D2.1

Overview and gaps of existing safety assessment frameworks

Project short name
SUNRISE

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

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
AD	Automated Driving
ADAS	Advanced Driver-Assistance System
ADF	Automotive Distribution Federation
ALKS	Automated Lane Keeping System
API	Application Programming Interface
AV	Automated Vehicle
CCAM	Cooperative, Connected and Automated Mobility
EU	European Union
EuroNCAP	European New Car Assessment Programme
GSR	General Safety Regulation
GUI	Graphical User Interface
HIL	Hardware-in-the-Loop
HTS	Highway Transportation System
ISO	International Standards Organization
KPI	Key Performance Indicator
METI	Ministry of Economy, Trade and Industry
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
SAE	Society of Automotive Engineers
SAF	Safety Assurance Framework
SCDB	Scenario Database
SDOs	Standards Development Organizations
SIP-adus	Scientific Investigatory Project - Automated Driving for Universal Services
SPSD	Safety Pool Scenario Database

V2I	Vehicle-to-Infrastructure
V2X	Vehicle-to-everything
VRU	Vulnerable Road User

Table 1 Abbreviations and acronyms

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 highly automated vehicles.

The SUNRISE project will develop and demonstrate a commonly accepted, extensible Safety Assurance Framework 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. The project 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, based on 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.

This document provides an overview of the existing safety assessment frameworks used for CCAM systems and identifies the gaps in these frameworks. The report begins by identifying the stakeholders and defining a set of requirements for each of them. It then provides a literature review of the existing safety assessment frameworks and analyses their strengths and weaknesses.

The report will identify several gaps in the current safety assessment frameworks, including the lack of standardization across different regions and the need for more comprehensive testing methods that consider complex real-world scenarios. Additionally, the report highlights the need for continuous improvement and adaptation of safety assessment frameworks to address emerging risks and technologies associated with CCAM systems. The second main objective the deliverable is to develop a roadmap including requirements and targets for the technical development of the SUNRISE SAF.

Overall, the deliverable aims to provide a comprehensive understanding of the existing safety assessment frameworks for CCAM systems and their limitations to support the development SUNRISE framework.

1 INTRODUCTION

1.1 Project introduction

Safety assurance of Cooperative, connected, and automated mobility (CCAM) technologies is a crucial factor for their successful adoption in society, yet it remains to be a significant challenge.

CCAM systems need to demonstrate reliability in all driving scenarios, requiring robust safety argumentation. 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 automated driving functions. These initiatives have already moved from conventional validation to a scenario-based approach and combine different test instances (physical and virtual testing) to avoid the million-mile issue.

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 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.

Evolving from the achievements obtained in HEADSTART and taking other initiatives as a baseline, it becomes necessary to move to the next level in the concrete specification and demonstration of a commonly accepted Safety Assurance Framework (SAF) for the safety validation of CCAM systems, including a broad portfolio of use cases and comprehensive test and validation tools. This will be done in SUNRISE, which stand for Safety assUraNce fRamework for connected, automated mobIlity SystEms.

The Safety Assurance Framework is the main element to be developed in the SUNRISE project. This framework takes a central role, fulfilling the needs of different automotive stakeholders that all have their own interests in using it.

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. The project 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, based on a virtual harmonised simulation environment with standardised, open interfaces and quality-controlled data exchange.

1.2 Purpose of the deliverable

This deliverable will identify and assess initiatives on safety assessment frameworks and their stakeholders, be it established or new. The stakeholders' sources include regulatory bodies, consumer testing, international SDOs, solution providers and industry driven initiatives and research institutes.

The deliverable will also contain the high-level requirements and a gap analysis to be used as a technical input for the rest of the Technical Work Packages

Who	Role
CHALMERS	Document review as WP leader and meeting attendance. Involved in discussions related to the content of this deliverable.
ERTICO	Contribution to SoA overview and identification of gaps focusing on international activities and cooperation (e.g., SAKURA project).
ICCS	Contribution to SoA and gap analysis based on the review of EU projects piloting CCAM.
IDIADA	Task leader. Contribution by providing the state-of-the-art information on current initiatives in the regulatory and consumer testing point of view. Contribution also from HEADSTART project input.
IKA	Contribution regarding Pegasus Family methodology.
RESA	Contribution for the Stakeholder OEM including use case description and gap analysis.

TNO	Contribution to the SoA overview and identification of gaps from the perspective of the scenario database hosts. Focus on international cooperations such as SAKURA (Japan), and CETRAN (Singapore). Contributions also result from other relevant projects such as HEADSTART and V4SAFETY.
VEDECOM	Contribution related to ADScene.
UoW	Contribution related to Safety Pool.
CRF	Involved in discussions related to the content of this deliverable.

Table 2 Partner contribution to D2.1

1.3 Intended audience

The intended audience of the deliverable will include all the project consortium as this deliverable will be used as a basis for the whole work of the project.

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

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

Chapter 2: Stakeholders use cases. Identification of the main stakeholders that will use the SUNRISE safety assurance framework. These will be the Homologation Technical Service, the Consumer Testing (EuroNCAP), the OEM and the Scenario Database Owner. For each one of these, a use case diagram and a set of requirements will be defined.

Chapter 3: State of the art methodologies. A brief description of each of the existing frameworks that have been analysed within this task.

Chapter 4: Gap analysis. The gap analysis between the requirements identified in chapter 2 and the methodologies identified in chapter 3.

Chapter 5: Conclusions. Summary of the main output (targets and requirements for the SAF) of the deliverable.

D2.1 does not receive input from any SUNRISE deliverable, but it has been aligned with D3.1 and D5.1. However, D2.1 output will be used for the future work in the deliverables from all the Technical Work Packages (WP2, WP3, WP4, WP5, WP6 and WP7).

2 STAKEHOLDER USE CASES

2.1 Introduction

Stakeholders play a crucial role in SUNRISE as they are individuals or groups who have a vested interest or are affected by the outcomes and activities of the SUNRISE project. Identifying and understanding stakeholders is vital for effective decision-making, collaboration, and ensuring overall project success. Stakeholder use cases help in defining specific scenarios or situations in which stakeholders are engaged or impacted. These use cases provide a deeper understanding of stakeholder requirements, expectations, and how their involvement can contribute to achieving project objectives.

