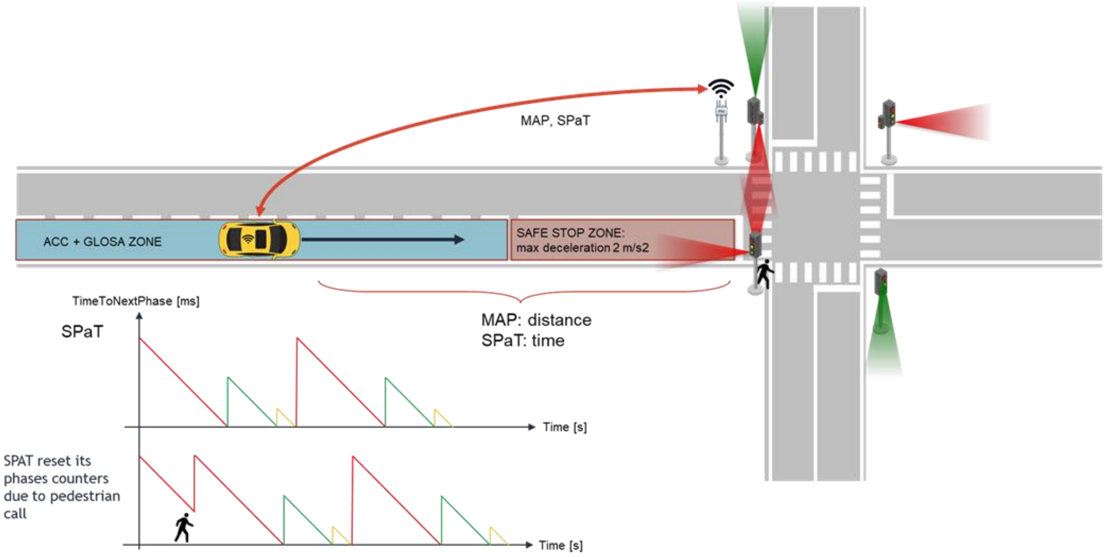

Figure 22: Schematic representation of sub-UC 1.2-C (ACC+GLOSA V2I without car following, TL reset countdown scenario).

- **<u>Test scenario sub-UC 1.2-D: IMA or redlight violation</u>**

The ego vehicle is approaching an urban intersection with ACC+GLOSA (Adaptive Cruise Control + Green Light Optimised Speed Advisory) turned on without any obstacle in front.

The ego vehicle adapts its speed based on the SPaT and MAP messages that includes Traffic Lights phases, timing and map information.

The ego vehicle receives CAM from other vehicle that is violating the red TL, as depicted in Figure 23.

The ego vehicle needs to stop avoiding the impact.

Parameters:

- *Vehicle speed range: 30-50 km/h*
- *Road type: Urban intersection*
- *Weather conditions: all*
- *Light conditions: all*

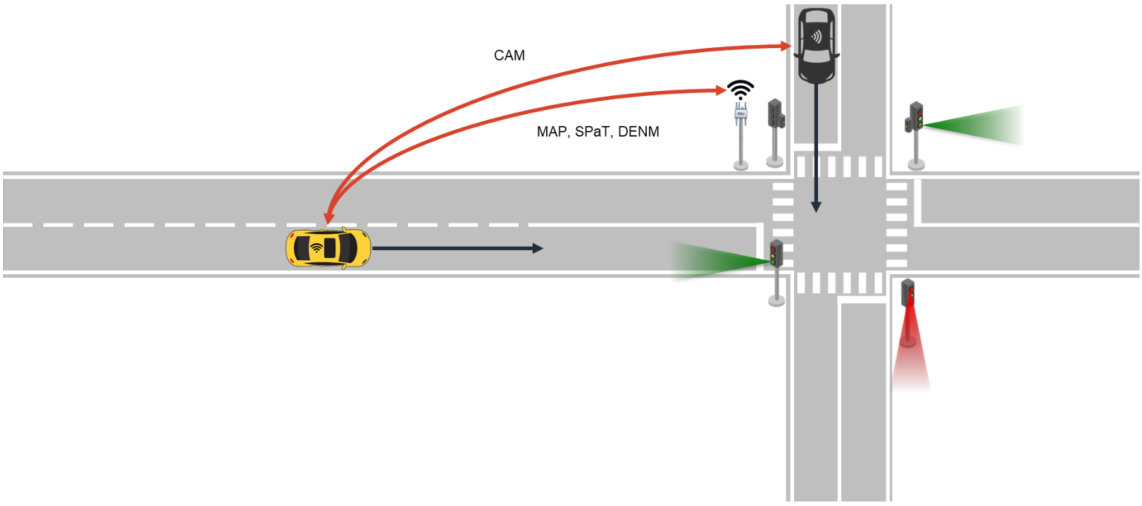

Figure 23: Schematic representation of sub-UC 1.2-D (IMA or redlight violation scenario).

4.2.4 Preliminary test plan

4.2.4.1 Virtual testing

The sub-UC 1.2 will be tested with the SiL and CoSim methods. Tests will start in SiL, where a prototype of the developed software will be integrated in the control loop to understand the performance of the algorithms in terms of latencies and KPI effectiveness and opportunely tune and test the fundamental parameters of the simulations and the critical aspects. This will be done in virtual environment with sensors and vehicle models.

Once appraised the performance of the developed software, tests will proceed in CoSim to simulate more than one agent using the designed algorithms to assess and possibly tune interesting parameters regarding the traffic interactions. This will be done in virtual environment with sensors and vehicle models and traffic flow simulation in diverse conditions.

Figure 24: Use case related to the handling of a pedestrian crossing in urban intersection [8].

Figure 24 and Figure 25 [8] depict possible representations of sub-UC 1.2 to be tested in virtual environment. The first one represents a pedestrian crossing in urban intersection, which can be examined with different speeds and position configurations related to the vehicle and the VRU. The second one, instead, depicts a traffic light violation, which can be analysed in different road and position configurations and speeds related to the vehicles involved.

Figure 25: Use case related to the handling of a traffic light violation in urban intersection [8].

4.2.4.2 Physical testing

After the virtual testing, the developed algorithms will be tested in physical world, i.e., on Proving Ground with traffic infrastructure, e.g., in Orbassano, Italy, see Figure 26. The behaviour of functionality will be compared with the different SiL and CoSim tests to confirm the effectiveness of the simulated approach.

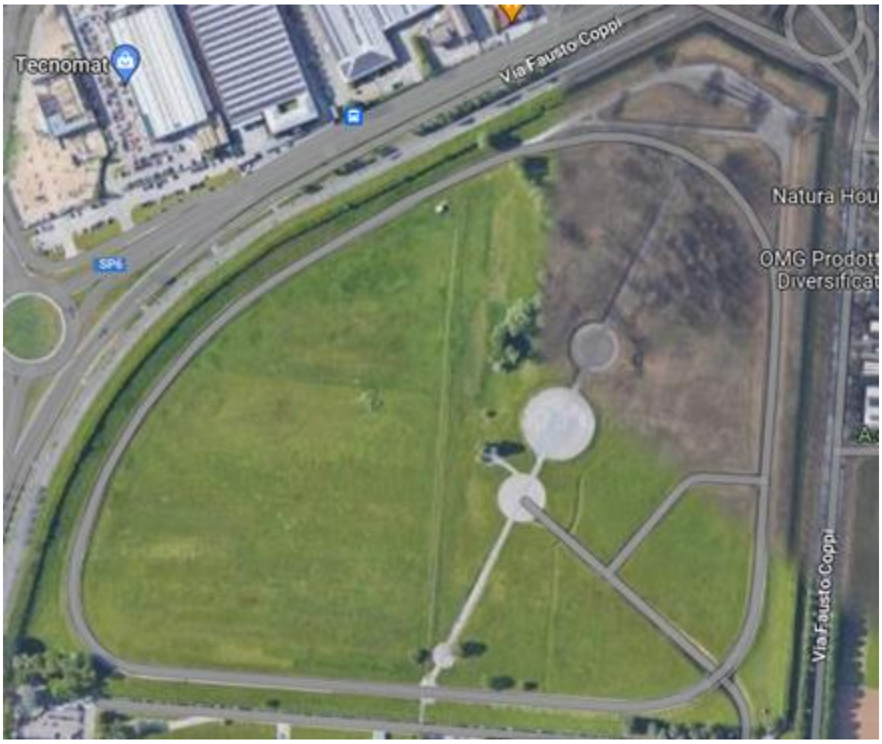

Figure 26: Top view of Centro Sicurezza proving ground in Orbassano (Turin), Italy.

4.2.5 Preliminary metrics for SA validation

The metrics which are planned in sub-UC 1.2 regard the following aspects:

- Speed profile [m/s] which is defined as the ego vehicle speed set by the ADS.
- Required acceleration profile [m/s2] which is the rate at which the vehicle's speed changes with respect to time.
- Jerk profile [m/s3] which is the rate at which the vehicle's acceleration changes with respect to time.
- Vehicle-Infrastructure distance [m] which is the length of the space between the vehicle position and the nearest RSU position.
- Vehicle speed at intersection [m/s] which is the speed of the ego vehicle during the intersection crossing.
- Time-to-collision (TTC) which is defined as the time until a collision between the ego vehicle and an object would occur.

Comparison of values relative to speed profile, jerk profile, vehicle-Infrastructure distance, vehicle speed at intersection will be done in the different SiL and CoSim tests. Moreover, the comparison of the ADS behaviour between virtual and physical tests (Proving Ground) will be done to validate and confirm the robustness of the simulated approach.

4.2.6 Preliminary input data requirements

Data required by sub-UC 1.2 for perception layer virtual testing include CAN-bus vehicle data, V2X data, ground truth data (for example from HD digital maps), connectivity latencies, etc. This data will be used for tuning the performance of the connected perception algorithms in simulation. Baseline scenarios creation will be also needed, e.g., baseline could be testing the same scenario by disabling any connectivity aspect).

For testing the CAD prototype, data required to be logged include:

- Ground truth data. *Real data manually labelled and obstacles with GPS, so distance, position and speed can be known*
- Perception systems output. *List of obstacles with corresponding classification, position, distance, and speed*
- Ego-vehicle positions, steering, brake and throttle measurements.
- Data coming from infrastructure, e.g., related to traffic lights and RSUs measurements.
- Connectivity information in terms of latencies, throughput, etc.
- Driver intervention flags, if any.
- Weather conditions, if needed.

4.2.7 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- UC1.2_REQ_SA_001: V2V connectivity for safety-related purposes shall be achieved exchanging maneuver and event data either through direct communication at 5.9 GHz (in the IEEE802.11p-based standards such as SAE DSRC and ESTI ITS G5 or in the 3GPP Rel 14/15 and ff. called PC5 standard interface) or through V2I communication in the cellular communication assigned bands, preferably with Multi Access Edge computing to keep within the low-latency requirements.
- UC1.2_REQ_SA_002: V2X communication interface shall be able to provide V2V and V2I connectivity related to the above-mentioned standards.
- UC1.2_REQ_SA_003: V2X detection range shall be at least 300 meters.
- UC1.2_REQ_SA_004: Perception system shall be able to work in adverse weather conditions, e.g., rainfall, fog, knowing in advance performance limitations to adapt the system accordingly.

- UC1.2_REQ_SA_005: Perception system shall be provide information needed to perform longitudinal manoeuvres except reversing.

- UC1.2_REQ_SA_006: Perception system shall be fuse information from the combination of sensors and V2X in urban intersections equipped with RSUs extending the CAV’s on-board FoV.

- UC1.2_REQ_SA_007: Perception system accuracy

    - *Separability of pedestrian in front or aside of crossing vehicle.*

- UC1.2_REQ_SA_008: Perception system acquisition speed

    - *Crossing traffic need to be detected fast enough to avoid collisions when entering/passing over the intersection.*

- UC1.2_REQ_SA_009: Perception system robustness

    - *Crossing traffic shall be detected by the radar system of infrastructure in the presence of adverse weather.*

- UC1.2_REQ_SA_010: Perception system sensitivity

    - *Crossing traffic need to be detected early enough, while early relates to the requirement of acquisition speed.*

- UC1.2_REQ_SA_011: ADS MRM

    - *Safe solutions in case of failure in the system shall be provided.*

B. High level requirements with respect to scenario description/generation:

- UC1.2_REQ_SDG_001: Mixed traffic – Mixed traffic situations shall concern a variable number of traffic objects, e.g., vehicles, trucks, buses, but also VRUs, which may be connected or not.

- UC1.2_REQ_SDG_002: Interaction with other users – The interaction with other users shall happen with connected vehicles via V2V, whereas the interaction with infrastructure shall happen via V2I through SPaT and CAM messages.

- UC1.2_REQ_SDG_003: Interaction with infrastructure via SPaT/CAM timely disseminated.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC1.2_REQ_TTM_001: Virtual testing shall include the SiL and CoSim methods.
- UC1.2_REQ_TTM_002: Physical testing shall be performed on Proving Ground with traffic infrastructure.
- UC1.2_REQ_TTM_003: Comparison of the ADS behaviour between virtual and physical tests (Proving Ground) shall be performed to validate and confirm the robustness of the simulated approach.

4.3 Sub-UC 1.3 "Cooperative perception testing”

4.3.1 Short description and objectives

The goal of this sub-UC is to demonstrate an overall safety argumentation for urban collective perception, concretely addressing current gaps with respect to:

- Combine perception with cooperative aspects for collective perception testing.
- Study scenario requirements in ODDs that include V2V connectivity for collective perception testing in simulation. Selecting non-line of sight critical scenarios for CAV testing.
- Study the need of simulation tools’ combination (i.e co-simulation) for collective perception testing.
- Discuss aspects of an overall safety argumentation in virtual cooperative perception testing.

Planned ICCS work includes a PoC small-scale collective perception validation framework in which new collective scenarios generation will be developed using Mathworks RoadRunner and CARLA focusing on sensor data exchange and sensor fusion testing, omitting the need to perform co-simulation with a traffic or network simulation tool, since these are not required to test perception. ICCS is also involved in EVENTS European project [48] leading the implementation of a collective perception UC for an urban roundabout in a hybrid testing environment including two real vehicles and CARLA agents, all connected to each other running the same scenario.

4.3.2 ADS under test

The cooperative environment perception layer system shall be capable of communicating with sensor equipped RSUs and vulnerable road users, by aggregating cooperative awareness information in CPMs.

- **SuT**

In this sub-UC the assumed ADS under test is the perception AD subsystem of an urban chauffer ADS which is also capable of sending/receiving and processing (on-board or off board e.g. employing a remote smart RSU node) rich V2X information data mainly consisting of object-level data perceived from other road users.

<u>Background info on collective perception</u>

As stated in SAE J 3216 “Cooperative driving automation (CDA)” aims to improve the safety and flow of traffic and/or facilitate road operations by supporting the movement of multiple vehicles in proximity to one another. This is accomplished, for example, by sharing information that can be used to influence (directly or indirectly) DDT performance by one or more nearby road users [10]. Vehicles and infrastructure elements engaged in cooperative automation may share information, such as state (e.g., vehicle position, signal phase), intent (e.g., planned vehicle trajectory, signal timing), or seek agreement on a plan (e.g., coordinated merge). Cooperation among multiple participants and perspectives in traffic can improve safety, mobility, situational awareness, and operations. However, nothing in this document is intended to suggest that driving automation requires such cooperation in order to be performed safely. Cooperative strategies may be enabled by the sharing of information in a way that meets the needs of a given application. The needs may be expressed in terms of performance characteristics, such as latency, transmission mode (e.g., one-way, two-way), range, privacy and security, and information content and quality. There are several potential technologies for communicating information between the subject vehicle and other participants.

The on-board sensors of connected autonomous vehicles (CAVs) are limited by their range and inability to see around corners or blind spots, otherwise known as non-line of sight scenarios (NLOS) [11]. Despite there being a substantial body of work on the development of communication and path planning algorithms for such scenarios, there is no standard method for generating and selecting critical NLOS scenarios for testing these algorithms in a scenario-based simulation environment. In this sub-UC, the focus is on testing the V2V-augmented perception layer, i.e. on collective perception testing when vehicle-to-vehicle communication is available (CAM, CPM ETSI messages). CAV control layer, i.e. which cooperative strategies should be implemented are out of scope since we focus only on perception layer. Notably, there are two recent works that offer a collective perception virtual testing (co-simulation) framework accompanied with a benchmark dataset, namely V2XSim and OpV2V [12]. Both referenced works make use of CARLA and a traffic simulation for generating realistic traffic at intersections.

- **ODD**

A textual format was used for ODD definition for this sub-UC using elements/attributes from AVSC00002202004 and BSI PAS 1883 ODD formats in a restrictive mode (i.e., what is not defined it is not permitted):

Road ODD includes B-roads straight road segments, urban unsignalized intersections and urban roundabouts. The envisioned road/lanes geometry is defined by straight roads without physical separation between traffic directions (i.e., “undivided” roads) joining at an intersection and possibly having pedestrian crossing structures. In terms of lanes, the supported ODD will account for at least one lane per driving direction with lane markings of *good quality (both solid and dashed). The roadway edge is expected to be line-marked and the road surface uniform (asphalt). In terms of environmental conditions, the enabler is expected to operate also in presence of calm wind and light or moderate rain, under daytime illumination conditions and irrespective of cloudiness or position of the sun. Finally, in terms of traffic, the ADS is expected to support ODDs of at least low flow rates and presence of vulnerable road users, especially pedestrians, as detectable objects. Max ego-vehicle speed is 50km/h. Special city zones like roadwork zones are excluded as well as heavy rain, flooded* or snowy roads. Other road users can be passenger cars, busses, trucks and pedestrians.