In order to understand the needs and interactions between the different sources defined in the grant agreement, stakeholders in this deliverable are understood as the main users of SUNRISE methodology and with this analysis all sources are expected to be covered. In the following lines is explained:

- Homologation Technical Service takes into consideration all regulatory bodies (e.g., UNICE VMAD, FRAV, GRVA, WP.29)

- OEM use cases are also considering the integration of solution providers and industry driven initiatives because they are the responsible of integrating the different components into the vehicles.

- EuroNCAP is also analysing the needs for any consumer testing entity.

- Scenario database host is also aligning the needs of the international SDOs (ISO, SAE, ASAM …) into their requirements.

- Research institutes are also integrated by performing a state-of-the-art analysis of the current methodologies related to scenario assessment approach for CCAM and a gap analysis is also done.

2.2 Stakeholder sources

The main goal of this section will be to gather the stakeholders use cases for the SUNRISE framework that will be used later as the baseline to analyse the gaps from previous projects and methodologies. The stakeholders defined for this analysis are the following:

- **Homologation Technical Service** (HTS). It is responsible for the testing and certification of vehicles, components, and systems in accordance with the regulations and standards set by the relevant authorities. It is typically authorized by national or international regulatory bodies to conduct testing and certification activities. The primary objective of a HTS is to ensure that vehicles and their components meet the safety, environmental, and performance requirements set by the regulatory bodies. This involves testing various aspects of the vehicle or component, including its structural integrity, emissions, noise levels, and performance characteristics. Once a HTS has completed testing, it issues a certification or approval that indicates if the vehicle or component has met the relevant standards.

- **Original Equipment Manufacturer** (OEM). It is an organization that designs, produces, and sells automobiles, motorcycles, or any other type of motorized vehicles. They are responsible for various stages of the manufacturing process, including engineering, prototyping, assembly, quality control, and distribution of vehicles to dealerships or consumers. Vehicle manufacturers often have their own distinct brands and models and play a crucial role in the automotive industry.

- **European New Car Assessment Programme** (Euro-NCAP). Euro-NCAP is an independent organization that performs crash tests and safety assessments on new cars sold in Europe. Euro-NCAP was founded in 1997 and is supported by several European governments, motoring organizations, and consumer groups. Euro-NCAP conducts a series of crash tests on each new car model, including frontal and side impact tests, as well as tests for pedestrian protection, child occupant protection, and safety assist features. The results of these tests are used to assign an overall safety rating for the car, ranging from one to five stars. These ratings are widely recognized and influential in the automotive industry, with many car manufacturers using them as a benchmark for safety performance. The ratings are also used by consumers to compare the safety performance of different car models before making a purchase decision.

- **Scenario Database host** (SCDB host). The SCenario DataBase host is the organisation that enables and organizes the development, use and maintenance of the SCDB. This includes providing the methodology, algorithms, and tools for identifying scenarios and generation of test cases.

The methodology to define the requirements coming from the stakeholders mentioned above, will consists in defining a use case diagram for each of the stakeholders and then, define each identified use case in detail.

2.3 Use Cases Description

In the following section the use case for each of the Stakeholders identified will be defined. The context section explains the current situation from the perspective of a SAF user. From this context, a schematic overview for the use of the SAF is then derived (in the section called Use Case Diagram), paving the way towards the definition of requirements in the section called Use Case Requirements.

The requirements are described following the structure detailed below:

- **Title**. Name of the requirement that also appears in the Use Case diagram. It stablishes the link between the diagram and the requirement.

- **Actors**. Stakeholder user related to the requirement. It stablishes the link between the stakeholder sources and the requirement.
- **State of the art**. How the requirement is being fulfilled now with the current methodologies and procedures available.
- **Behaviour**. How the requirement will be fulfilled using SUNRISE SAF.
- **Rationale**. Description of the need identified from a Stakeholder that needs to be covered by SUNRISE SAF.

2.3.1 Homologation Technical Service

2.3.1.1 Context

Technical harmonisation in the EU is based on the Whole Vehicle Type-Approval System (WVTA). Under the WVTA, a manufacturer can obtain certification for a vehicle type in one EU country and market its EU-wide without further tests. The certification is issued by a type-approval authority and the tests are carried out by the designated technical services.

Over the past decades, road safety has significantly improved reducing road fatalities every year. Despite this, decreases in the number of victims have stalled in the recent years and some Member States are even recording increases in fatalities rates. In view of this situation, the European Parliament and the Council adopted a New Regulation revising the General Safety Regulation (GSR). The aim of this review together with the new type-approval framework is to make road mobility safer, cleaner and more efficient for all EU citizens.

Taking into account new developments in connected and automated driving, the new GSR generalizes advanced and intelligent safety features in different categories of vehicles sold in the EU market. Some of the CCAM-related features which will be mandatory for cars are:

- **Advanced emergency braking (cars and vans).**
- **Drowsiness and attention detection (cars, vans, trucks and buses).**
- **Distraction recognition/prevention (cars, vans, trucks and buses).**
- Event (accident) data recorder (cars, vans, trucks and buses).
- **Intelligent speed assistance (cars, vans, trucks and buses).**
- **Lane keeping assist (cars and vans).**
- **Reversing camera or detection system (cars, vans, trucks and buses).**
- **UN R79 Commanded and Automatically Commanded Steering functions.**
- **UN R151 Blind Spot Information- System for the Detection of bicycles.**

- **UN R157 ALKS Test Scenarios.**
- **EU General Safety Regulation 2019/2144 – ADAS Requirements.**

This new GSR was a clear statement towards AD in the European Union. This position has been ratified during 2022 with new regulations entering into force regarding the type-approval of the automated driving systems (ADS) of fully automated vehicles and the whole vehicle type approval for fully automated vehicles produced in small series.

This driver-free future aims to increase road safety and contribute to the 0-fatalties vision. However, the transition towards automation will trigger new interactions between self-driving vehicles and regular ones which threat the current safety validation process. A standard set of scenarios to be tested is no longer a reliable approach and new safety assessment methods need to be introduced. The risk evaluation in failure condition turned out to be harder than ever to perform. Fundamental differences, not only in architecture but also in intended functionality, make a generic procedure difficult to define. The fact that the vehicle is undertaking (partially or totally) the driving responsibilities means that the requirements on road safety are not left on the user side, but also on the vehicle side.

Latest regulations on automated driving systems introduce a new approach, so called 4-Pillar Approach. The homologation step has turn out to be a process which expands throughout all the vehicle development timeline. Therefore, technical services are now assessment bodies that actively interact with the OEMs during the entire development process.

An important point of the regulation is that users should gradually get accustomed to new automated features. Making advanced safety features mandatory for vehicles, paves the way to automated vehicles, enhancing the acceptance towards full autonomous driving.

2.3.1.2 Use Case Diagram

As mentioned before, the technical service is the organization designated by each approval authority as the testing laboratory to carry out the tests for the type approval but also as a conformity assessment body to carry out the initial assessment and other tests or inspections on behalf of the approval authority.

Under the type approval for AV scope, the technical service shall verify the compliance of the proposed system with the current safety standards and regulations so to assure that the vehicle is safe enough to operate on open road.

In the following diagram, the different use-cases under the SUNRISE project scope for a technical service stakeholder are presented and defined:

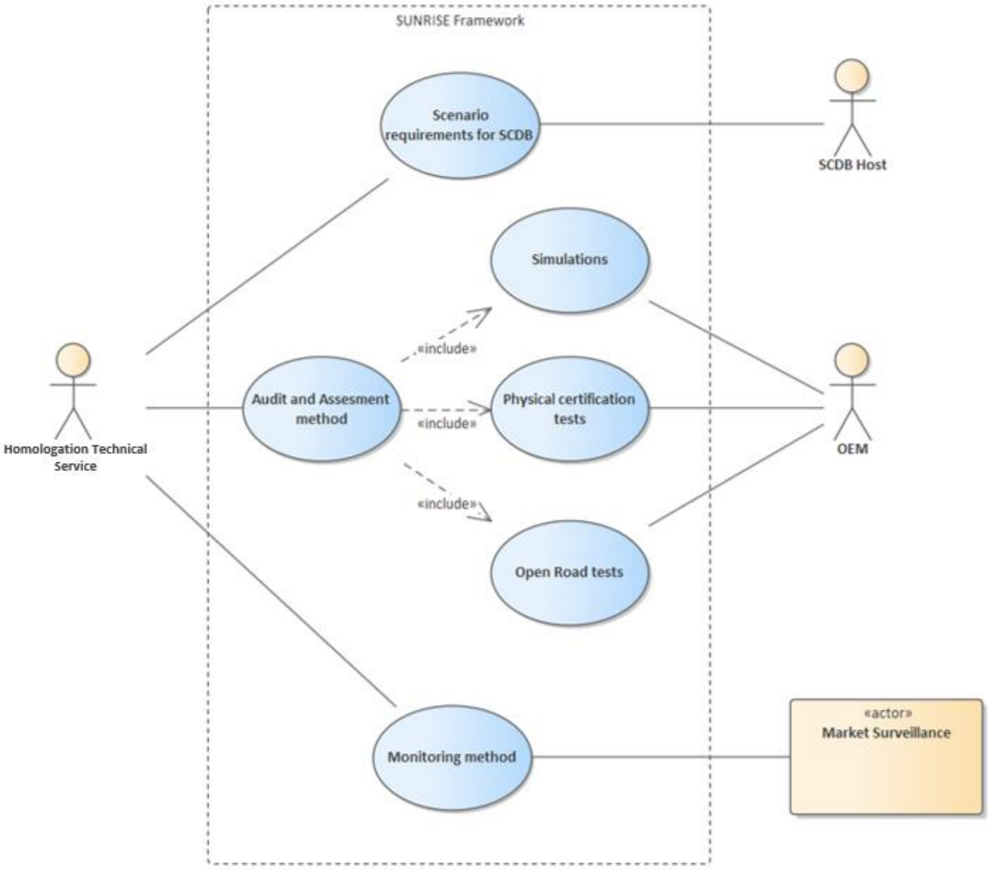

Figure 1 Homologation Technical service Use Case diagram

2.3.1.3 Use Case Requirements

- **UC Homologation 001**
  - **Title:** Scenario requirements for SCDB
  - **Actors:** Homologation Technical Service, SCDB Host
  - **State of the art:** A limited set of scenarios is provided in regulation annexes to be evaluated by the technical services.
  - **Behaviour:** A catalogue of scenarios is delivered by the database owner to the homologation technical service.
  - **Rationale:** The number of scenarios for CCAM systems is increasing exponentially so a regular homologation approach is no longer valid. Therefore, an assessment of the most critical scenarios shall be performed by a technical service in order to identify worst case scenarios to be tested.
- **UC_Homologation_002**
  - **Title:** Audit & Assessment_Simulation

- **Actors:** Homologation Technical Service, OEM
- **State of the art:** The ODD for the AV to operate on has been determined, together with a reliable source of scenarios to be tested and the risk assessment by the OEM.
- **Behaviour:** Safety validation is performed by the technical service on simulation tools for those identified scenarios.
- **Rationale:** Virtual tests and simulations help to speed up and lower costs of the safety validation process. Therefore, any possible scenario that can be validated on virtual simulation tools shall be performed on this way.

- **UC_Homologation_003**
  - **Title:** Audit & Assessment_PhysicalCertificationTest
  - **Actors:** Homologation Technical Service, OEM
  - **State of the art:** Safety assessment has been concluded and worst-case scenarios identified. Virtual validation has been concluded for those possible scenarios.
  - **Behaviour:** Targeted worst case scenarios during the assessment process are reproduced in test tracks by the technical service in order to validate the functions on the AV. The test track results shall be coherent with those of the simulations executed by the manufacturer.
  - **Rationale:** Some functions need physical tests to be validated, therefore, worst case scenarios shall be reproduced and studied in physical test tracks.

- **UC_Homologation_004**
  - **Title:** Audit & Assessment_OpenRoadTests
  - **Actors:** Homologation Technical Service, OEM
  - **State of the art:** Safety assessment has been concluded and worst-case scenarios identified. Virtual validation and test track validation has been concluded.
  - **Behaviour:** Following the current regulations in each state and after the test-track validation has been concluded, the final step of real-world testing should be performed under the requirements identifies during the audit/assessment process.
  - **Rationale:** AVs on open roads, led to a new horizon of possible scenarios which cannot be feasibly reproduced in test tracks nor simulation. Therefore, a real-world operation step on the safety validation process is needed. This step may provide new unexpected situations which were not reproduced on the test tracks, and help to provide a clear view of the behaviour of AVs in real mixed traffic conditions.