Note: CARLA does not offer bicyclist agent that is the reason why we excluded them.

4.3.3 Indicative test scenarios

Based on Euro NCAP VRU test catalogue, C2C consortium scenarios and Hi-Drive EU project UC/test scenarios catalogue, three scenarios are considered for assessing the cooperative perception system performance in the present sub-UC 1.3. These scenarios will take into consideration urban roads and intersections with sensor-equipped RSUs and the inclusion of vulnerable road users (pedestrians, bicyclists, etc.) in the target ODD.

Exchange of Collective Perception Messages (CPMs) transferring information on surrounding objects is supported by a smart RSU which should be supported by the scenario editor. CAV behaviour is not to be assessed since the focus is on assessing the extension of the FoV through collective perception. No driver in the loop is considered.

Figure 27: Scene illustration of sub-UC 1.3-A "Darting-out pedestrian" scenario (straight road segment).

- **<u>Test scenario sub-UC 1.3-A: Darting-out pedestrian</u>**

The Figure 27 illustrates a common urban situation where multiple parked vehicles on the right side of the CAV hinder the FoV and the detection of pedestrians: due to occlusion created by the parked buses, CAV cannot not detect the pedestrian coming from behind the bus. The pedestrian is detected by other vehicles moving in the opposite lane which are able through V2X to broadcast their perception output through CPMs to a smart infrastructure node and ultimately to the CAV.

Baseline scenario: Straight road segment, 2 lanes total, no pedestrians, stopped vehicle ahead

- **Test scenario sub-UC 1.3-B: Urban junction**

This test scenario includes a four-leg intersection where four two-directional roads meet as shown in Figure 28.

Trigger: The CAV drives on a two-directional road approaching an intersection and receives an aggregated cooperative sensing information from the MEC server.

- The CAV (ego vehicle B in the sketch) plans to cross straight ahead when it receives information that another vehicle, A, is also crossing straight with dynamics that are detected by the ego vehicle as leading to a potential collision. The CAV slows down and possibly stops to avert a collision.
- The CAV plans to turn left. The received information indicates that vehicle A is blocking its route and that a potential collision has been detected. The ego vehicle B slows down smoothly and waits for vehicle A to move away before moving into the intersection conflict area.
- The vehicle A plans to turn left. The received information indicates that a pedestrian is crossing the street along its route and that a potential collision has been detected. Ego vehicle A slows down smoothly and waits for the pedestrian to cross before moving into the intersection conflict area.

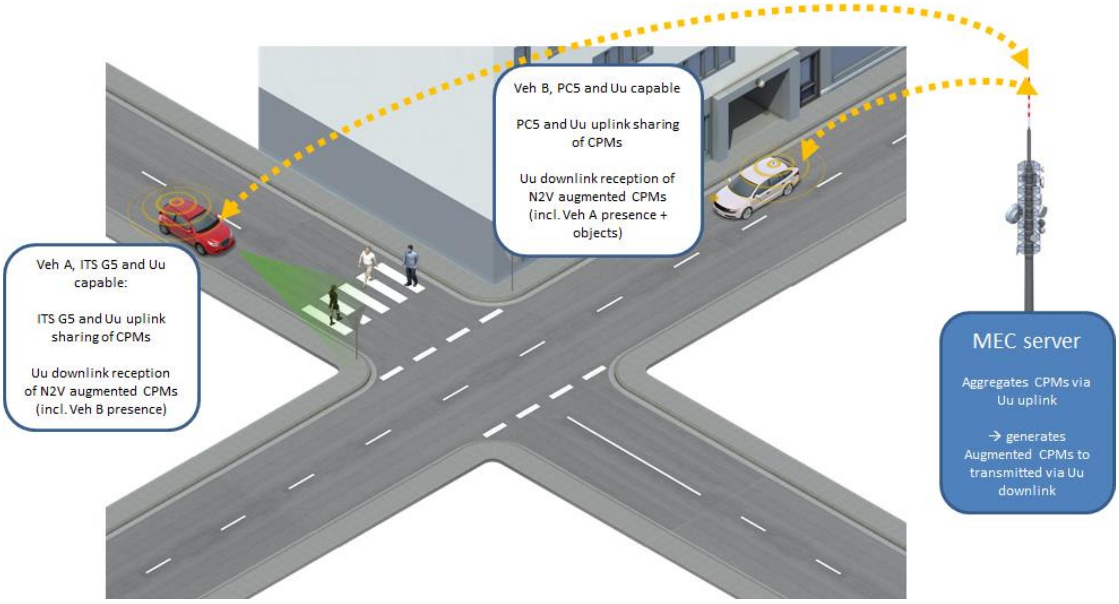

Figure 28: Schematic representation of sub-UC 1.3-B “urban junction” scenario (image source: [47]).

- **Scenario sub-UC 1.3-C: urban roundabout**

Roundabouts present specific challenges in the complexity of driving behaviour, in terms of high variance in the number of lanes and increased uncertainty in perception due to the road geometry. The roundabout shape that will be used in this scenario is shown in Figure 29.

The ego vehicle approaches a roundabout and receives additional information about the junction and other road users via the infrastructure.

1. The roundabout entry is free, and the vehicle enters and takes the desired exit.
2. The roundabout entry is not free, and the vehicle does not enter and waits for an appropriate time to enter.
3. The ego vehicle approaches the roundabout entry alongside a large vehicle and has its view obscured.

If there are objects behind the occlusion, the ego vehicle will wait for an appropriate gap to enter the junction. Otherwise, it will enter the roundabout.

Figure 29: Schematic representation of sub-UC 1.3-C "urban roundabout" scenario (the present sub-UC was borrowed from Hi-Drive project D3.1, see also EVENTS project D2.1).

4.3.4 Preliminary test plan

First a 100% virtual testing framework will be developed based on Matlab RoadRunner, CARLA and ROS. Then and if resources permit it, a hybrid testing will be investigated by deployment of a prototype connected research vehicle which will communicate real-time with CARLA cloud simulation with the analogy of virtual versus physical testing to be 70/30.

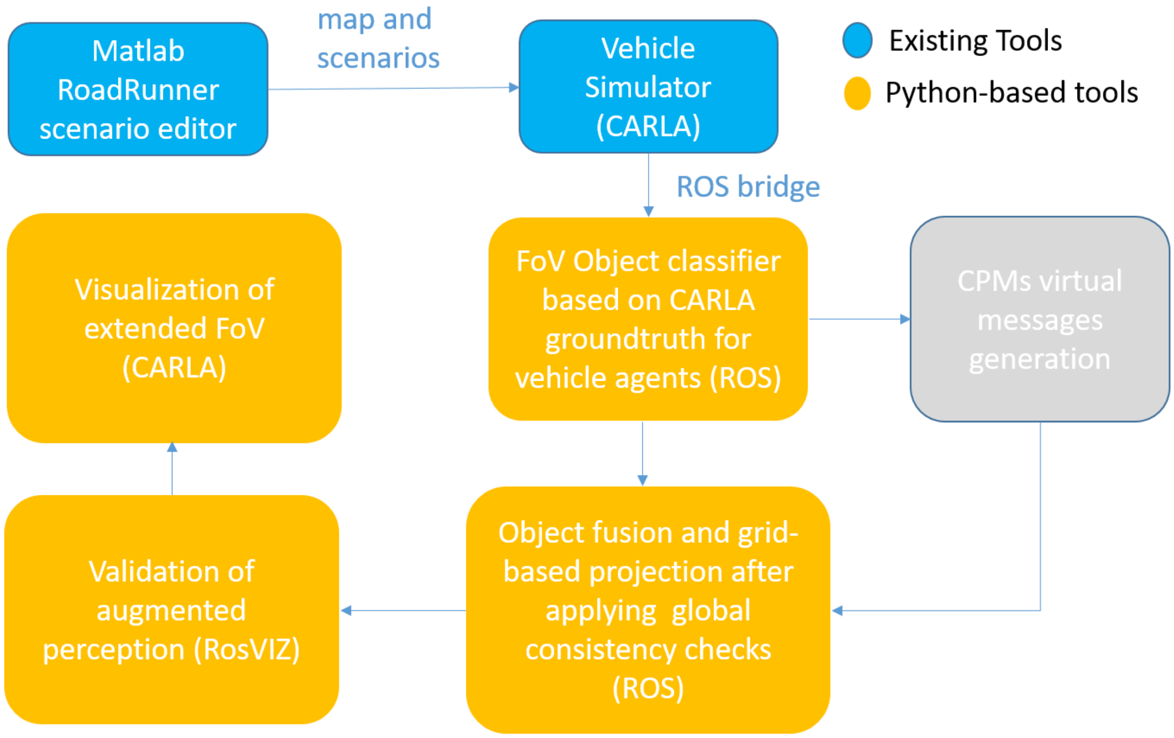

Figure 30: Virtual testing framework draft architecture for the sub-UC 1.3.

4.3.4.1 Virtual testing

In this sub-UC1.3, Carla is selected because of its flexible architecture, which allows extending the simulator capabilities. For example, ROS bridge, Autoware, Sumo, and Vissim co-simulation environments are directly supported by Carla. Also, one can create new maps and simulation environments with Mathworks RoadRunner and import them to Carla. Considering that Carsim, MATLAB, and Carla software can communicate with Unreal Engine, it is possible to create co-simulation environments where the vehicle dynamics are simulated in MATLAB or Carsim in a Carla simulation.

The basic virtual testing framework logical and SW components are shown in Figure 30. The framework can be later extended by including a traffic simulation like SUMO or a network simulator like ARTERY.

4.3.4.2 Physical testing

Not currently planned. Based on available resources, ICCS will consider the setup of a hybrid testing environment within NTUA campus using the ICCS prototype vehicle equipped with an OBU offering DSRC connectivity and combined with CARLA.

4.3.5 Preliminary metrics for SA validation

For the selected NLOS scenarios of sub-UC 1.3, the following perception layer-related KPIs could be considered (ongoing work will be updated based on SUNRISE conducted research):

- object detection probability based on the available evidence.
- object classification confidence based on the available evidence.
- object clutter rate
- correctness of the assumed measurement noise for each object considered in the scene.

Further KPIs could be established to check the performance of the V2X communication depending on specific requirements like:

- Network latency of receiving and processing incoming messages shall be as low as possible to be able to process as many messages as possible and finally gather as much information as possible.
- Number of incoming and outgoing messages and the type of messages the ADS can handle by aggregating cooperative awareness information in CPMs.

Finally, metrics that can be used in hybrid testing setups, either used to compare simulation with proving ground tests or used to assess aspects of the hybrid setup parameterization, can be also considered and derived (ongoing work will be updated based on SUNRISE conducted research).

4.3.6 Preliminary input data requirements

The following types of data are required for setting up the UC validation study:

- Sensor ground truth data:
  - *(1) recorded data from the (virtual) V2X on-board units (OBUs) of the vehicles*
  - *(2) recorded data from the (virtual) road-side units (RSUs)*
  - *(3) recorded data from the (virtual) on-board sensors (camera, lidar) of the vehicles*
- Scenario data: *Selected set of NLOS scenarios in urban environment*
- Perception data:
  - *(1) simulated CPM data coming from other road users in the vicinity of the ego-vehicle CAV*
  - *(2) simulated CPM data coming from smart road-side units (sRSUs).*

(3) annotated recorded data or simulated object-level data (including uncertainties) derived from the perception layer of the ego-vehicle and other vehicles in the vicinity. Annotated recorded birds-eye-view drone data could be studies for creation of realistic scenarios in CARLA.

4.3.7 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

Apply ISO21448 and analyze safety of the intended functionality for a perception system that integrates external V2X information (SOTIF) focusing on:

i. UC1.3_REQ_SA_001: V2X info reliability and consistency against on-board sensor suite.

ii. UC1.3_REQ_SA_002: V2X info fusion precision and update rate for objects outside CAV FoV and inside CAV FoV.

iii. UC1.3_REQ_SA_003: V2X info fusion robustness against V2X communication delays

iv. UC1.3_REQ_SA_004: Cooperative Perception **system performance in nominal ODD**:

1. *shall detect and track vehicles and pedestrians outside FoV with a confidence of at least 80%.*
2. *shall run in real time with a maximum delay of 50 ms.*
3. *(optional-only if network simulation is involved) I2V timely disseminated validated through latency, throuput validation.*

v. UC1.3_REQ_SA_005: Cooperative Perception **system performance in adverse ODD**:

1. *focus on conditions that might affect V2X connectivity (DSRC, 5G) like clutter, high buildings, rain.*
2. *Co-simulation with a network simulator is needed if testing of communication performance is also of interest.*

B. High level requirements with respect to scenario description/generation:

- UC1.3_REQ_SDG_001: Mixed traffic – Mixed traffic situations shall concern a variable number of traffic objects, e.g., vehicles, parked buses and pedestrians. A subset of vehicles is considered connected. Sources for scenario tuning can be:
  - *C2C and Euro NCAP intersection scenarios can be used for selecting test scenarios and extracting validation requirements relevant for cooperative perception system testing*
  - *CARLA leader board scenarios (NHTSA inspired)*
  - *C-Roads infrastructure-enabled scenarios [49]*
- UC1.3_REQ_SDG_002: Interaction with other users – The interaction with other users shall happen via V2I through CPM messages. A subset of vehicles are considered connected and able to broadcast CPMs to the smart RSU which in turn broadcasts the fused global object scene back to receivers (connected AV and other connected vehicles).
- UC1.3_REQ_SDG_003: In principle nominal ODDs shall be addressed but few tests could be performed on challenging ODDs (by simulating adverse weather or connectivity conditions and their effects on object detection that could be supported via synthetically noisy data generation). This is in line with EU General Safety Regulation (EU) 2019/2144 which requires the testing of ADS to include both nominal ODD and ODD boundary conditions.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC1.3_REQ_TTM_001: Virtual testing shall include SiL and CoSim methods.
- UC1.3_REQ_TTM_002: Hybrid ViL testing including physical testing with a connected vehicle on a Proving Ground in parallel to a virtual scenario executed on the cloud, if supported, requires a PG with V2C connectivity.
- UC1.3_REQ_TTM_003: Sub-UC specific data shall be considered like:
  - *simulated CPM data coming from other road users in the vicinity of the ego-vehicle CAV*
  - *simulated CPM data coming from smart road-side units (sRSUs).*
  - *annotated recorded data or simulated object-level data (including uncertainties) derived from the perception layer of the ego-vehicle and other vehicles in the vicinity.*

D. High level requirements with respect to the user perspective:

- UC1.3_REQ_UP_001: SAF scenario editor user should be able to tag objects that are outside ego-vehicle FoV.

- UC1.3_REQ_UP_002: SAF scenario editor user should be able to add static or dynamic agents that transmit or receive V2X information so that a cooperative perception scenario can be configured.

5 UC ID 2 – TRAFFIC JAM AD VALIDATION

5.1 Short description and objectives

Based on "ERTRAC Connected, Cooperative and Automated Mobility Roadmap (2022)" [3] the scope of the **UC ID 2 "Traffic Jam AD validation"** is to validate the automated lane keeping system (ALKS) in a virtual/real manner for highly automated vehicles (SAE L4) on motorways and motorway similar roads via the implementation of a hybrid validation testing, by combining virtual simulations and physical tests.

This UC is focusing on AD behavior validation and aims to optimise the workflow from test case generation to model creation and integration, as well as to test execution and assessment through new metrics designed for various scenarios.

Background on ALKS

Traffic Jam AD Validation is mainly derived from Automated Lane Keeping System (ALKS) [13] regulation, which is the very first regulatory step for an ADS. Both longitudinal and lateral movements are considered as in the scope of UN-R 157 [14]. Collision avoidance coverage prevents or minimize the risk that caused by even driver or environmental effects, such as cutting vehicles, VRUs, etc.

Predominantly, latest amendment of UN-R 157 [14], shall operate the driving task in place of driver behaviours, capable to handle failures and avoid collision by executing MRM up to 130 km/h. Environmental awareness and sudden risk evaluation algorithms provide safer transportation and efficient ADS. However, the present UC targets the original UN-R 157 with a maximum speed of 60 km/h.

To evaluate the performance and safety metrics, related KPI's from both real-world testing and SiL simulations will be considered for the comparison. The proposed complete workflow enables the generation of the combinatorial test cases, as well as the execution and reporting of assessment criteria.

5.2 ADS under test

This UC is focusing on AD motion planning/control subsystems' validation.

- **SuT**

The presented ADS under test (ALKS) includes some basic feature requirements and also some DDT requirements for SAE L4 vehicles to operate safely in on-road traffic, including longitudinal and lateral control, object and event detection and response, prediction of other road users' actions and manoeuvring.