- **UC_Homologation_005**
  - **Title:** Monitoring
  - **Actors :** Homologation Technical Service, Market surveillance
  - **State of the art:** The AV has passed the safety validation process and is already under deployment.
  - **Behaviour:** New vehicles being introduced to the market shall be revaluated in order to ensure that the safety requirements are still met. Moreover, monitoring of in-use vehicles shall provide new scenarios not considered by the initial risk assessment and, therefore, amplify robustness of the system.
  - **Rationale:** Following the EU 2018/858, vehicles under commercialization must follow market surveillance standards. Therefore, a monitoring process is to be defined for AV.

2.3.2 Consumer testing (Euro NCAP)

2.3.2.1 Context

Euro NCAP (European New Car Assessment Programme) is an independent organization that evaluates the safety performance of new vehicles sold in Europe. It provides consumers with information on the safety levels of various car models, encouraging automakers to improve vehicle safety standards.

Consumers can refer to Euro NCAP's ratings and safety reports to make informed decisions when purchasing new vehicles, considering factors beyond aesthetics and performance and prioritizing safety as a critical aspect of their choice.

In recent years, Euro-NCAP has increased its focus on advanced safety technologies, such as automatic emergency braking, lane departure warning, and blind spot detection. These features are now included in the assessment criteria and can contribute to a higher overall safety rating for a car. In addition, in the area of Safe Driving and specifically targeting Occupant Status Monitoring and Speed Assist Systems (like Intelligent Adaptive Cruise Control) a protocol has recently been released, namely the “ASSESSMENT PROTOCOL – SAFETY ASSIST SAFE DRIVING” (Implementation 2023), which deals with the assessment of the Safety Assist functions based on performance requirements verified by Euro NCAP. In this protocol, advanced ADAS functions featuring conditional speed limits, road features or local hazards are also discussed.

Overall, Euro-NCAP plays an important role in improving vehicle safety standards in Europe, promoting the development and adoption of advanced safety technologies, and raising awareness among consumers about the importance of choosing safe vehicles.

2.3.2.2 Use Case Diagram

The following image shows the main interaction or requirements from a consumer testing organization perspective. One of the main interests for those initiatives is to have a clear definition of the scenarios that need to be selected to assess the performance of ADAS systems.

It's important to remark that due to the exploding number of scenarios, there is the need to integrate virtual testing to complement the current physical testing assessment.

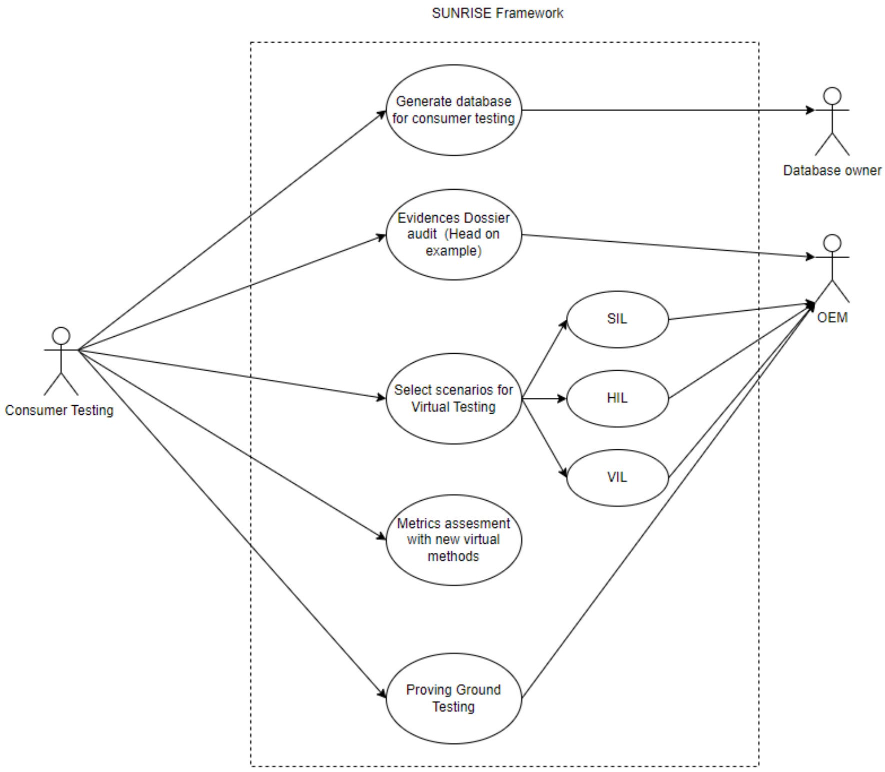

Figure 2 Consumer testing (EuroNCAP) Use Case diagram

2.3.2.3 Use Case Requirements

- **UC_EuroNCAP_001**
  - **Title:** Scenario identification
  - **Actors:** EuroNCAP Technical Service, Database Owner
  - **State of the art:** At the moment scenario assessment is made based on accidentology studies coming from different sources but not specific database is used for this purpose.
  - **Behaviour:** SUNRISE should be able to identify scenarios from EuroNCAP protocols in order to be used for selecting the test cases to be executed in proving grounds.
  - **Rationale:** The number of scenarios increases exponentially for high levels of automation and to have a test matrix covering all test cases is not feasible. It's necessary to have a methodology for defining test cases based in databases.

- **UC_EuroNCAP_002**
  - **Title:** Evidence dossier audit (head on example)
  - **Actors:** EuroNCAP Technical Service, OEM
  - **State of the art:** For some scenarios which are risky to be executed in proving grounds, OEMs are generating an evidence dossier where the performance of the ADAS feature is demonstrated by a methodology that is not based in any EuroNCAP protocol.
  - **Behaviour:** SUNRISE framework should be able to use its methodology to support OEM's in creating dossiers where safety performance is going to be audited by the technical service.
  - **Rationale:** Many test cases can't be replicated in proving grounds and it's necessary to give to the OEM room for demonstrating the proper performance of their systems by creating evidence dossiers.

- **UC_EuroNCAP_003**
  - **Title:** Select scenarios for virtual testing
  - **Actors:** EuroNCAP Technical Service, OEM
  - **State of the art:** At the moment there is a working group in EuroNCAP defining how virtual testing should be introduced. However, it's in an early stage and not concrete method has been defined.
  - **Behaviour:** SUNRISE Framework should support EuroNCAP in defining a criteria for allocation scenarios in virtual environment and the methodology should be agreed between OEM and technical service.
  - **Rationale:** Number of scenarios for high levels of automation is huge and virtual testing could be a good methodology for demonstrating the proper performance of the systems without the need of proving grounds.
- **UC_EuroNCAP_004**
  - **Title:** Metrics Assessment with new virtual methods
  - **Actors:** EuroNCAP Technical Service, OEM
  - **State of the art:** At the moment there is a working group in EuroNCAP defining how virtual testing should be introduced. However, it's in an early stage and not concrete method has been defined.
  - **Behaviour:** SUNRSE Framework should define a methodology where the rating for EuroNCAP with the usage of virtual environment is clearly well defined.

- **Rationale:** With the introduction of virtual methods, it’s necessary to define specific evaluation criteria for EuroNCAP assessment due to limitations in correlation with real world testing.

- **UC_EuroNCAP_005**
  - **Title:** Proving ground testing
  - **Actors:** EuroNCAP Technical Service, OEM
  - **State of the art:** EuroNCAP assessment is currently based in physical testing.
  - **Behaviour:** SUNRISE Framework should enrich NCAP assessment with other testing methods for scenario allocation and this should affect the way how physical testing is being executed in NCAP until now.
  - **Rationale:** If new testing methods like virtual testing can be used for NCAP assessment, this could have an impact in the way how physical testing is being defined until now.

2.3.3 OEM

2.3.3.1 Context

The automotive industry is moving steadily towards intelligent automation, with ADAS and fully autonomous systems being integrated in today's vehicles. These systems are emerging as the solution to several problems primarily caused by humans on roads, such as accidents and traffic congestion. However, these benefits come with great challenges as verification and validation (V&V) of those systems for safety assessment.

It is quite easy to obtain metrics about human mistakes leading to safety issues on the roads, however switching from human drivers to artificial intelligence (AI) systems is really challenging. These systems are not deterministic and should be seen as unsafe until proven otherwise -- ISO26262. This is the ISO that provides a framework to develop safety critical systems in the automotive sector.

The problems only increase when considering different OEMs, with different technologies and testing their vehicles in different conditions. A specific vehicle working in Europe in highways does not behave the same as a vehicle from another OEM working in US roads. Data regarding system limitations, used technology, operational design domain and so on should be gathered in order to make OEM's solution comparable. This data is really useful for other CCAM developers/integrators, making possible to know possible errors in advance, and what kind of systems work better for specific ODDs, accelerating the whole development process and related safety assessment.

OEMs will play a key role, identifying and communicating new possible failures during their validation process. Verification and validation will be both based on physical and virtual testing.

2.3.3.2 Use Case Diagram

The figure below shows the use case diagram from the perspective of the OEM. This figure pictures verification and validation process of any AD functionality and relationship between different stakeholders: Within the OEM, validation, verification and CCAM developer teams; and external to the OEM, a CCAM database owner or, in other words, the SCDB host.

Verification refers to the process of checking if the AD functionality fulfils the design specifications. This can be done while developing the functionality: CCAM developer teams test their product against those design specifications to verify the solution and find possible bugs. Design specifications are determined by the verification team based on the information gathered from the CCAM database owner. Lower part of the figure corresponds to this process. Validation can be found in the upper part of the figure. It refers to the process of checking the final AD product against requirements. Failures/bugs that could not be found during the verification process should be found here. Validation is performed by the validation team, which checks relevant safety metrics for a specific AD functionality within the CCAM database. The following section details more how verification and validation is performed in an OEM and the role of the different stakeholders.

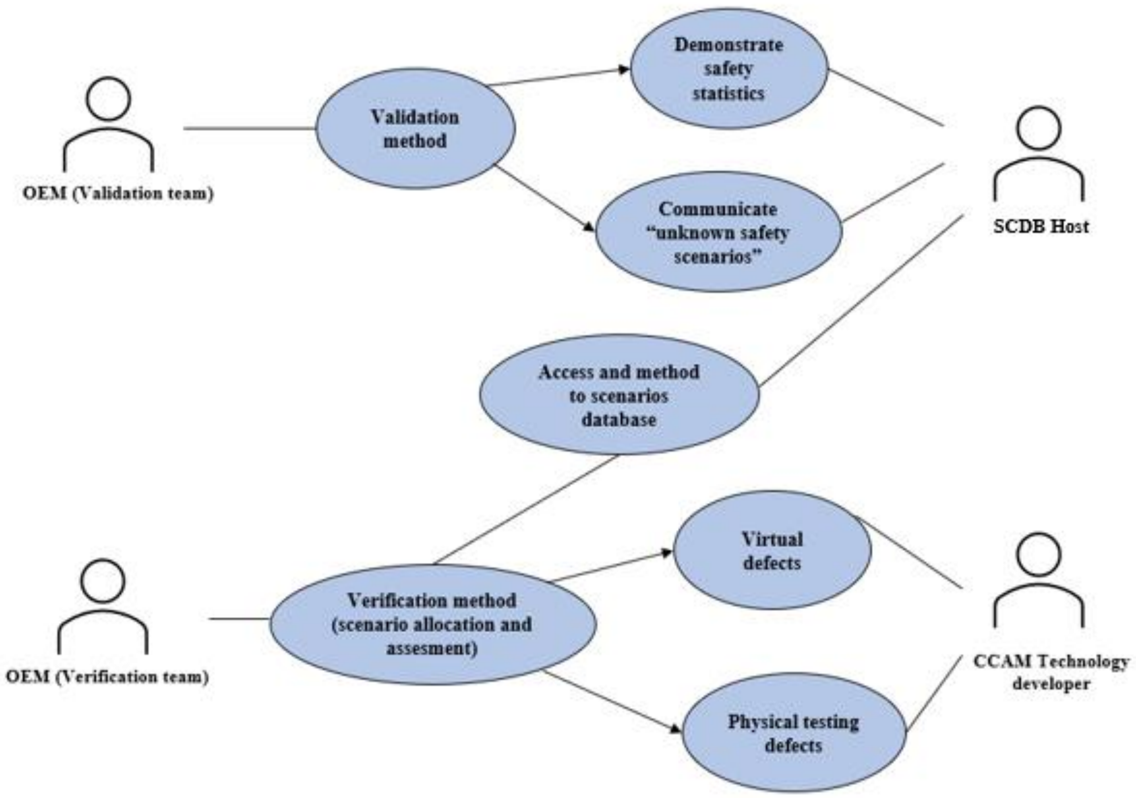

Figure 3 OEM Use Case diagram

2.3.3.3 Use Case Requirements

- **UC_OEM_001**
    - **Title:** Verification method (scenario and allocation assessment).