Basic Feature Requirements

- If the ADS is activated, the feature must perform the DDT.

- If the ADS is activated, the feature must not cause any collisions that are reasonably foreseeable and preventable.

- If the ADS is activated and if a collision can be safely avoided without causing another one, the feature must avoid the collision.

- If the ADS is activated, the feature must comply with traffic rules relating to the DDT in the country of operation, including responding to emergency/enforcement vehicles.

- **DDT/OEDR**

  - If the ADS is activated, the feature must keep the vehicle inside its lane of travel and ensure that the vehicle does not unintentionally cross any lane marking (outer edge of the front tyre to outer edge of the lane marking).

  - The ADS must aim to keep the vehicle in a stable lateral and longitudinal motion inside the lane of travel to avoid confusing other road users.

  - If the ADS is activated, the feature must control the speed of the vehicle.

  - If the ADS is activated, the feature must be able to detect the distance to the next vehicle in front.

  - If the ADS is activated, the feature must adapt the vehicle speed to adjust a safe following distance in order to avoid a collision.

  - If the ADS is activated and for operating speeds above 60 km/h, the feature must comply with minimum following distances in the country of operation.

  - If the ADS is activated, the feature must detect the risk of collision in particular with another road user ahead or beside the vehicle, due to a decelerating lead vehicle, a cutting in vehicle or a suddenly appearing obstacle.

  - If the ADS is activated, the feature must automatically perform appropriate manoeuvres to minimize risks to safety of the vehicle occupants and other road users.

  - If there’s an imminent collision risk, the ADS must carry out an emergency manoeuvre.

  - If the ADS is activated, the feature must recognize all situations in which it needs to transition the control back to the driver.

- **ODD**

The description of the generic ODD coverage for the present UC contains a set of attributes/parameters and their respective sub-attributes in parallel with their capabilities and limit ranges, as depicted in Table 8.

Table 8: ODD coverage for the UC ID 2.

Attribute	Sub-attribute	Sub-attribute	Capability & Limit
Drivable area type	Motorways(M)		Yes - without active traffic management
	Radial roads (A-roads)		No
	Distributor roads (B-roads)		No
	Minor roads		No
	Slip roads		No
	Parking		No
	Shared space		No
Drivable area geometry	Horizontal plane *pg. 7 in PAS 1883*	Straight roads	Yes
		Curves	Yes - minimum 520 (SOP1) or 250 (SOP2) m radius of curvature
	Vertical plane *pg. 7 in PAS 1883*	Up-slope	Yes
		Down-slope	Yes
		Level plane	Yes
	Transverse Plane *pg. 7 in PAS 1883*	Divided/undivided	Divided
		Pavements	Not applicable
		Barriers on edges	No
		Types of lanes together	Not applicable
Drivable area lane specification	Lane dimensions		TBD
	Lane marking		Not applicable
	Lane type	Bus lane	No
		Traffic lane	Yes
		Cycle lane	No
		Tram lane	No
		Emergency lane	No
		Special purpose lane	No
	Number of lanes		Yes - Single or Multi lanes are allowed
	Direction of level	Right-hand	Yes

		Left-hand	Yes
Drivable area surface	Surface type	Asphalt	Yes
		Concrete	Yes
		Cobblestone	Not applicable
		Gravel	Not applicable
		Sand	Not applicable
	Surface features - damage	Cracks	Not applicable
		Pothole	Not applicable
		Rut	Not applicable
		Swell	Not applicable
	Induced road surface condition	Icy	Not applicable
		Flooded roadways	Not applicable
		Mirage	Not applicable
		Snow	Not applicable
		Standing water	Not applicable
		Wet road	Not applicable
		Surface contamination	Not applicable
Drivable area signs	Type	Information signs	Yes
		Regulatory signs	Yes
		Warning signs	Yes
	Time of operation	Part-time	No
		Full-time	Yes
	State	Variable	No
		Uniform	Yes
Drivable area edge	Line markers	Solid	Yes
		Broken	No
		Temporary	No
	Shoulder	Paved	No
		Gravel	No
		Grass	No
	Solid barriers	Grating	No
		Rails	No
		Curb	Yes
		Cones	No
Junctions - Roundabout	Normal	Signalized/non-signalized	No

	Compact	Signalized/non-signalized	No
	Double	Signalized/non-signalized	No
	Large	Signalized/non-signalized	No
	Mini	Signalized/non-signalized	No
Junctions - Intersection	T-junctions		No
	Staggered		No
	Y-junctions		No
	Crossroads		No
	Grade separated		No
Special structures	Automatic access control		No
	Bridges		Yes
	Pedestrian crossing		No
	Rail crossing		No
	Tunnels		No
	Toll plaza		No
Fixed road structures	Buildings		Not applicable
	Street lights		Not applicable
	Street furniture (e.g bollards)		Not applicable
	Vegetation		Not applicable
Temporary road structures	Construction site detours		No
	Refuse collection		No
	Road works		No
	Road signage		No
Weather - wind	Calm [0–0.2 m/s]		TBD
	Light air [0.3–1.5 m/s]		TBD
	Light breeze [1.6–3.3 m/s]		TBD
	Gentle breeze [3.4–5.4 m/s]		TBD
	Moderate breeze [5.5–7.9 m/s]		TBD
	Fresh breeze [8.0–10.7 m/s]		TBD
	Strong breeze [10.8–		TBD

	13.8 m/s]		
	Near gale [13.9–17.1 m/s]		TBD
	Gale: 17.2–20.7 m/s;		TBD
	Strong gale [20.8–24.4 m/s]		TBD
	Storm [24.5–28.4 m/s]		TBD
	Violent storm [28.5–32.6 m/s]		TBD
	Hurricane force [≥ 32.7 m/s]		TBD
Weather - rainfall	Light rain [precipitation rate(p.r.) < 2.5 mm/h]		Yes
	Moderate rain [2.5 < p.r < 7.6 mm/h]		Yes
	Heavy rain [7.6 < p.r < 50 mm/h]		No
	Violent rain [50 < p.r < 100 mm/h]		No
	Cloudburst [100 mm/h < p.r]		No
Weather - snow	Light snow [1km < visibility]		No
	Moderate snow [0.5 < visibility < 1km]		No
	Heavy snow [visibility < 0.5km]		No
Particulates	Marine		Not applicable
	Mist/fog		Visibility range TBD
	Sand		Not applicable
	Dust		Not applicable
	Smoke		Not applicable
	Volcanic ash		Not applicable
Illumination	Day [>2000 lx]	Elevation of sun above horizon [deg]	Not applicable
		Position of sun (e.g front, left, right etc.)	Front, behind
	Night/Low [< 1 lx]		No
	Cloudiness	Clear	Not applicable
		Partly Cloudy	Not applicable
		Overcast	Not applicable
	Artificial		Yes

Connectivity type	V2V	Cellular	Not applicable
		Satellite	Not applicable
		802.11p (e.g DSRC, ITS-5G)	Not applicable
	V2I	Cellular	Not applicable
		Satellite	Not applicable
		802.11p (e.g DSRC, ITS-5G)	Not applicable
Connectivity positioning	Galileo		Not applicable
	GLObal Navigation Satellite System		Not applicable
	Global Positioning System		Not applicable
Dynamic traffic elements	Density of agents		Minimal, Normal, Rush-hour traffic
	Volume of traffic		Minimal, Normal, Rush-hour traffic
	Flow rate		Not applicable
	Agent Type	Vehicle	Yes
		Two-wheelers	Yes
		Bicycles	No
		Pedestrians	No
		Animals	No
	Presence of special vehicles (e.g ambulance)		No
	Speed Limit		15 km/h
Subject Vehicle	Autonomus Lane change capability	Normal circumstances	No
		In case degregation mode	No

5.3 Indicative test scenarios

Twelve scenarios are considered for assessing the ADS performance (Traffic Jam Chauffeur, TJC) in UC ID 2 with respect to speed control and ALKS.

- **Test scenario UC ID 2-A: TJC speed limit adaptation to new speed limit and distance to vehicle ahead**

Situation Description: Ego vehicle is traveling on its own lane maintaining safe following distance to a lead vehicle, there's a new speed limit which is lower than current ego vehicle speed (Figure 31).

Trigger: A speed limit lower than current ego vehicle speed is detected.

Expected Feature Behaviour: Feature decelerates ego vehicle to meet the new speed limit and keeps maintaining following distance to be at least minimum following distance.

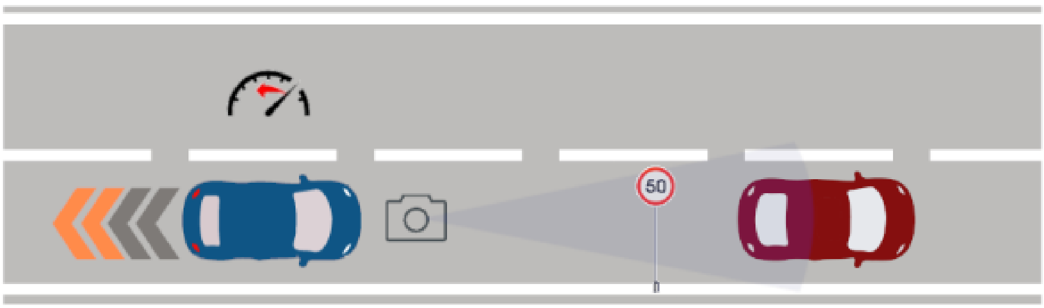

Figure 31: Schematic representation of test scenario UC 2-A (TJC speed limit adaptation to new speed limit and distance to vehicle ahead).

- **Test scenario UC 2-B: TJC speed limit adaptation to vehicle ahead**

Situation Description: Ego vehicle is traveling on its own lane, a lead vehicle on the lane inside the feature detection range appears (Figure 32).

Trigger: A lead vehicle on ego vehicles lane of travel appears.

Expected Feature Behaviour: Feature adapts ego vehicle speed to adjust the following distance to be at least minimum following distance.

Figure 32: Schematic representation of test scenario UC 2-B (TJC speed limit adaptation to vehicle ahead).

- **Test scenario UC 2-C: TJC cut-in**

Situation Description: Ego vehicle is traveling on its own lane maintaining safe following distance to a lead vehicle, a target vehicle from an adjacent lane cuts-in to ego vehicle's lane of travel inside the feature detection range (Figure 33).

Trigger: A target vehicle cuts-in between ego vehicle and lead vehicle.

Expected Feature Behaviour: Feature decelerates ego vehicle according to cut-in vehicle to adjust the following distance to be at least minimum following distance.

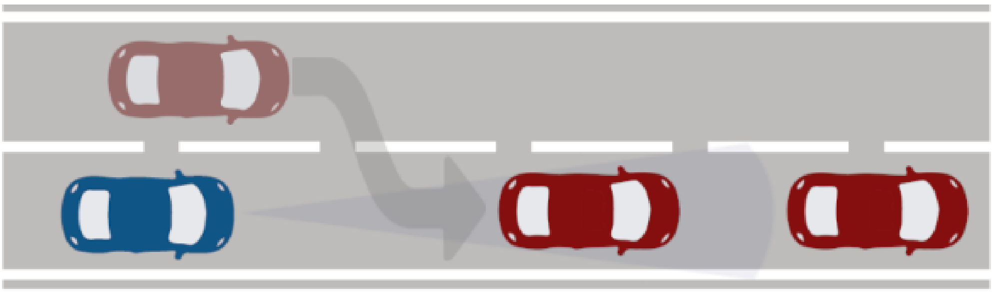

Figure 33: Schematic representation of test scenario UC 2-C (TJC cut-in).

- **Test scenario UC 2-D: TJC cut-out**

Situation Description: Ego vehicle is traveling on its own lane, a lead vehicle in ego vehicle's lane of travel cuts out to another lane, another lead vehicle inside the feature detection range appears (Figure 34).

Trigger: A lead vehicle in ego vehicle's lane of travel cuts out to another lane, another target vehicle appears.

Expected Feature Behaviour: Feature adapts ego vehicle speed to adjust the following distance to be at least minimum following distance.

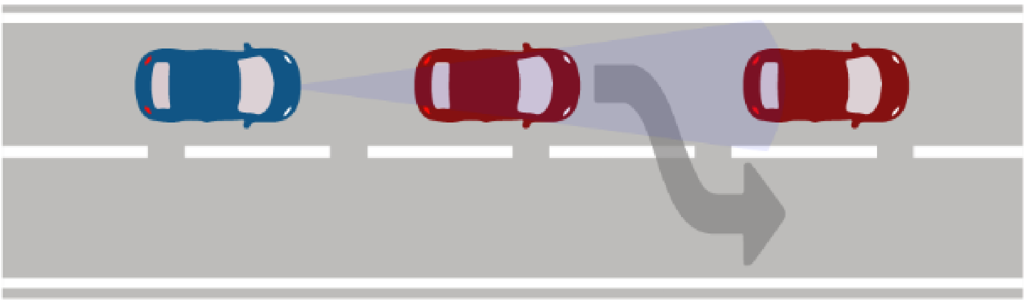

Figure 34: Schematic representation of test scenario UC 2-D (TJC cut-out).

- **Test scenario UC 2-E: TJC blocked lane by stationary object**

Situation Description: Ego vehicle is traveling on its own lane; a stationary road user appears or there's a blocked lane of travel (Figure 35).

Trigger: A stationary road user appears or there's a blocked lane of travel.

Expected Feature Behaviour: Feature brings the ego vehicle to a complete stop to avoid a collision.

Figure 35: Schematic representation of test scenario UC 2-E (TJC blocked lane by stationary object).

- **<u>Test scenario UC 2-F: TJC start moving after full stop</u>**

Situation Description: Ego vehicle is in standstill behind a stationary target vehicle, target vehicle starts moving (Figure 36).

Trigger: Target vehicle starts moving.

Expected Feature Behaviour: Feature accelerates the ego vehicle while maintaining at least minimum following distance.

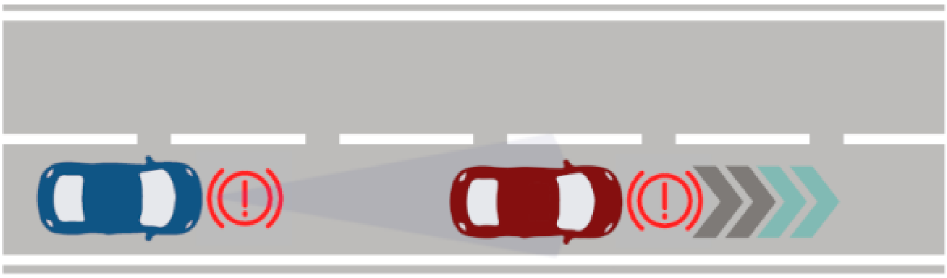

Figure 36: Schematic representation of test scenario UC 2-F (TJC start moving after full stop).

- **<u>Test scenario UC 2-G: TJC deceleration</u>**

Situation Description: Ego vehicle is traveling on its own lane, a lead vehicle in ego vehicle's lane of travel inside the feature detection range decelerates, emergency manoeuvre is not necessary (Figure 37).

Trigger: A lead vehicle in ego vehicle’s lane of travel decelerates.

Expected Feature Behaviour: Feature adapts ego vehicle speed to adjust the following distance to be at least minimum following distance.

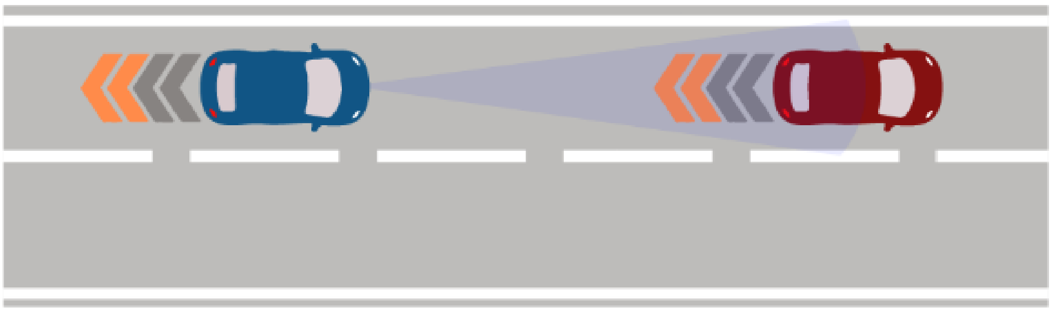

Figure 37: Schematic representation of test scenario UC 2-G (TJC deceleration).

- **<u>Test scenario UC 2-H: TJC crossing pedestrian</u>**

Situation Description: Ego vehicle is traveling on its own lane, an unobstructed pedestrian crossing the carriageway appears in the front, emergency manoeuvre is not necessary (Figure 38).

Trigger: An unobstructed pedestrian appears.

Expected Feature Behaviour: Feature decelerates ego vehicle in order to avoid a collision with the pedestrian.