- **Actors:** Verification team, OEM.
- **State of the art:** The ODD for the AV to operate on has been determined together with a reliable source of testable design specifications. New AV functionality (systems and software) is being released or existing functionality is being updated.
- **Behaviour:** Scenario and allocation are assessed depending on ODD, specific AV functionality and design specifications. Different methods are defined based on needs – Checking documents, design, code, virtual or physical defects.
- **Rationale:** Systems design and software undergo physical and virtual testing under known scenarios so bugs can be found early in the development cycle. These bugs can be corrected before the validation phase.

- **UC_OEM_002**
  - **Title:** Virtual defects.
  - **Actors:** CCAM Technology developer.
  - **State of the art:** A verification method for a specific AV functionality has been determined. ODD and possible defects are known. Developer is developing an AV functionality and it knows already a verification methodology that could be used for testing specific cases in virtual environments.
  - **Behaviour:** Defects verification is performed on simulation tools for identified scenarios.
  - **Rationale:** Virtual tests and simulations help to speed up and lower costs of the verification process. Therefore, any possible scenario that can be validated on virtual simulation tools shall be performed on this way.
- **UC_OEM_003**
  - **Title:** Physical testing defects.
  - **Actors:** CCAM Technology developer.
  - **State of the art:** A verification method for a specific AV functionality has been determined. ODD and possible defects are known. Developer is developing an AV functionality and it knows already a verification methodology that could be used for testing specific cases in physical environments.
  - **Behaviour:** Some functions need physical tests to be validated, therefore, worst case scenarios shall be reproduced and studied in physical test tracks.
  - **Rationale:** Some functions need physical tests to be validated, therefore, worst case scenarios shall be reproduced and studied in physical test tracks.

- **UC_OEM_004**
    - **Title:** Access and method for scenarios database.
    - **Actors:** OEM verification team and SCDB Host.
    - **State of the art:** There is an existing data base collecting possible failures in different scenarios coming from different OEMs. Database is updated with new data coming from validation process or a new design process for AV functionality started.
    - **Behaviour:** Define access and methods for making a good use of the database, and how this can be translated into specific design requirements for different AV functions.
    - **Rationale:** Possible defects/failures are already included in a database so those could be already considered in the design process of an AV functionality, making the development faster and bug-free.
- **UC_OEM_005**
    - **Title:** Validation method.
    - **Actors:** Validation team, OEM.
    - **State of the art:** Safety assessment has been concluded and a new AV functionality/release is ready to be tested against requirements for a specific ODD. New AV functionality is ready to be tested as a final product.
    - **Behaviour:** A validation method is designed to test the verified system in real roads. The real test should be within the specific ODD for which the system has been designed. This allows to identify unknown failures, or how the vehicle behaves in situations that were not considered.
    - **Rationale:** Validation is used to ensure that a system is free from any unreasonable risks due to unknown hazards. Validation is also used to identify failures that did not appear during the verification process.
- **UC_OEM_006**
    - **Title:** Demonstrate safety statistics.
    - **Actors:** Validation team, OEM.
    - **State of the art:** A specific AV functionality is being validated**.**
    - **Behaviour:** A safety KPI is determined for the functionality and the ODD – e.g., driven kilometres per disengagement. This is an input to the CCAM technology developer.

- **Rationale:** Knowing safety metrics by different OEMs allows to focus research and innovation work in the right direction – e.g., perception system is the one causing most of the disengagement when driving autonomously.

- **UC_OEM_007**
  - **Title:** Communicate “unknown safety scenarios”
  - **Actors:** Validation team, OEM
  - **State of the art:** A specific AV functionality is being validated. This specific AV functionality fails to perform correctly in a specific scenario.
  - **Behaviour:** The scenario is repeated physically or virtually so the origin of the failure can be properly identified. This could be a useful input to another CCAM technology developer.
  - **Rationale:** It is important to communicate this new ODD where a specific AD system fails to perform correctly, so this can be considered by others in their design specifications, paving the way to failure free AVs. This communication should be done to the corresponding SCDB with a parameter range extension or creations of new parameters for a specific ODD.

2.3.4 SCDB host

2.3.4.1 Context

In many national and international programs and projects in the last decade, data-driven methods have been developed to provide realistic and relevant tests for the safety assessment of all levels of CCAM systems on-board vehicles. Traditionally, in-depth accident databases were reviewed to define a set of tests e.g., for the Euro NCAP safety rating. It was generally recognized that this is no longer sufficient for the safety assessment of CCAM systems with higher levels of automation (SAE Level 3 and 4). The HEADSTART project showed the common structure of data-driven scenario-based assessment:

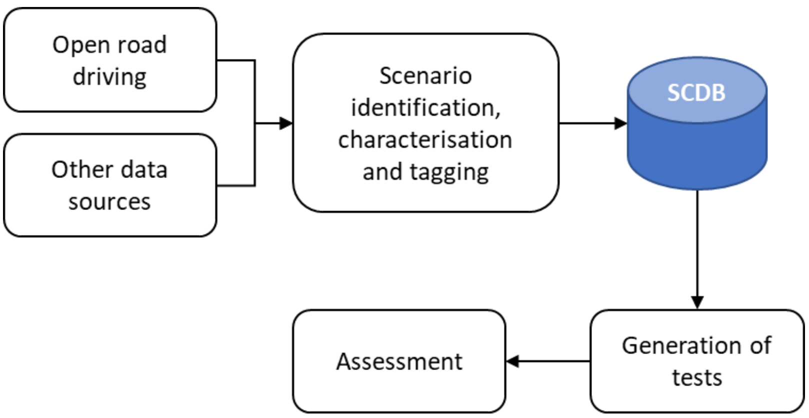

Figure 4 Common structure of the data-driven scenario-based safety assessment approach

Though following the structure as shown in Figure 4, in this way several consortia were initiated that each cover a certain region of application. In SUNRISE D3.1, an overview of the different consortia for the establishment of scenario databases is given.

None of the existing SCDBs has sufficient coverage to be used for the type approval or the safety rating of a CCAM system that might be deployed in any of the countries in the EU. SUNRISE proposes a federated approach, in which the relevant tests for a certain system are based on scenarios found in possibly multiple SCDBs.

2.3.4.2 Use Case Diagram

Figure 5 shows the use case diagram from the perspective of the SCDB hosts. Other stakeholders in the governance of the scenario databases (and the federation layer) are the EC, the homologation authority, the homologation technical service and the OEM or CCAM developer. In the use case diagram, two streams are distinguished: in blue the stream regarding the requirements for the components in the safety assessment methodology (data collection, scenarios in the SCDB, and the test cases) and in black the stream on the actual data flow according to the requirements. Following the basic flow as given in Figure 4, two additional blocks are added:

- Federated access: the technology and tool(s) to be developed in SUNRISE to allow the generation of test cases based on scenarios that are stored in multiple SCDBs that are each hosted by another entity. The federated access is also assumed to allow studying scenario statistics over different regions that are covered by the collective SCDBs.
- ODD: Scenarios can be used to describe the ODD of a given system; in principle the OEM/CCAM developer has the information to describe the ODD of the system under test. If the ODD is known, then it can be used to determine what scenarios are relevant for the assessment of the system under test.

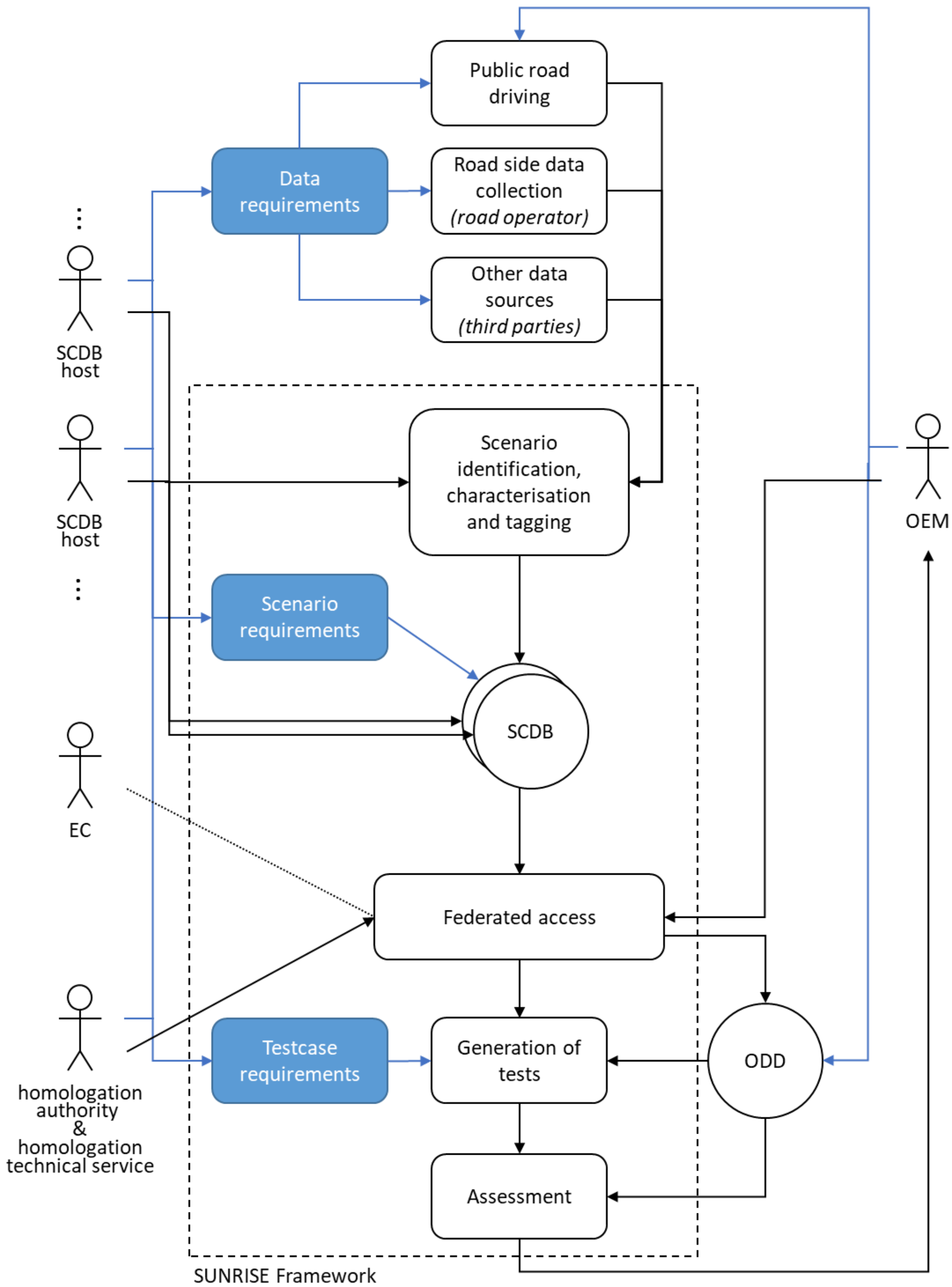

Figure 5 Use case diagram from the perspective of the SCDB owners/hosts

2.3.4.3 Use Case Requirements

- **UC_SCDBhost_001**
  - **Title:** Adding scenarios to the SCDB
  - **Actors:** SCDB host, homologation authorities, OEMs/CCAM developers, possibly third parties

- **State of the art:** Individual SCDBs exist without common ontology, each following own developed processes for extending the SCDB and for generating test cases based on information available in the SCDB.
- **Behaviour:** Requirements to the data, scenarios and tests are being agreed upon among the different SCDB hosts, e.g., following ISO 34501. SCDB host to provide quality indicators for the completeness and coverage of the SCDB (may be region based). Also, an interface definition is agreed to allow the functionality of a federation layer.
- **Rationale:** A generic scenario-based methodology is provided for the safety assessment of CCAM systems. For CCAM safety validation, the SCDB needs to be complete for the addressed ODD. This puts requirements to scenario ontology, the data to be processed, the way of describing the ODD, the way of generating tests and the way of addressing the SCDBs through the federation layer.