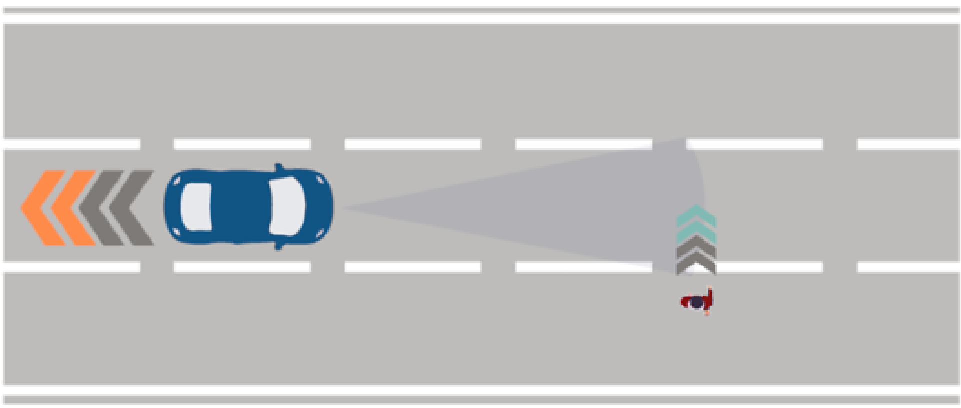

Figure 38: Schematic representation of test scenario UC 2-H (TJC crossing pedestrian).

- **<u>Test scenario UC 2-I: TJC emergency deceleration</u>**

Situation Description: Ego vehicle is traveling on its own lane, a lead vehicle in ego vehicle's lane of travel inside the feature detection range decelerates resulting in an imminent collision risk, emergency manoeuvre is deemed necessary (Figure 39).

Trigger: A lead vehicle in ego vehicle's lane of travel decelerates resulting in an imminent collision risk.

Expected Feature Behaviour: Feature performs an emergency manoeuvre, decelerating the ego vehicle while not crossing lane markings.

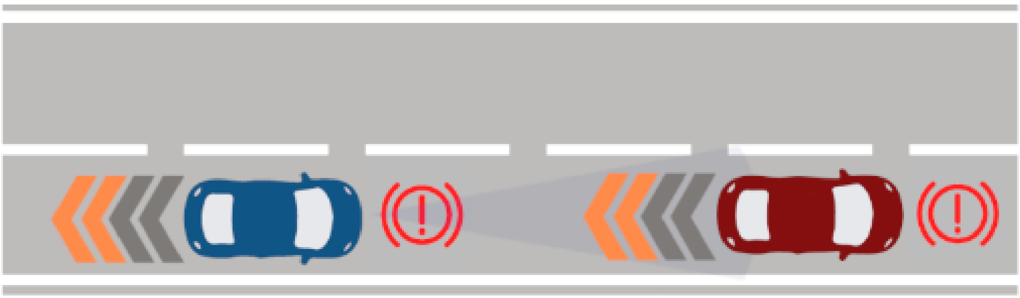

Figure 39: Schematic representation of test scenario UC 2-I (TJC emergency deceleration).

- **<u>Test scenario UC 2-J: TJC start moving after emergency stop</u>**

Situation Description: Ego vehicle has come to a standstill after an emergency manoeuvre, the imminent collision risk has disappeared (Figure 40).

Trigger: The imminent collision risk disappears.

Expected Feature Behaviour: Feature drives off the ego vehicle again automatically, while deactivating the hazard warning lights.

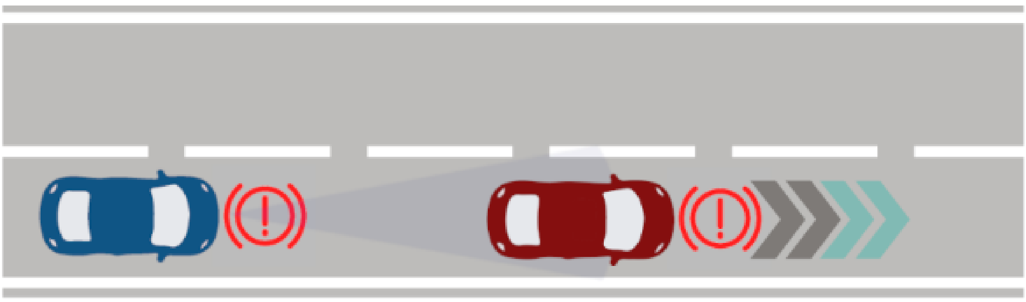

Figure 40: Schematic representation of test scenario UC 2-J (TJC start moving after emergency stop).

- **<u>Test scenario UC 2-K: TJC emergency stop due to crossing pedestrian</u>**

Situation Description: Ego vehicle is traveling on its own lane, an unobstructed pedestrian crossing the carriageway or a stationary obstacle appears in the front, resulting in an imminent collision risk, emergency manoeuvre is deemed necessary (Figure 41).

Trigger: An unobstructed pedestrian or a stationary obstacle appears.

Expected Feature Behaviour: Feature performs an emergency manoeuvre, decelerating the ego vehicle while not crossing lane markings.

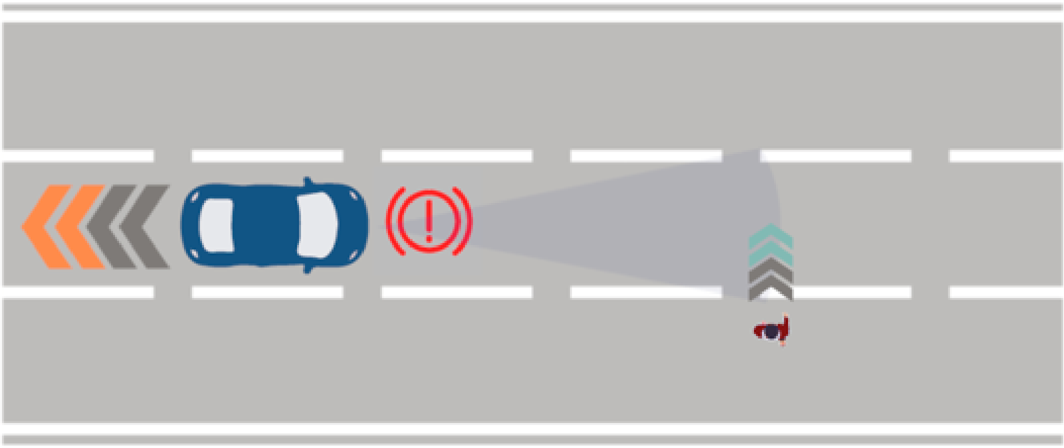

Figure 41: Schematic representation of test scenario UC 2-K (TJC emergency stop due to crossing pedestrian).

- **<u>Test scenario UC 2-L: Lane keeping while entering a curve</u>**

Situation Description: Ego vehicle is traveling on its own lane and enters a curve with a different radius of curvature compared to before (Figure 42).

Trigger: Ego vehicle enters a curve with radius of curvature higher than the minimum operational radius of curvature.

Expected Feature Behaviour: Feature maintains ego vehicle at the center of the lane.

Figure 42: Schematic representation of test scenario UC 2-L (Lane keeping while entering a curve).

5.4 Preliminary test plan

The share between virtual and physical testing will not be defined in advance but will be a result of the SUNRISE SAF for this UC. One of the planned subsystems to be developed is a method to decide on the “domain split” between simulation and proving ground testing.

In fact, the amount of proving ground tests depends on the model correlation quality.

5.4.1 Virtual testing

This UC will be tested by applying SiL simulations. The software under test will be provided by CAF and comprises the TJC ADS by covering the requirements listed in the above sections. As there is no perception software included, object list data will be generated from the virtual sensor models.

According to SUNRISE WP3 and WP4, appropriate scenario generation methods will be applied to ensure maximum coverage of the ODD. Also, SiL tests are planned to be executed in the cloud for large-scale testing.

5.4.2 Physical testing

The share of physical tests will be defined as a result of the domain split subsystem in WP4.

The tests will be conducted with a test vehicle and on a proving ground (e.g. ZalaZONE in Hungary).

A detailed test plan will be defined in T7.2, along with a definition of how to integrate the TJC ADS in the test vehicle.

5.5 Preliminary metrics for SA validation

Certain metrics will be developed that enable a more realistic evaluation of ADS performance in executed test instances (scenarios). This strengthens the overall safety argumentation necessary for the ADS safety validation, as depicted in Table 9.

Target values are only listed if the underlying regulation states a KPI threshold.

Table 9: KPIs and metrics for the UC ID 2.

Target Description	**Unit**	**Target Value** (according to regulations)
Maximum distance to the centre of the ego lane when the system is lane centering	m	
Maximum distance to the centre of the ego lane when the system is lane offsetting	m	
Maximum lateral acceleration induced by the system during a curve	m/s^2	
Maximum longitudinal acceleration provided by the system whilst in active mode	m/s^2	
Maximum longitudinal acceleration provided by the system whilst in MRM	m/s^2	
Maximum longitudinal deceleration provided by the system whilst in active mode	m/s^2	
Maximum longitudinal deceleration demanded by the system MRM	m/s^2	4
Maximum value of the average lateral jerk over half a second	m/s^3	

generated by the system		
Maximum longitudinal postive jerk provided by the system whilst in active mode	m/s^3	
Maximum longitudinal positive jerk provided by the system whilst in MRM	m/s^3	
Maximum longitudinal negative jerk provided by the system whilst in active mode	m/s^3	
Maximum longitudinal negative jerk provided by the system whilst in MRM	m/s^3	
Maximum time delay for steering actuation to be provided by the system when system enters active mode	s	
Time after which optical warning is given to the driver after the start of the transition demand	s	
Time after which given optical warning is escalated after the start of the transition demand	s	Max. 4
Time it takes the TJC to generate the signal to activate the hazard warning lights once ego vehicle is in standstill after the transition phase	s	Max. 5
Time it takes the TJC to start an MRM if the driver is not responding to a transition demand after the start of the transition demand	s	Min. 10
Time it takes HMI to indicate TJC is in active mode after driver activates	s	
Time it takes HMI to indicate TJC is in Fault mode after a fault occurs	s	
Time it takes HMI to indicate TJC is in Transition Phase once at least one condition is true	s	
Time it takes the TJC to accelerate the ego vehicle after the target vehicle accelerates and the headway increases	s	
Time it takes the TJC to accelerate the ego vehicle after the target vehicle exits the ego lane	s	
Time it takes the TJC to decelerate after detecting a slower moving vehicle in the ego lane	s	
Time it takes TJC to accelerate after driver activates TJC	s	
Time it takes TJC to decelerate after driver activates TJC	s	
Time it takes HMI to indicate TJC feature is deactivated after driver override	s	
Time it takes HMI to indicate TJC is deactivated after driver deactivates through HMI	s	
Time it takes TJC to give a transition demand after a planned event outside of feature ODD is detected	s	
Steering force application threshold for the driver to trigger a feature override	N	50
Steering force application duration for the driver to trigger a feature override	s	

Brake pedal press threshold for the driver to trigger a feature override		
Accelerator pedal press threshold for the driver to trigger a feature override		
Lateral distance that the ego vehicle can detect lane boundaries	m	
Longitudinal distance ahead of the ego vehicle that the system can detect an adjacent lane's boundaries	m	
Longitudinal distance ahead of the ego vehicle that the system can detect ego lane boundaries	m	
Longitudinal distance behind the ego vehicle to detect target lane markings	m	
The maximum lane width for TJC feature operation	m	
The minimum lane width for TJC feature operation	m	
The minimum radius of lane curvature for TJC feature operation	m	520 (SOP1) - 250 (SOP2)
Time it takes for the camera to detect ego lane and target lane markings	s	
Distance parallel to ego vehicle in an adjacent lane at which the system can detect a vehicle	m	
Lateral distance ahead of ego vehicle in an adjacent lane at which the system can detect a vehicle	m	
Lateral distance behind the ego vehicle in an adjacent lane at which the system can detect a vehicle	m	
Longitudinal distance ahead of ego vehicle in an adjacent lane at which the system can detect and classify a vehicle	m	Min. 46
Longitudinal distance ahead of ego vehicle in the ego lane at which the system can detect and classify a vehicle	m	Min. 46
Longitudinal distance behind the ego vehicle in an adjacent lane at which the system can detect a vehicle	m	
Time it takes to calculate relative speed of an object after it enters nominal sensor detection range	s	
Time it takes to classify an object after it enters nominal sensor detection range	s	
Time it takes to detect an object after it enters nominal sensor detection range	s	
Minimum vehicle speed for TJC feature operation	km/h	0
Maximum vehicle speed for TJC feature operation	km/h	15
Front collision of ego vehicle with another road user	-	
Side collision of ego vehicle with another road user	-	
Rear collision of ego vehicle with another road user	-	
Time to collision between ego vehicle and lead vehicle	s	
Time to collision between ego vehicle and cut-in vehicle	s	

Time to collision between ego vehicle and stationary obstacle	s	
Time to collision between ego vehicle and pedestrian	s	

5.6 Preliminary input data requirements

The required data for the execution of the UC ID 2 in virtual and real-world environments can be summarized as follows:

Regulatory documents:

- as input for system engineering and requirements, as well as for scenario definition.

Vehicle dynamics data:

- Basic vehicle parameters (e.g. dimensions, weight distribution)
- Measurement data for creating a digital vehicle twin of the test vehicle (steering system, powertrain, wheels, brakes, suspension, chassis controls, etc.)
- 3D vehicle body model for visualization (e.g. in Unreal Engine / CARLA)

Scenario data:

- ODD definition for creating the scenario ontology
- OpenSCENARIO files for simulation execution, created from the ontology
- Maneuver catalogue for proving ground tests (e.g. in AVL SMS™)

Road data:

- OpenDRIVE files of the proving ground to correlate measurements with simulation, road pavement surface data
- OpenDRIVE files for synthetic road models for simulation including parametric variations in lane width, curvature, road markings etc.
- Pavement surface data for synthetic road models for simulation including parametric variations in longitudinal and lateral roughness.

Sensor data:

- Environment sensor specifications (sensor type, FoV, etc.)
- Sensor layout on vehicle body (position and mounting angle of camera, Radar, Lidar, ultrasonic etc.)
- Generated object list data from the sensor models.

Result data:

- Generated results of SiL/proving ground data for KPI assessment and dashboarding [csv, mdf, mf4, mat]

5.7 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- UC2.1_REQ_SA_001: In case of feature activation, ADS must keep the vehicle in the lane markings.
- UC2.1_REQ_SA_002: Obstacles position, distance and speed shall be perceived in real time with acceptable delays.
- UC2.1_REQ_SA_003: The ADS shall be capable of detecting speed limit signs or receiving speed limit information from map data.
- UC2.1_REQ_SA_004: The ADS shall be able to perform all the longitudinal manoeuvres (speed keeping, braking, accelerating, etc.) except reversing.
- UC2.1_REQ_SA_005: The ADS shall be capable to control the longitudinal movement of the vehicle except reversing to adapt the velocity.
- UC2.1_REQ_SA_006: The ADS shall adapt its speed to slower vehicles ahead driving on same lane by keeping the safety distance in case of lower speeds than ego vehicle.
- UC2.1_REQ_SA_007: The ADS shall adapt its speed according to road slope and curvature received.
- UC2.1_REQ_SA_008: ADS MRM – Fail-safe solutions in case of failure in the system shall be provided.

B. High level requirements with respect to scenario description/generation:

- UC2.1_REQ_SDG_001: This UC targets the original UN-R 157 with a maximum speed of 60 km/h.
- UC2.1_REQ_SDG_002: Apart from the regulation, the scenario include lane keeping while various curve driving.
- UC2.1_REQ_SDG_003: The test cases must cover the complete ODD and DDT (based on the regulation) through ontology approaches and smart scenario generation methods (e.g., combinatorial testing).

C. High level requirements with respect to the test framework (methods/tools/data):

- UC2.1_REQ_TTM_001: Test vehicle should be fully equipped with the complete system to execute consecutive proving ground tests.

- UC2.1_REQ_TTM_002: Vehicle shall be equipped with a perception system, e.g., camera, able to detect and track vehicles and trucks and lane markings in a range of around 100 ms.

- UC2.1_REQ_TTM_003: Vehicle shall be equipped with a map system (e.g. eHorizon or HERE maps) able to provide road information within a specific horizon regarding curvature, slope, etc.

- UC2.1_REQ_TTM_004: Vehicle shall be equipped with ACC system, compliant with the corresponding reference standard.

- UC2.1_REQ_TTM_005: Physical vs. virtual testing: the amount of proving ground tests depends on the model correlation quality.

- UC2.1_REQ_TTM_006: The simulations must be real-time capable and deterministic.

- UC2.1_REQ_TTM_007: Safety KPIs must include: TTC, acceleration and deceleration (lateral and longitudinal), vehicle speed.

- UC2.1_REQ_TTM_008: Simulation framework should be capable to simulate real world simulations, including controller performance and environmental conditions.

- UC2.1_REQ_TTM_009: There should be a built-in scenario management tool to allow manual selection and parametrization of test cases.

- UC2.1_REQ_TTM_010: Cloud computing interface to run parallel simulations.

- UC2.1_REQ_TTM_011: Middleware for integrating various models and software tools (CAN, FMU, ROS, Python, etc.).

- UC2.1_REQ_TTM_012: Simulation model output must correlate with physical measurements, expressed by correlation and error KPIs such as R^2, RMSE or correlation coefficients.

- UC2.1_REQ_TTM_013: The simulation has to have a proven deterministic behaviour and repeatable results.

D. High level validation requirements from the user perspective:

- UC2.1_REQ_UP_001: KPI dashboard for easy and quick evaluation and reporting of results.

- UC2.1_REQ_UP_002: The KPI dashboard should be configurable and adaptable, e.g., the type of KPIs and their thresholds.

6 UC ID 3 – HIGHWAY (CO-OPERATIVE) AD VALIDATION

According to the Connected, Cooperative and Automated Mobility Roadmap [3] the Highway Chauffeur **UC ID 3, “Highway (Co-operative) AD validation**”, aims to demonstrate the SUNRISE SAF on an equivalent system with additional V2C (map updates) or V2X (e.g. via use of V2V for C-ACC function) communication capability.

The UC ID 3 can be seen as an extension of the UC ID 2 “Traffic Jam AD validation”, which is the first homologated system on the market (Mercedes Benz Drive Pilot [15] and [16]) according to the regulation UN-R No. 157 for ALKS [13]. The main difference between the two systems is the speed, because a TJC based on the ALKS regulation works for a speed range up to 60 kph. In theory there can be also other differences, like the ability for automated lane changes or the need for a leading vehicle presence, but in our case the ADS will not be tested for automated lane change since the focus is on advanced ACC-alike systems.

Following the above, the scope of UC ID 3 is to validate semi/highly automated vehicles (SAE L2/L3+) on motorways and motorway similar roads via the implementation of a hybrid validation testing, by combining virtual simulations and physical tests. In SUNRISE project, UC ID 3 includes two main sub-UCs as follows:

- sub-UC 3.1 «Map-based perception & decision-making & control testing»
  focus on demonstrating how the vehicle’s safety and awareness can be improved based on information coming from maps, sensors or connected services about road characteristics or road dynamic events.

- sub-UC 3.2 «Cooperative perception & decision making & control testing»
  focus on demonstrating how safety and surrounding awareness could be improved on motorways by including cooperative V2X functionality (with other vehicles in the neighbourhood) in the Highway Pilot (HWP) system (e.g., by leveraging and upgrading the driver assistance functionality developed previously in C-ACC from sub-UC 1.2).

It is important to note that up until now tests with ADS similar to ones considered in UC ID 3, the demonstration of effectiveness of cooperative manoeuvres in highway using diverse sources, e.g., maps and V2X communication, has been limited to specific scenarios defined by experts and mostly related to the analysis of connectivity services. Therefore, the goal is to overcome the defined limitations to demonstrate a sufficient ODD coverage by taking advantage of different virtual validation techniques and several (real-world) scenarios sources.

6.1 ADS under test

In the followings we describe both ACC and C-ACC systems considered in sub-UC 3.1 and sub-UCN3.2 since these are similar systems based on their DDT/OEDR specification.

- **SuT**

In sub-UC 3.1 SuT is an advanced ACC including augmented perception that integrates info from dynamic maps and over-the-air received road hazards warning info.

In sub-UC 3.2 SuT is a Cooperative-advanced ACC including augmented perception that integrates info from other road vehicles transmitted via V2X.

The implemented driver assistance systems (e.g., based on ACC) receive information from diverse and heterogeneous sources, i.e., on board and through V2X, about obstacles, geometry, features, and dynamic events related to the driven path, and provide longitudinal controls to increase vehicle's safety and awareness in the ODD context of the highways. SUNRISE members CRF and Applus+ IDIADA will contribute to both of the aforementioned sub-UCs 3.1 and 3.2.

The main requirements for the ADS design are the presence of longitudinal control capability and connected board for V2X communication to extend the vehicle perception. In line with international standards, V2V connectivity for safety-related purposes shall be achieved exchanging manoeuvre and event data either through direct communication at 5.9 GHz (in the IEEE802.11p-based standards such as SAE DSRC and ESTI ITS G5 [23] or in the 3GPP Rel 14/15 and ff. called PC5 standard interface [24]) or through V2I communication in the cellular communication assigned bands, preferably with Multi Access Edge computing to keep within the low-latency requirements.

- **DDT/OEDR**

The implemented driver assistance systems (e.g., on top of ACC) receive information from different sources, on board and trough connection, about objects surrounding the vehicle, road geometry (slope and curvature), road features (traffic signs, speed limits, traffic lights) and road dynamic events (weather conditions, road conditions, traffic, emergency situations). Based on these data, the system provides longitudinal controls to increase vehicle's safety and awareness in the ODD context of the highways and at L3 level also lateral control for lane centring.

<u>More specifically</u>:

- The ADS shall be capable to control the longitudinal and lateral movement of the vehicle to adapt the velocity to speed limits and to keep the vehicle at the centre of its lane.

- The ADS shall be capable of detecting lane markings surrounding it, which means to detect its lane. In case of missing or not detected lane markings or too wide lanes the ADS shall not operate.

- The ADS shall be capable of detecting and tracking other vehicles ahead on same lane, also possible cut-out manoeuvres.

- The ADS shall adapt its speed to slower vehicles ahead driving on same lane by keeping the safety distance in case of lower speeds than ego vehicle.

- The ADS shall also detect and track vehicles on neighbouring lanes (also coming from behind) doing a cut-in manoeuvre.

- The ADS shall be capable of detecting speed limit signs or receiving speed limit information from map data.

- The ADS shall detect the driver's state and always be overwritable by the driver.

- In case of any situation outside the operational design domain, any system error, or any hazard like unavoidable collision the ADS shall stop the vehicle or give control back to the driver if possible and in active mode, or otherwise not be able to be activated by the driver if inactive.

- Even if the ADS is deactivated it shall permanently check the environment to be able to detect any situation outside its ODD and to block its activation.

- In case the driver is not attentive the ADS shall bring the vehicle to a safe stop with activated hazard lights.

- The ADS shall be capable of controlling the longitudinal movement of the vehicle considering safety aspects based on information about road slope, curvature and in general road geometry coming from the maps and consider information about dynamic road events coming from V2X and connected services.

- The ADS shall be capable of detecting road signs and receiving such speed limit information from map data and adapt the vehicle's speed in a safe way after the speed limit was confirmed by the driver.

- The ADS shall detect vehicles ahead on its lane and adapt the speed to the vehicle ahead without any risks if it is slower or equal to the requested speed. Otherwise, the requested speed shall be kept.

Background info on applicable speed range of the ADS

In Germany there is no general maximum speed on motorways, but 130 kph is recommended which is also the highest general maximum speed on motorways (or public roads at all) in the other European countries except of Poland with a maximum speed of 140 kph [18]. It is also planned soon to raise up the allowed maximum speed for ALKS within the regulation UN-R No. 157 to 130kph [14].

Based on these facts a speed range of 0-60 kph is recommended for TJC and 60-130 kph for HWP or merge both systems into one with a speed range of 0-13 0kph. We cover here option one and distinguish between TJC and HWP based on this 60 kph speed margin, but for systems from option 2 simply apply UC ID 2 and UC ID 3 on the same system.

- **ODD**

Using the ODD definition provided by the UC3 working group, an ISO 34503 compliant ODD representation is given below:

Base state: Restrictive
#Composition statements

Scenery
Included drivable area type is [motorways]
Cond_1 Conditional drivable are type is [slip road]
Included lane type is [traffic lane]
Included direction of travel is [right- hand travel]
Included direction of travel is [right-hand travel]
Excluded number of lanes is < [2]
Included lane width is < [3.5]
Included drivable area surface conditions is [dry, wet road]
Included drivable area surface features are [cracks, swells]
Included road surface type are [segmented, uniform]
Included horizontal plane is [straight roads, curved roads]
Included vertical plane are [up-slope, down-slope, level plane]
Included transverse plane is [divided roads]
Included types of lanes together is [traffic lanes]
Included drivable area surface type is [asphalt, concrete]
Included drivable area signs are [regulatory, warning, information]
Excluded traffic information signs [traffic lights]
Included special structures are [bridges]

Environmental conditions
Included wind is [no wind, calm, light air, light breeze, gentle breeze]
Excluded rainfall is [violent rain, cloudburst]
Included particulates is [non-precipitating water droplets]
Included illumination is [day, cloudiness]
Included communication is [V2X]
Included V2X is [DSRC, ITS-G5]
Included V2C for dynamic map updates (only applicable to sub-UC 3.1)

Dynamic Elements
Excluded agent type is [vulnerable road users, animals, non-motor vehicles]
Excluded special vehicles is [all]
Excluded flow rate is [<60kph]
Excluded density of agents is [>185 agents per mile per lane]

6.2 Sub-UC 3.1 "Map-based perception & decision-making & control testing"

6.2.1 Short description and objectives

In the sub-UC 3.1, map-based perception & decision-making & control driving performance with scenarios will be evaluated. The main objective will be to demonstrate how the ADS-equipped vehicle can plan its path in the most secure manner considering the environment. The information considered can come from maps, sensors or connected services.

R&D on geo referenced events (Traffic Jam, etc..) communicated to the vehicle to influence the C-ACC have been performed, for example in the TEAM IP FP7 [19] ended in 2016 and AUTOPILOT [20] ended in 2020, mostly focused on traffic efficiency, comfort and automated speed adaptation (V2x for longitudinal control acting on target ACC speed) and the recent Italian national project MISE SCALA ending in 2023. So far evaluation on activities have been limited to pilot trials on selected roads and conditions.

Further evaluation / assessment needs to be done on all traffic conditions, road characteristics (curvature, slope, etc.) and with different road events communicated via V2X or connected services (dynamic speed limits, road works, traffic jam warnings, etc). In addition, there haven't been specific studies so far addressing safety related to ACC features, In SUNRISE project the goal is to cover as many scenarios as possible that address these aspects.

6.2.2 Indicative test scenarios

The following three scenarios will be used to rate the map-based driving performance of the HWP system:

- **Test scenario sub-UC 3.1-A: Adapting speed according to new speed limit**

New speed limit in front of ego vehicle (source can be static/dynamic speed limit sign, information can come additionally via V2I or HD maps). Several speeds of ego, distances to speed limit and speed limit changes (reduction and increase) shall be tested (Figure 43).

Scenario to be tested in highway environment, the vehicle will automatically adapt the speed without any risks to the speed limit ahead if it is lower than the ACC set-speed. The only action required to the driver is to accept the speed adaptation once requested, otherwise the speed limit will be ignored.

Scenario Parameters:
Vehicle speed range: 90-130 km/h
Speed limits: 90-130 km/h
Road type: Highway – toll gate-to-toll gate
Weather conditions: all
Light conditions: all

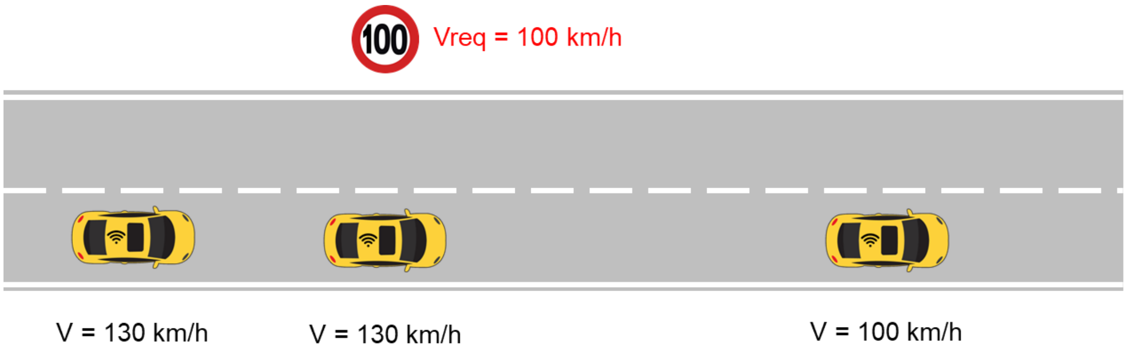

Figure 43: Schematic representation of test scenario sub-UC 3.1-A (adapting speed according to new speed limit).

- **<u>Test scenario sub-UC 3.1-B: Adapting velocity to road slope</u>**

This scenario is about the automatic adaptation of the vehicle speed to the road slope ahead to the vehicle (Figure 44). Different values and sequences of slopes shall be tested. Scenario to be tested in highway, the vehicle speed will be adapted accordingly to the slopes ahead with a tolerance of ±5 Km/h to the set-speed, no actions are required by the driver.

<u>Scenario Parameters:</u>
Vehicle speed range: 60-130 km/h
Slope range: ±5% (Italian highway range)
Road type: Highway – toll gate-to-toll gate
Weather conditions: all
Light conditions: all

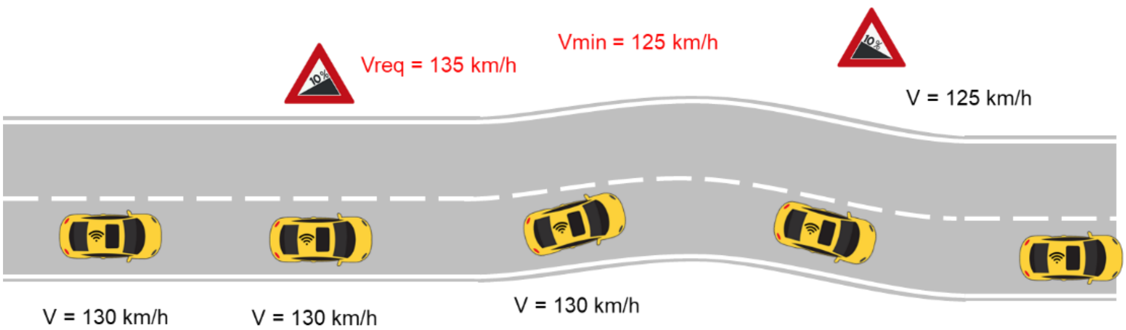

Figure 44: Schematic representation of test scenario sub-UC 3.1-B (adapting velocity to road slope).

- **<u>Test scenario sub-UC 3.1-C: Adapting velocity to road curvature</u>**

This scenario is about the automatic adaptation of the vehicle speed to the road curvature ahead to the vehicle (Figure 45). Different curvature values shall be tested. Scenario to be tested in highway, the vehicle speed will be adapted accordingly to the curvature ahead minimum allowed speed to be reached at the beginning of the curve and maintained for the whole curve length, no actions are required by the driver.

Scenario Parameters:
Vehicle speed range: 60-130 km/h
Curve radius range: >400m (Italian highway range)
Road type: Highway – toll gate-to-toll gate
Weather conditions: all
Light conditions: all

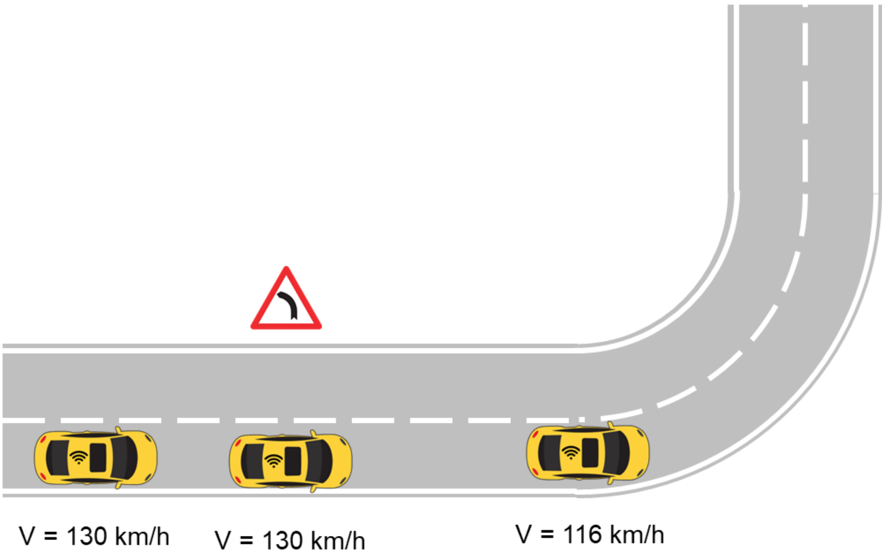

Figure 45: Schematic representation of test scenario sub-UC 3.1-C (adapting velocity to road curvature).

6.2.3 Preliminary test plan

The validation proposal for sub-UC 3.1 includes virtual testing with SiL method, Proving Ground (PG) and Field Operational Tests (FOTs). It will focus on all longitudinal manoeuvres except reversing, entering, exiting in highway contexts with normal weather, including entry/exit, with KPIs mainly related to safety and the influence of HD map data. In this context, among scenario data used for the test cases coming from expert knowledge, regulatory or scenario databases, mainly map data will be used.

6.2.3.1 Virtual Testing

SiL approach will be used to evaluate the ADS in virtual environments containing probabilistic sensor models and realistic vehicle model of ego vehicle for traffic signs (speed limits), slope and curvature testing. Furthermore, a HiL approach to include map provider (e.g., eHorizon or HERE) in the loop will be considered. This will provide real map-based data about slope, curvature, road geometry and traffic signs (speed limits).

6.2.3.2 Physical Testing

Motorway similar test tracks on proving grounds will be used in combination with the prototype vehicle for validation of the map-based driving performance. In field operational tests European highways (e.g., in Italy or Spain) will be used to validate the map-based driving performance of the prototype vehicles in real traffic scenarios.

6.2.4 Preliminary metrics for SA validation

There are several KPIs to check the map-based driving performance, like speed and distance adaptation in a secure and controllable manner due to speed limits, curvature or road slopes. The distance to a vehicle ahead should be at least the safety distance or if unavoidable restored very fast. Additionally, the latency for receiving or processing of map data shall be sufficient and reliable to ensure a safe driving performance. Errors or false data shall be compensated by the perception and sensor data.

For the safety assessment of the functionality and for the rating of the controllability of the vehicle the main KPIs are de-/accelerations or torques.

6.2.5 Preliminary input data requirements

For the sensor verification the sensor parameter data is needed like altitude and azimuth angles, the type of sensor, or sensor's range. Additionally, real sensor's raw or object data will be used for the sensor verification. For the system or vehicle verification the prototype vehicle's parameter data is needed, like mass, location of centre point, or inertia. For the scenarios the ASAM OpenSCENARIO and OpenDRIVE standards will be used, and the scenario data can come from real measurement data, scenario database, experts' knowledge, or regulations.

The map data does include speed limits, slope and curvature data and comes mainly from map-data service providers like eHorizon or HERE maps.

For testing the AD prototype, with a focus in map-based driving, data required is the following:

- Ground truth data, e.g., from HD maps. *Real data manually labelled and obstacles with GPS, so distance, position, speeds and road information*

- Perception systems output. *List of obstacles with corresponding classification, position, distance, and speed*

- Ego-vehicle positions, steering, brake, throttle measurements.

- Data coming from maps, e.g., from eHorizon or HERE like road slope, curvature, traffic signs, etc.

- Driver intervention flags, if any.

- Weather conditions, if needed.

6.2.6 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- UC3.1_REQ_SA_001: Obstacles position, distance and speed shall be perceived in real time with acceptable delays.
- UC3.1_REQ_SA_002: The ADS shall be capable of detecting speed limit signs or receiving speed limit information from map data.
- UC3.1_REQ_SA_003: The ADS shall be able to perform all the longitudinal manoeuvres (speed keeping, braking, accelerating, etc.) except reversing.
- UC3.1_REQ_SA_004: The ADS shall be capable to control the longitudinal movement of the vehicle except reversing to adapt the velocity.
- UC3.1_REQ_SA_005: The ADS shall adapt its speed to slower vehicles ahead driving on same lane by keeping the safety distance in case of lower speeds than ego vehicle.
- UC3.1_REQ_SA_006: The ADS shall adapt its speed according to road slope and curvature received.

B. High level requirements with respect to scenario description/generation:

- UC3.1_REQ_SDG_001: The scenario space and therefore the number of tests strongly depends on the number of parameters and their ranges. The ODD is used to create the scenario subspace to be also influenced later by the methodology coming from WP3 w.r.t ODD coverage.
- UC3.1_REQ_SDG_002: The present sub-UC extends the original UN-R 157 and hence reference test scenarios from there could be relevant.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC3.1_REQ_TTM_001: Test vehicle should be fully equipped with the complete system to execute consecutive proving ground tests.
- UC3.1_REQ_TTM_002: Vehicle shall be equipped with a perception system, e.g., camera, able to detect and track vehicles and trucks and lane markings in a range of 100 m.
- UC3.1_REQ_TTM_003: Vehicle shall be equipped with a map system (e.g. eHorizon or HERE maps) able to provide road information within a specific horizon regarding curvature, slope, etc.

- UC3.1_REQ_TTM_004: Vehicle shall be equipped with ACC system, compliant with the corresponding reference standard.

- UC3.1_REQ_TTM_005: Virtual testing shall include the SiL and HiL method.

  - *The system shall be configurable in its essential parameters, e.g., time to collision.*

- UC3.1_REQ_TTM_006: Physical testing shall be performed on Proving Ground and with Field Tests.

6.3 Sub-UC 3.2 "Cooperative perception & decision making & control testing"

6.3.1 Short description and objectives

The main aim of sub-UC 3.2 will be to demonstrate how safety could be improved on motorways by including cooperative functions in the HWP system. One example for this HWP functionality is the leveraging and upgrading the driver assistance functionality developed previously in C-ACC from sub-UC 1.2.

The main functionality of an HWP or ALKS responsible for the longitudinal control and therefore for the safety is the ACC system which automatically adjusts the vehicle speed to maintain a safe distance from a vehicle ahead. V2V enables the extension to C-ACC concept thanks to additional information obtained from connected vehicles ahead. The system shall be capable of communicating with other road users using V2X messages (e.g., CAM or DENM) for cooperative perception and share its perception or map information with others as well.

C-ACC is a driver assistance system implemented on top of ACC, it may be combined with other functionalities such as FCW (Forward Collision Warning), EEBL (Emergency Electronic Brake Light) for an increased safety. It receives information from different sources, on board and through connection, about objects surrounding the vehicle and road features.

Today there are projects like MuCCA where cooperative manoeuvres using V2V communication have been demonstrated on proving grounds by the usage of a few scenarios defined by experts. Furthermore, there are projects like the EU-funded research project 5G-CARMEN (5G for Connected and Automated Road Mobility in the European UnioN) [21], where cooperative manoeuvres using V2X communication have been demonstrated in specific cross-border scenarios on public roads along the highway corridor Munich-Bologna with the goal, defined by experts, to test continuity of 5G services for CCAMs and to measure 5G KPIs for automated driving.

As can be seen, the demonstration of effectiveness of V2X communication in cooperative manoeuvres has been limited to specific scenarios defined by experts and mostly related to the operability analysis of connectivity services. Therefore, the goal is to go beyond the defined limitations regarding the scenarios and the connectivity studies. In fact, by applying the SUNRISE SAF, the ODD coverage can be demonstrated, not spatially or functionally limited to specific operating fields and conditions. This is possible by taking advantage of different virtual validations, e.g., usage of extended realistic scenarios where cooperative manoeuvres between agents can be proven by variating all the interesting parameters, even in corner cases or in safety critical conditions. After extensive virtual tests demonstrating the virtual ODD coverage, the designed cooperative functions can be proven in real-world scenarios regarding the main identified use cases and parameters, in order to provide a sufficient test coverage of the ODD.

6.3.2 Indicative test scenarios

The following four test scenarios will be used to rate the cooperative perception of the HWP system:

- **Test scenario sub-UC 3.2-A: cooperative ACC**

In this scenario we will test the target vehicles detection through V2X CAM messages on the same ego lane (Figure 46).

The ego vehicle is driving in highway, it detects a cooperative vehicle ahead on the same lane through V2X CAM messages and decide to turn the cooperative ACC setting the speed accordingly with the vehicle in front even if it is obstructed by other no cooperative vehicle in the middle with a higher speed.

Scenario Parameters:
Vehicle speed range: 60-130 km/h
Road type: Highway
Weather conditions: all
Light conditions: all

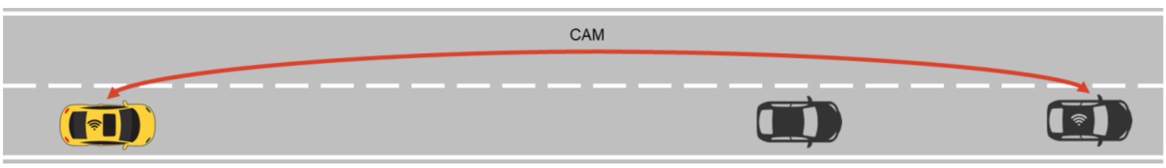

Figure 46: Schematic representation of test scenario sub-UC 3.2-A (cooperative ACC).

- **Test scenario sub-UC 3.2-B: deceleration vehicle in front**

The ego vehicle is driving in highway, it detects a cooperative vehicle ahead on the same lane through V2X CAM messages and decide to turn the cooperative ACC setting the speed accordingly with the vehicle in front even if it is obstructed by other faster and no cooperative vehicle in the middle (Figure 47). The ACC is controlling the distance through radar sensing.

The preceding vehicle cut-outs, the ego vehicle decelerates knowing that the cooperative vehicle is decreasing speed. Except of the V2X communication this scenario is similar to the deceleration and cut-out scenario from regulation UN-R No. 157 for ALKS.

Scenario Parameters:
Vehicle speed range: 60-130 km/h
Road type: Highway
Weather conditions: all
Light conditions: all

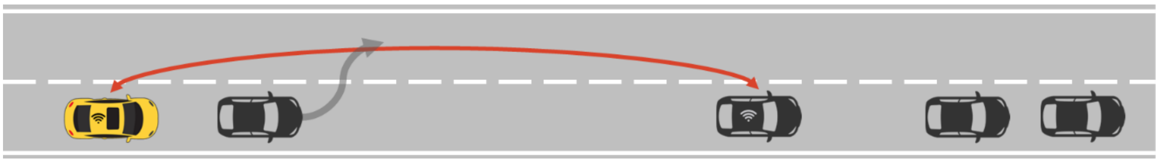

Figure 47: Schematic representation of test scenario sub-UC 3.2-B (deceleration vehicle in front).

- **Test scenario sub-UC 3.2-C: Cut-In into ego's lane**

The ego vehicle is driving in highway with cooperative ACC turned on, it detects a cooperative vehicle on the next lane that wants to perform a cut-in (Figure 48). The ego vehicle accepts to decelerate opening a gap with the vehicle in front. Except of the V2X communication this scenario is similar to the cut-in scenario from regulation UN-R No. 157 for ALKS.

Scenario Parameters:
Vehicle speed range: 60-130 km/h
Road type: Highway
Weather conditions: all
Light conditions: all

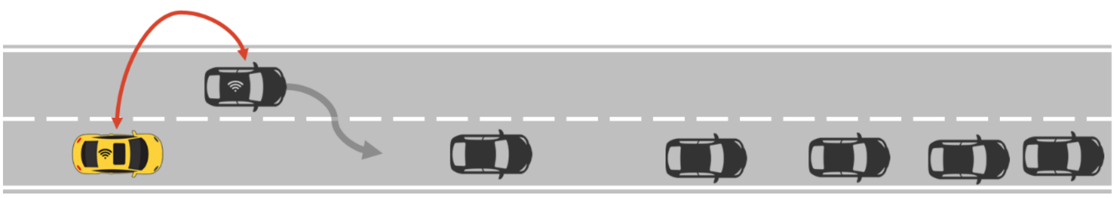

Figure 48: Schematic representation of test scenario sub-UC 3.2-C (cut-In into ego's lane).

- **Test scenario sub-UC 3.2-D: vehicle control loss**

The ego vehicle is driving in highway with cooperative ACC turned on, it detects a cooperative vehicle on the same lane (Figure 49). The ego vehicle receives a CAM (or DENM) that informs that the vehicle has the ESC/ABS triggered and is losing control. The ego vehicle decides to perform a harsh brake manoeuvre.

Scenario Parameters:
Vehicle speed range: 60-130 km/h
Road type: Highway
Weather conditions: all
Light conditions: all

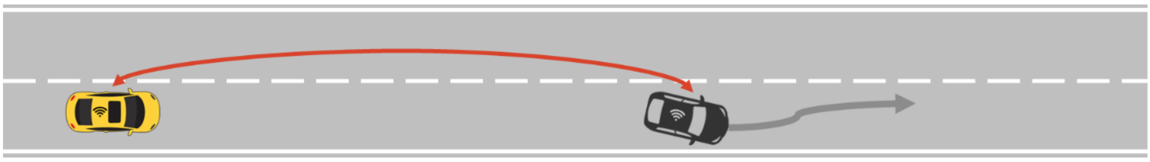

Figure 49: Schematic representation of test scenario sub-UC 3.2-D (vehicle control loss).

6.3.3 Preliminary test plan

The validation proposal for sub-UC 3.2 includes virtual testing with SiL and CoSim methods, PG and FOTs. It will focus on all longitudinal manoeuvres except reversing, entering, exiting in contexts of mixed interactions with other road users, using KPIs mainly related to safety and the influence of V2X communication. In this context, among scenario data used for the test cases and map data, additional data coming from other vehicles via V2X communication (e.g., cooperative perception or position data).

6.3.3.1 Virtual Testing

The sub-UC 3.2 will be tested with the MiL, SiL, CoSim, methods. Tests will start in MiL, to preliminarily model and test the defined algorithms and tune the related parameters to cover all the requirements.

Tests will proceed in SiL, where a prototype of the developed software will be integrated in the control loop to understand the performance of the algorithms in terms of latencies and effectiveness and opportunely tune and test the fundamental parameters of the simulations and the critical aspects. This will be done in virtual environment where the vehicles and related sensors will be modelled to have accurate perception and corresponding decision making.

Once appraised the performance of the developed software, tests will conclude in CoSim to simulate more than one agent using the designed algorithms to assess and possibly tune interesting parameters regarding the traffic interactions (e.g., V2X part in HiL). This will be done again in virtual environment to accurately model vehicles and traffic flows.

The following Figure 50 depicts an example of virtual validation regarding the longitudinal control adaptation to an emergency event ahead. This could be tested in different configurations related to the road and the vehicles involved in terms of speeds and distances.

Figure 50: Use case related to longitudinal control adaptation related to slow/stationary vehicle ahead [8].

6.2.3.1 Physical Testing

For more safety critical scenarios proving grounds will be used for validation purposes of V2X communication and decision making and control with dummies and prototype vehicle. Especially the perception part will be validated in real traffic using FOTs on European motorways (e.g., in Italy and Spain).

6.3.4 Preliminary metrics for SA validation

For this use case safety relevant KPIs play an important role and that ones which are needed to check the performance of the V2X communication. As safety relevant KPIs there are the vehicle speed, distance to vehicle ahead, and acceleration, deceleration, or torque. The driver state plays an important role for hand-over manoeuvres for L3 system. For the V2X part the network latency, the number of received and sent messages and the type of messages are used.

It shall be checked if the speed was adapted to the minimum of by the driver requested speed, allowed speed limit and vehicle ahead if available. It shall also be checked if new speed limit information received from perception part or from maps was first approved by the driver before any speed adaptation. The distance to vehicle ahead shall be larger or equal to safety distance and in case of sudden cut-in the safety distance shall be restored quickly. The vehicle shall be always controllable, means all accelerations, decelerations or torques shall be within specific ranges. In case of hazard situations, unavoidable collisions or running outside ODD the ADS shall give the control back to the driver within a specific time range. In case of absence of the driver the ADS shall bring the vehicle to safe stop with activated hazard warning lights in case of the L3 system with lateral control.

For the V2X part the network latency of receiving and processing incoming messages shall be checked, the network latency shall be as low as possible to be able to process as many messages as possible and finally gather as much information as possible. Additionally, the number of incoming and outgoing messages and the type of messages the ADS can handle like CAM or DENM messages shall be checked.

6.3.5 Preliminary input data requirements

For this sub-UC additionally, the parameter data of the V2X on-board units (OBUs) and optionally parameter data of the road-side units (RSUs) if used. As well as the recorded data of such OBUs or RSUs for the verification of these units.

For testing the AD prototype, with a focus in cooperative driving, data required is the following:

- Ground truth data, e.g., from HD maps. *Real data manually labelled and obstacles with GPS, so distance, position, speeds and road information*.
- Perception systems output. *List of obstacles with corresponding classification, position, distance, and speed*.
- Ego-vehicle positions, steering, brake, throttle measurements.
- Data coming from V2X, e.g., related to connected vehicles (from OBUs) and infrastructure (from RSUs).
- Driver intervention flags, if any.
- Weather conditions, if needed.

6.3.6 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- o UC3.2_REQ_SA_001: Obstacles position, distance and speed shall be perceived in real time with acceptable delays.
- o UC3.2_REQ_SA_002: The ADS shall be capable of communicating with other road users using V2X messages (e.g., CAM or DENM) for cooperative perception and share its perception or map information with others as well.
- o UC3.2_REQ_SA_003: The ADS shall be capable of detecting speed limit signs or receiving speed limit information.
- o UC3.2_REQ_SA_004: The ADS shall be able to perform all the longitudinal manoeuvres (speed keeping, braking, accelerating, etc.) except reversing.

- UC3.2_REQ_SA_005: The ADS shall be capable to control the longitudinal movement of the vehicle to adapt the velocity to events ahead.

- UC3.2_REQ_SA_006: The ADS shall adapt (increase/decrease) its speed to vehicles ahead driving on same lane identified by cooperative perception given by sensor fusion including V2X information.

- UC3.2_REQ_SA_007: The ADS shall be able to facilitate a cut-in manoeuvre related to another vehicle wanting to move in its lane.

- UC3.2_REQ_SA_008: The ADS shall be able to detect and handle a control loss related to another vehicle ahead in its lane.

B. High level requirements with respect to scenario description/generation:

- UC3.2_REQ_SDG_001: The scenario space and therefore the number of tests strongly depends on the number of parameters and their ranges. The ODD is used to create the scenario subspace to be also influenced later by the methodology coming from WP3 w.r.t ODD coverage.

- UC3.2_REQ_SDG_002: The present sub-UC extends the original UN-R 157 and hence reference test scenarios from there could be relevant.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC3.2_REQ_TTM_001: Test vehicle should be fully equipped with the complete system to execute consecutive proving ground tests.

- UC3.2_REQ_TTM_002: Vehicle shall be equipped with a perception system, e.g., camera, able to detect and track vehicles and trucks and lane markings in a range of 100 m.

- UC3.2_REQ_TTM_003: Vehicle shall be equipped with a map system (e.g. eHorizon or HERE maps) able to provide road information within a specific horizon regarding curvature, slope, etc.

- UC3.2_REQ_TTM_004: Vehicle shall be equipped with ACC system, compliant with the corresponding reference standard.

- UC3.2_REQ_TTM_005: Virtual testing shall include the SiL and HiL method.

    - *The system shall be configurable in its essential parameters, e.g., time to collision.*

- UC3.2_REQ_TTM_006: Physical testing shall be performed on Proving Ground and with Field Tests.

7 UC ID 4 – FREIGHT VEHICLE AUTOMATED PARKING VALIDATION

The scope of **"UC ID 4 – Freight vehicle automated parking validation"** is to validate the environment perception and connected cyber-security perception for highly automated freight transport vehicles in confined areas via the implementation of a hybrid validation testing, by combining virtual simulations and physical tests. In SUNRISE project, UC ID 4 includes two main sub-UCs as follows:

- sub-UC 4.1 « Truck-low speed perception & decision-making testing»
- sub-UC 4.2 «Truck-low speed connected perception cyber-security testing»

In both cases, starting from a pre-defined area, the truck will reverse into a loading dock. A sensor mounted on the loading dock will monitor the area behind the truck and communicate its observations to the truck. It will not be possible to start from a random starting point, and there won't be the capability to start forward facing and then turn around before reversing.

These sub-UCs can be considered related with the following "ERTRAC Connected, Cooperative and Automated Mobility Roadmap (2022)" use cases [3].

- Highway and Corridors: Hub-to-hub transport and L4 transport between terminals/hubs in selected supervised corridors.
- Confined Areas: L4 Unmanned truck/trailer operation in-Terminal/Hub to improve productivity and safety.

7.1 ADS under test

- **SuT**

In general, the capabilities of interest for an automated truck that needs to reverse and park at the docking bay in a logistic hub are listed below: Accurate sensing: The automated truck would need to be able to accurately sense its surroundings, including the docking bay, any obstacles or vehicles in the area, and the distance between the vehicle and the bay. This could be achieved through the use of sensors such as cameras, LiDAR, and radar.

Path planning:
Once the truck has sensed its surroundings, it would need to be able to plan a path to the docking bay that avoids any obstacles and ensures that it can safely manoeuvre into the bay. This would involve using algorithms to determine the optimal path based on the vehicle's size, the area's layout, and other relevant factors.

Precision manoeuvring:

Once the truck has planned its path, it would need to be able to manoeuvre precisely into the docking bay. This could involve using automated steering and braking technologies to ensure the truck is correctly aligned with the bay and can be safely docked.

Real-time adjustments:
During the reversing process, the truck would need to be able to make real-time adjustments based on any changes in the environment, such as the movement of other vehicles or changes in the layout of the area. This would require the truck to monitor its surroundings and adjust its behaviour as necessary constantly.

It should be mentioned that the aforementioned capabilities are not necessarily those that will be implemented and assessed by sub-UCs 4.1 & 4.2. More information will be provided in Tasks 7.2 and 7.3 of the SUNRISE project.

- **ODD**

The UC ID 4 initial operational design domain (ODD) will be "sunny day" operational design where the specific driving conditions are defined to bring the complexity of the testing space to a minimum for the intended ADS and the implementation thereof. The selected ODD is expected to be the baseline where the ADS operates safely and effectively.

A "sunny day" ODD refers to the ideal driving conditions where visibility is good, the road surface is dry, and there are no adverse weather conditions such as rain, fog, or snow. The term "sunny day" is used metaphorically to describe the perfect driving conditions that allow the ADS to function optimally.

Defining a "sunny day" ODD is important because it allows developers to focus on testing the ADS's performance under specific and controlled conditions. This approach makes it easier to assess the ADS's behaviour and identify any potential shortcomings that need to be addressed before the ADS can be deployed on public roads.

However, it is also important to recognize that the real world is not always sunny and ideal, and that the ADS needs to be able to operate safely and effectively under a wide range of driving conditions. Therefore, the ODD and testing in UC ID 4 will progressively extend to include more diverse scenarios, where performance limitations stemming from the sensors come into play, to investigate how to evaluate ODD-related arguments that the ADS can handle a broad range of driving conditions and situations.

At the top level of the ODD (see Figure 1), the environmental conditions are classified as a distinct attribute alongside scenery and dynamic elements. The scenery attribute encompasses all non-movable elements of the operating environment, such as roads or traffic lights. The dynamic elements attribute includes all movable elements of the ODD, such as traffic or subject vehicles. In the UC ID 4, the ODD parameters in scenery and dynamic elements will be kept simplistic and primarily static; the environmental conditions attribute will be permutated to capture the variability of weather and atmospheric conditions, which can significantly impact the performance of sensors.

Automated vehicle designers and operators can better account for this critical variable in their system design and operational planning by explicitly recognising environmental conditions as a distinct attribute in the ODD. This, in turn, can help to investigate ODD coverage metrics for safe and effective operation of automated trucks across a wide range of environmental conditions, from sunny and clear to rainy and foggy.

Following the above, an ISO 34503 compliant ODD draft representation for the UC ID 4 is given below:

Base state: Restrictive
#Composition statements

Scenery
Included drivable area type is [freight distribution centre, shared space]
Included lane type is [special purpose lanes]
Included direction of travel is [left-hand travel]
Included drivable area induced surface conditions is [dry, wet road]
Included drivable area surface features are [cracks, swells]
Included road surface type are [segmented, uniform]
Included horizontal plane is [straight roads, curved roads]
Included vertical plane are [up-slope, down-slope, level plane]
Included transverse plane is [Undivided roads]
Included types of lanes together is [traffic lanes]
Included drivable area surface type is [asphalt, concrete]
Included drivable area signs are [regulatory, warning, information]

Environmental conditions
Included wind is [no wind, calm]
Excluded rainfall is [violent rain, cloudburst]
Included particulates is [non-precipitating water droplets]
Included illumination is [day, cloudiness]
Included communication is [V2I]

Dynamic elements
Excluded agent type is [vulnerable road users, animals, non-motor vehicles]
Excluded special agents are [ambulances, police vehicles]

- **OEDR/MRM**

UC ID 4 deals with the freight vehicle low-speed perception & decision-making & control testing and covers a scenario with a truck during low-speed operation reversely manoeuvre close to a loading dock at, e.g., a warehouse.

The ego vehicle is a truck with trailer, which operates between two terminals in selected supervised corridors (hub-to-hub L4 transport). The scenario-space regarding movable object is quite limited, due the restricted interactions and manoeuvres.

7.2 Sub-UC 4.1 "Truck low-speed perception & decision-making testing"

7.2.1 Short description and objectives

It is important to note that the main objective of sub-UC 4.1 is not to develop a flawless technological function ready for the streets. Rather, the aim is to investigate and develop effective and efficient methods for third-party assessment of assurance cases based on evidence gathered through a scenario-based testing approach relevant to the automated reverse driving system. Further investigation topics within the sub-UC 4.1 explore how evidence provided by accelerated testing can be confined within the area of validity for the claims they are intended to support, e.g., how a large number of simulation results, validated with limited track testing, give support to a more significant safety claim. Also, termination conditions for the testing are of interest, e.g., how can safety criteria be defined in relation to a scenario, scenario space and the ODD.

Advancement within the assessment and audit area is essential for ensuring the system meets the necessary safety standards and can be certified for use on public roads. Thus, the purpose of developing sub-UC 4.1 is to create a sample sub-UC that can be used as a basis for drawing broader conclusions about the assessment procedure's effectiveness, assessment here meaning the narrower scope of an audit. This sub-UC serves as a tool for testing and refining the assessment procedure to ensure that it can efficiently and effectively provide evidence of the defined ADS's safety and efficacy. In other words, the focus is improving the assessment procedure to evaluate the effectiveness of the evidence for the ADS's safety based on the novel scenario-based testing approach. Ultimately, the goal is to improve the overall safety and effectiveness of the automated reverse driving system by developing an efficient and reliable assessment procedure or at least guiding such an effort.

7.2.2 Indicative test scenario

A schematic view of an example showing sub-UC 4.1 is shown in Figure 51. As it is out of the scope of SUNRISE to perform the complete UC ID 4, the focus on the sub-UC 4.1 is at the logistic terminal when the truck with the trailer has arrived and from a staging area should automatically drive and dock to an assigned loading bay.

As the truck shall be able to use with different trailers, the assumption is that the ADS under test cannot rely on sensors on the trailer. Instead, one or more fixed sensors at the loading dock communicate with the automated truck to supplement the perception enabling the automated function.

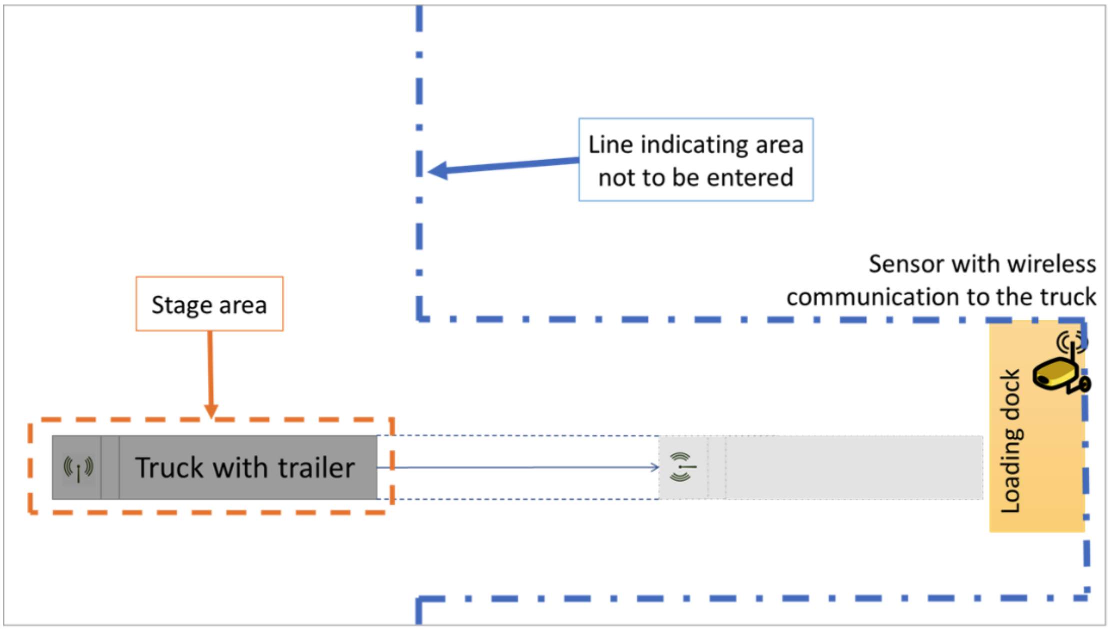

Figure 51: Schematic illustration of sub-UC 4.1 with truck and trailer remotely driving to a loading dock.

Preferably, the area with the loading dock should be confined, but from a safety perspective, the automated reverse driving function must be able to cope with any obstacle object, like a human, and perform a safe operation in case an obstacle is detected. The goal is to start simple and, on the one hand, add functionality for a more realistic sub-UC and, on the other hand, gain insights into creating and refining an assessment procedure for the scenario-based strategy accompanying the expanded functionality.

7.2.3 Preliminary test plan

The test plan is connected to the planned expiation in functionality where an incremental planned progress approach. Starting with a simplified, automated docking procedure starting from a staging area with the assumption that there are no obstacles between the truck and the loading bay in a "sunny day" operational design domain (ODD), i.e. no operational design parameters are limiting the performance of the selected sensors.

The plan gradually adds and tests more complex functionalities. This approach allows for a systematic and controlled testing and development process that ensures the safety and effectiveness of the automated system in tandem with the advancement of a connected assurance case. Essential to keep in mind here is that the goal of sub-UC 4.1 is not to develop the function or even the task of proving that it is safe; it is instead to, by the use of an ADS-relevant use-case, investigate and develop effective and more efficient methods for third party assessment of assurance cases based on evidence proved by a scenario-based testing approach.

7.2.3.1 Virtual testing

The virtual testing plan for the sub-UC 4.1 includes both Model-in-the-Loop (MiL) and Software-in-the-Loop (SiL) testing.

MiL testing:

This type of testing involves creating a virtual model of the ADS and testing it in a simulated environment. For the present ADS, this could involve creating a model of the vehicle, the docking bay, and the surrounding environment, and then simulating the docking process to evaluate the performance of the ADS and define an envelope for the possible acceptable movements in the above scenario.

The capabilities of this testing would include the ability to modify the parameters of the ADS, such as the size of the vehicle or the layout of the docking bay, to evaluate how the ADS performs under different conditions.

SiL testing:

This type of testing involves testing the software component of the ADS in a simulated environment. For the present ADS, this could involve running simulations of the software that controls the docking process to evaluate its accuracy and reliability.

The capabilities of this testing would include the ability to modify the software parameters, such as the algorithms used to control the vehicle's movement, to evaluate how changes to the software affect the performance of the function. The SiL testing should mirror the physical testing.

7.2.3.2 Physical testing

The physical testing plan for the sub-UC 4.1 includes both Model Truck and Full-Size Truck testing.

Model Truck Physical Testing:

The majority of the physical testing will be performed using model trucks with trailers. From a pre-defined area, the truck will reverse into a loading dock. There will be a sensor mounted on the loading dock that monitors the area behind the truck and communicates its observations to the truck.

Full Size Truck Physical Testing:

A full-size physical testing will be run using Chalmers REVERE's Volvo FH16 “Rhino” with their Parator semi-trailer “Hippo”. From a pre-defined area, the truck will reverse into a loading dock. There will be a sensor mounted on the loading dock that monitors the area behind the truck and communicates its observations to the truck.

7.2.4 Preliminary metrics for SA validation

Metrics are to be defined based on a SOTIF analysis. The safety test objectives will be specified as a performance reference model of a human driver. Any accidents that this human driver is capable of avoiding, the ADS should also be able to avoid. Exact metrics to be defined in Task 7.2. Relevant KPIs could be:

Collision Avoidance Performance:

This indicator would measure the ability of the ADS to avoid collisions with other vehicles or obstacles in the environment. It could be measured by tracking the number of collisions that occur during testing and comparing it to the number of collisions that a human driver would have avoided in the same scenario.

Accuracy of Docking:
This indicator would measure the ability of the ADS to accurately position the vehicle within the docking bay. It could be measured by calculating the distance between the vehicle and the docking bay after the docking process is complete and comparing it to the desired tolerance.

Reliability of Docking:
This indicator would measure the consistency and reliability of the ADS. It could be measured by tracking the number of successful dockings during testing and comparing it to the total number of attempts.

Response Time:
This indicator would measure the speed of the ADS's response to changing conditions in the environment. It could be measured by tracking the time it takes for the function to detect and respond to a sudden obstacle or hazard in the environment.

Environmental Robustness:
This indicator would measure the ability of the ADS to perform in a range of environmental conditions, such as different lighting or weather conditions. It could be measured by testing the ADS under a range of conditions and comparing its performance to the desired safety test objectives.

7.2.5 Preliminary input data requirements

The required data is in relation to the KPIs under possible investigation and could be:

Sensor Data:
Data from sensors such as cameras, lidar, or radar could be used to track the position and movement of the vehicle and other objects in the environment and to detect any potential obstacles or hazards.

Control Data:
Data from the automated control system, including information on the commands sent to the vehicle's actuators, could be used to evaluate the accuracy and reliability of the docking process.

Environmental Data:
Data on the environmental conditions during testing, such as lighting, weather, or temperature, could be used to evaluate the ADF's ability to perform in various conditions.

Performance Data:
Data on the ADS's performance during testing, including the number of successful dockings, response time to changing conditions, and docking accuracy, could be used to evaluate its overall safety and reliability.

All of these data would need to be carefully collected and analyzed to assess the safety and performance of the ADS and identify any improvement areas. Additionally, to ensure the safety and reliability of the ADS, the data should be collected from a range of scenarios that cover the full range of possible environmental and operational conditions that the ADS may encounter.

High-level validation requirements for the sub-UC 4.1 and the ADS under test are listed below. Note that not all listed high-level validation requirements will be implemented and assessed by sub-UC 4.1 PoC.

7.2.6 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- UC4.1_REQ_SA_001: AD system accuracy
  The ADS must accurately position the vehicle within a certain tolerance of the docking bay. This tolerance should be defined based on the size of the vehicle and the space available in the logistics hub.

- UC4.1_REQ_SA_002: AD system reliability
  The ADS must be reliable and consistent in its behaviour. This means it should be able to dock the vehicle correctly every time, without fail.

- UC4.1_REQ_SA_003: AD system safety
  The ADS must be designed to ensure the vehicle's safety, the cargo it is carrying, and any people in the vicinity. This may involve incorporating safety features such as collision detection and avoidance systems, emergency stop buttons, and fail-safe mechanisms. The tests will be defined based on expert knowledge: The risks are identified by a HARA. Primary compliance efforts will be towards ISO 21448, ISO 26262, ISO 21434 [25], [26], [27].

- UC4.1_REQ_SA_004: AD system adaptability
  The ADS should be adaptable to different types of docking bays and vehicles and varying environmental conditions such as lighting and weather. The ADS developed should run faithfully in simulation, in a scale model and in full size vehicle.

B. High level requirements with respect to scenario description/generation:

- UC4.1_REQ_SDG_001: The scenario-space regarding movable object is quite limited, due the restricted interactions and manoeuvres, but is expanded by efforts to maintain service in different environmental conditions.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC4.1_REQ_TTM_001: The ADS should be thoroughly tested in various conditions to ensure it meets all the above requirements, and to gain insights into scenario-based testing. This will involve simulated testing in a controlled environment and testing in real-world logistics hubs.

7.3 Sub-UC 4.2 "Truck low-speed connected perception cyber-security testing"

7.3.1 Short introduction and objectives

This sub-UC builds on top of the AD system of UC 4.1 and the perception system of sub-UC 1.3 and deals with a connected perception AD subsystem that is compromised by cyber-security threats. The main aim is to combine in a simulation environment several aspects simultaneously (physical environment, perception, V2X connectivity) and study the effects of physical or remotely executed cyber threats on collective environment awareness.

A simulation environment will be created to represent V2X messaging exchange from a connected static smart sensor (parking monitoring camera) as well as to artificially create I2V messages which are corrupted. The objective is to study the effects of noisy/corrupted I2V info integration into the AV object-level perception and test possible countermeasures by object-level info plausibility checks based on info from various sources (smart RSU and on-board sensors). For this purpose, the sensor ground truth data from CARLA driving simulator will be used in combination with a custom ROS-based collective perception module bridged with CARLA. Integration of a V2X-dedicated simulation tool ARTERY, is under investigation. This latter focuses on the ITS-G5 architecture and provides straightforward integration of ETSI V2X messaging protocols.

The innovation beyond the SoTA includes: (a) combine perception with V2X connectivity and cyber-security features, (b) propose scenario and tools requirements for safe and cyber-secure perception and V2X connectivity within the scope of a SAF. The main challenge is to properly enrich the simulation framework of sub-UC 1.3 in order to support aspects of collaborative perception including V2X cybersecurity aspects. The experiment will be limited to the ADS (and ODD) of sub-UC 4.1.

7.3.2 Indicative test scenarios

The following two potential scenarios are selected to be studied but not necessarily what finally be developed for sub-UC 4.2 PoC. Both scenarios assume some kind of I2V message compromise as illustrated in Figure 52.

- **Test scenario sub-UC 4.2-A: “Distorted camera input”**

Camera object detection is compromised by a strong external source of light. The AV (low-speed truck) should rely on other sensors to perceive the environment and move appropriately. The collective perception component installed on-board or on the RSU should fuse all available object-level info and discard inaccurate or compromised information.

- **Test scenario sub-UC 4.2-B: “CAM messages attacked”**

An attacker targets V2X messages that are sent from the ego vehicle as Cooperative Awareness Messages (CAM). The message is modified and falsified information is sent to the infrastructure, including either altered position of the ego vehicle or the appearance of ghost vehicles or other traffic agents nearby affecting the ego’s trajectory. The ego vehicle shall be in place to perceive the malicious modifications and ignore them or proceed to safe maneuvers.

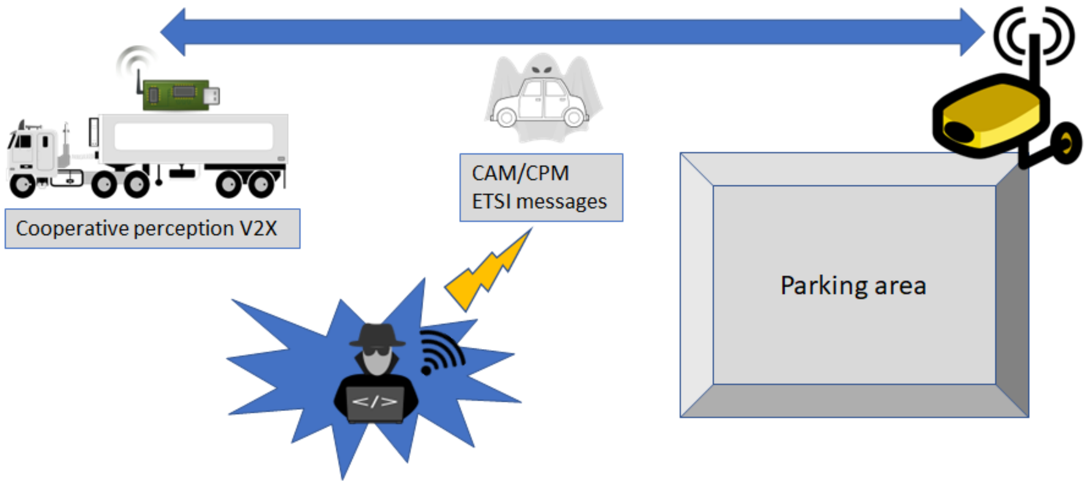

Figure 52: Schematic representation of sub-UC 4.2.

7.3.3 Preliminary test plan

7.3.3.1 Virtual testing

The main testing instance includes SiL and MiL, which both are planned to be realized under simulation (Figure 53). The most qualified simulation tool is a combination of existing simulation tools, each with different scope and potentials. The open-source CARLA tool will be used to represent the physical environment and the AV/RSU sensor detections, while ROS bridge to an external collective perception module will be integrated to CARLA. ARTERY can be potentially used to simulate V2X connectivity. But this requires a more complex co-simulaiton framework development.

7.3.3.2 Physical testing

No physical testing is going to be executed in sub-UC 4.2.

7.3.4 Preliminary metrics for SA validation

KPIs and metrics that will be used for the evaluation of the sub-UC 4.2:

Collective Perception (CP) Robustness:
This indicator would measure the ability of the CP module to perform in a range of environmental conditions and artificially created cyber threats affecting the quality of V2I object information. Appropriate baseline conditions shall be constructed considering any physical tests available from sub-UC 4.1.

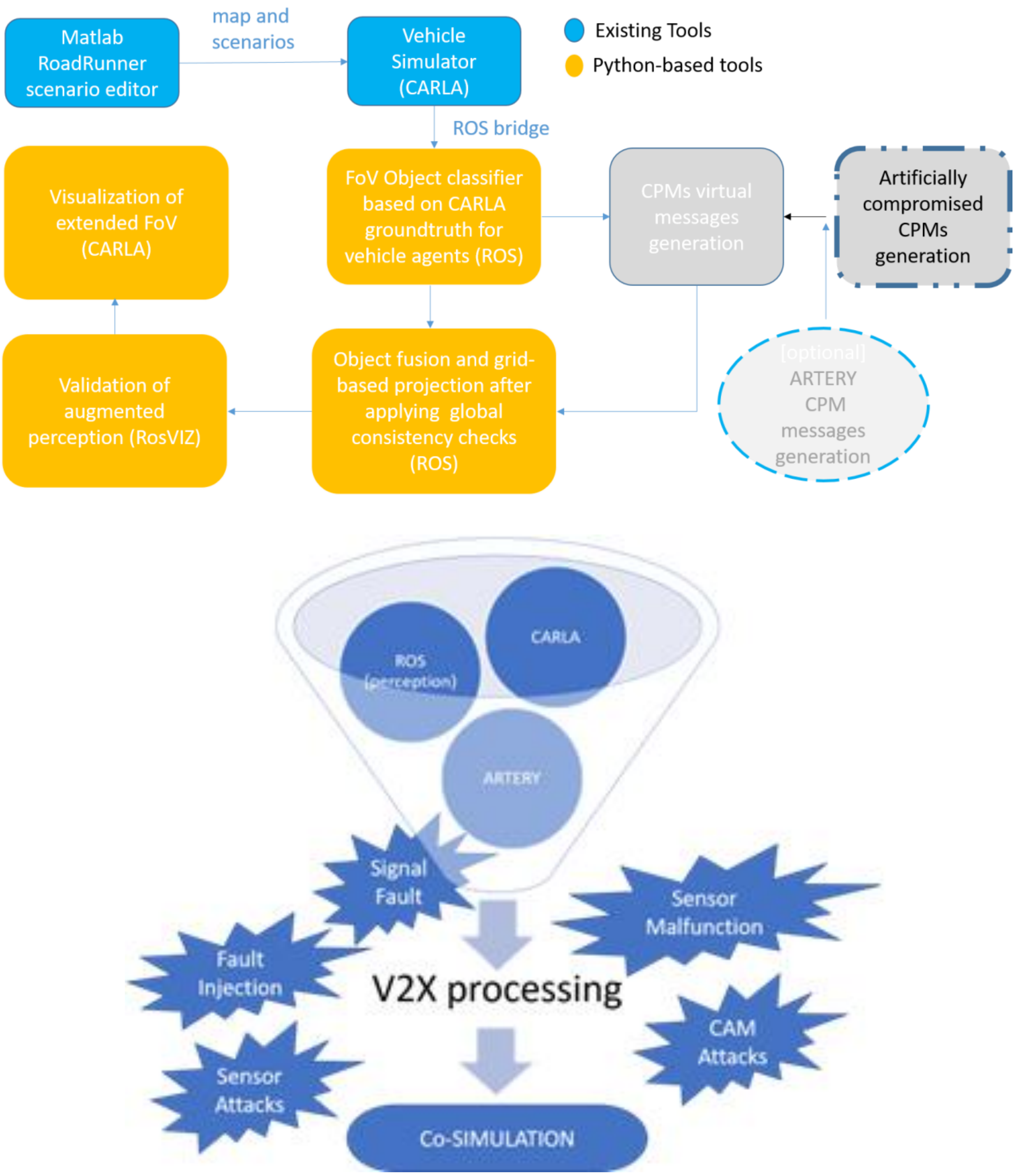

Figure 53: Draft virtual testing architecture for sub-UC 4.2.

Collective Perception Response Time:

This indicator would measure the runtime requirements of the CP module tested in CARLA-ROS simulation framework.

7.3.5 Preliminary input data requirements

Artificially generated CPM messages are needed based on CPM properties (falsifying position, speed or other object characteristics). VEREMI dataset (containing different types of attacked messages) will be studied.

7.3.6 UC high-level validation requirements summary

A. High level requirements with respect to ADS functional safety assessment:

- UC4.2_REQ_SA_001: Apply ISO21448 and analyze safety of the intended functionality for a perception system that integrates external V2X information (SOTIF) while being under attack. The focus is the same with what has already been mentioned in section 4.4.7 for sub-UC 1.3, but in the present sub-UC 4.2 safety and security co-engineering shall be applied by following ISO/TR 4804.

- UC4.2_REQ_SA_002: CP system accuracy
  The CP system must accurately self-localize the vehicle within a certain tolerance within the area of the docking bay. This tolerance should be defined based on the size of the vehicle and the space available in the logistics hub.

- UC4.2_REQ_SA_003: CP system reliability
  The CP system must reliably detect object positions around the AV

- UC4.2_REQ_SA_004: CP system robustness to different cyber threats
  The CP system should be robust to different effects of cyber-attacks in I2V messages.

B. High level requirements with respect to scenario description/generation:

- UC4.2_REQ_SDG_001: The scenario-space regarding movable object is quite limited, due the restricted interactions and manoeuvres, but is expanded by efforts to maintain service in different environmental conditions and under different types of attacks.

C. High level requirements with respect to the test framework (methods/tools/data):

- UC4.2_REQ_TTM_001: The main focus is on evaluating collective perception in CARLA, see sub-UC 1.3 with additional uncertainties generated by intended cyber threats. Network and traffic simulators integration are not considered here since the focus in not on evaluating V2X connectivity and the present sub-UC 4.2 does not involve other traffic agents.

8 SUMMARY OF VALIDATION REQUIREMENTS

In the previous chapters, a set of application specific CCAM systems is described. A set of validation requirements can be derived for testing a broad range of existing AD functions covering both their functional (target operational domain including connectivity, traffic context and supported manoeuvres, driver in-the-loop considerations) and non-functional aspects (safety, cybersecurity).

The present chapter aims to provide instructions or guidelines on how SAF or/and PoC developers can get to the right information. For this purpose, a total summary of high-level validation requirements presented in the previous sections for all the selected SUNRISE UCs and sub-UCs are depicted in Table 10.

Table 10: Summary of high-level requirements for all the selected SUNRISE UCs and sub-UCs.

	HIGH LEVEL VALIDATION REQUIREMENTS			
UC / sub-UC	**A. with respect to ADS functional safety assessment**	**B. with respect to scenario description / generation**	**C. with respect to the test framework (methods / tools / data)**	**D. with respect to the user perspective**
1.1: Perception testing *(section 4.1.7)*	15	4	3	-
1.2: Connected perception testing *(section 4.2.7)*	11	3	3	-
1.3: Cooperative perception testing *(section 4.3.7)*	5	3	3	2
2.1: Safety assessment & decision-making testing *(section 5.7)*	8	3	13	2
3.1: Map-based perception &	6	2	6	-

decision-making & control testing *(section 6.2.6)*				
3.2: Cooperative perception & decision making & control testing *(section 6.3.6)*	8	2	6	-
4.1: Truck low-speed perception & decision-making testing *(section 7.2.6)*	4	1	1	-
4.2: Truck low-speed connected perception cyber-security testing *(section 7.3.6)*	4	1	1	-
TOTAL	**61**	**19**	**36**	**4**

Based on the work preceded (requirements derived in sections 4-7), we outline hereafter a reduced set of requirements supported by the majority of the UCs (clustered as defined above):

A. High level requirements with respect to ADS functional safety assessment:

- Apply safety standards for the assessment of the ADS under test
- ADS performance in nominal ODD
- ADS performance in adverse ODD
- ADS accuracy
- ADS reliability
- ADS adaptability
- ADS robustness

- ADS sensitivity
- ADS MRM

B. High level requirements with respect to scenario description/generation:

- The test cases must cover the complete ODD and DDT (based on the regulation) through ontology approaches and smart scenario generation methods (e.g., combinatorial testing)
- The test cases target the original UCs presented in ERTRAC.

C. High level requirements with respect to the test framework (methods/tools/data):

- Physical vs. virtual testing: *the amount of proving ground tests depends on the model correlation quality*
- The simulations must be real-time capable and deterministic.
- The simulations should have a proven deterministic behaviour and repeatable results.
- Safety KPIs such as TTC, acceleration and deceleration (lateral and longitudinal), must be included.
- Simulation frameworks should be capable to simulate real world simulations, including controller performance and environmental conditions.
- Simulation model outputs must correlate with physical measurements, expressed by correlation and error KPIs such as R^2, RMSE or correlation coefficients.
- Test vehicles should be fully equipped with the complete systems to execute consecutive proving ground tests.

D. High level requirements with respect to the user perspective:

- There should be a built-in scenario management tool to allow manual selection and parametrization of test cases.
- Cloud computing interface to run parallel simulations.
- Middleware for integrating various models and software tools (CAN, FMU, ROS, Python etc.)
- KPI dashboard for easy and quick evaluation and reporting of results.

- The KPI dashboards should be configurable and adaptable, e.g., the type of KPIs and their thresholds.

9 CONCLUSIONS

In the previous chapters, a set of application-specific CCAM systems was described. A set of validation requirements covering scenarios, tools and data types has also been derived for testing a broad range of existing ADS through four (4) selected UCs and eight (8) selected sub-UCs. These requirements cover both functional (target operational domain including connectivity, traffic context and supported manoeuvres, driver in-the-loop considerations) and non-functional aspects (safety, cybersecurity).

The present deliverable guides the conception and the design of the generic SAF in WP2 and can be used as a technical input for the rest of the technical WPs (WP3 – Method, WP4 - Toolchain, WP5 – Ontology, and WP6 – Data framework).

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ANNEX 1: KEY CARD TEMPLATE FOR USE CASES

SUNRISE

Use Case X.X – Key Card

<TITLE>

Main aim		
1-2 sentences, problem statement, vision, etc.		
State-of-the-art	**Beyond SotA / Innovation**	**Targeted TRL**
short description	*short description*	*TBD*
Setup		
block diagram, partner roles, etc.		
Benchmark scenario/mission/etc.		
description of the scenario space (supported manoeuvres, driver-in-the loop considerations, etc.)		
Validation process and high-level requirements		
Relation to SAF high-level requirements		
Testing and evaluation tools		
Evaluation platform - simulation/driving simulator/etc.		
KPIs and metrics for assessment		**Baseline**
KPIs which evaluate the success of the demonstrator in line with the stated requirements		*Baseline for KPIs*
Data required		
real world input data; extreme data; human driving data, etc.		