- **UC_SCDBhost_002**
  - **Title:** Development tests by the OEM/CCAM developer
  - **Actors:** SCDB host, OEM/CCAM developer
  - **State of the art:** An OEM/CCAM developer has access to its own SCDB, or a specific SCDB of one of its partners.
  - **Behaviour:** The OEM/CCAM developer has access to multiple SCDBs through the federation layer to achieve a higher coverage of the EU or a higher completeness for specific regions of interest.
  - **Rationale:** Already in the development phase of CCAM functionality, it is important for the manufacturer to have insight into the expected ODD of the function, and the large variety of scenarios and parameter ranges within the ODD.
- **UC_SCDBhost_003**
  - **Title:** Homologation tests
  - **Actors:** SCDB host, OEM/CCAM developer, homologation technical service, homologation authority
  - **State of the art:** In a first phase, the OEM/CCAM developer will perform its own safety assessment to provide evidence of the correct and safe function of the CCAM system to be deployed under UNECE or EC regulation. In a second phase, based on the assessment results provided by the OEM/CCAM developer, the homologation authority might request additional tests, that are performed by the homologation technical service in cooperation with the OEM/CCAM developer. The SCDB host supports the process in providing access to the SCDB and to the SCDB

statistics – e.g., to answer the question how well the SCDB covers the ODD, to generate relevant tests.

- **Behaviour:** The OEM/CCAM developer makes use of the federated layer to make the selection of tests for its own safety assessment to provide evidence of the correct and safe function of the CCAM system to be deployed under UNECE or EC regulation. The homologation authority has an overview of the complete process according to the SUNRISE framework, and consequently has the knowledge to overlook and audit the process of scenario selection, test case generation, and safety assessment. Based on requests of the homologation authority, the homologation technical service might perform additional tests (spot checking) to enhance the safety assessment. The SCDB host supports the process in providing access to the SCDB and to the SCDB statistics.

- **Rationale:** The SUNRISE framework allows not only access to a collection of SCDBs, it also allows the homologation authority to audit the process from introducing scenarios into the database to the generation of test cases. With SCDB metrics related to completeness (e.g., for a specific regional area) and coverage (e.g., for a specific ODD), as developed within SUNRISE, the statistical relevance of the tests used in the safety assessment can be determined and shared with the homologation authority.

- **UC_SCDBhost_004**
  - **Title:** Scenario research for the EC, e.g., as input to safety impact assessment
  - **Actors:** SCDB host, OEM/CCAM developer, research organisation consulting the EC
  - **State of the art:** Different SCDB initiatives exist. Each initiative has a different coverage and region of interest. Each of the SCDBs can be used for scenario analysis, and the results are consequently only applicable for the region of interest covered by the specific SCDB. It is expected to be infeasible for a single party to increase coverage such, that results are available for all of the countries in EU.
  - **Behaviour:** Through the SUNRISE federated access, it can be more easily arranged to perform a scenario analysis over a larger region of interest.
  - **Rationale:** Scenarios do not contain any information regarding the CCAM (or other vehicle) system for which a safety assessment is being performed. Also in this UC, there is no interest for the study in system performance. Studies into scenarios are conducted to get an understanding of what situations can happen on the public road, and what variations might occur. The frequency of occurrence is an important parameter. If such data is available for different regions and countries, what typical similarities and differences exist between these regions and countries. Such information is valuable, for instance when safety impact assessment is considered.

3 STATE OF THE ART METHODOLOGIES

3.1 Introduction

A number of EU CCAM-related projects are considered relevant towards the development of a safety assurance framework. The L3Pilot [1] created a Code of Practice [2] which analysed functional safety, cybersecurity, the implementation of updates, Safety of the Intended Functionality, and data recording, privacy and protection aspects. The Code of Practice is a document which guides the reader on safety and security issues through a number of targeted questions, distributed in different development phases.

The Hi-Drive project [3] aims to extend the Code of Practice for the development of AD functions and further create another code of practice for road testing. It will focus on piloting and testing methodology, which is separated in three pillars: assessing user effects, technical effects and impact. Cybersecurity is dealt as one single enabler in the process, while the overall aim is to lead to defragmentation of ODD in the AV operation.

In the EVENTS project [4], safety is approached through the description of unexpected situations that may disrupt the normal operation of CAVs. Such events are related to VRUs and their interaction in complex urban environments, non-standard and unstructured road conditions, and low visibility and adverse weather conditions. The project focuses on testing each AD system layer separately and as an end-to-end system in both real world, virtual and hybrid settings, and aims to create a robust and resilient perception and decision-making system, that may lead to an improved minimum risk maneuver.

Within V4Safety project [5] a prospective safety assessment framework is expected to be created. It deals with all road users in pre-crash and post-crash safety using realistic baseline scenarios in virtual testing. The outcome will be a harmonized simulation-based methodology to provide accurate, transparent, relevant and comparable results used by all relevant stakeholders.

The i4Driving project [6] will establish a credible and realistic human road safety baseline for virtual assessment of CCAM systems, paving the way for a driving license for AVs. It will deal with credible models of heterogeneous human driver behaviors, using scenario-based and traffic-based safety assessment. The methodology will use heterogeneous and complex road traffic data on how human drivers behave in critical driving simulations, to compare the safety performances of AVs and human-driven vehicles. This will be realized through an extendable simulation library that combines models for human driving behavior, and the investigation of uncertainty in both human behaviors and use case circumstances.

3.2 Methodologies

3.2.1 HEADSTART

The HEADSTART project is a European project, predecessor to SUNRISE, which developed and defined a harmonized validation methodology for connected and automated driving functions. There were several participant countries all over Europe involved, including Germany, Spain, France, Sweden, Belgium, Greece and the Netherlands.

The main objective was to find a harmonized European solution for testing automated road transport. To achieve this, HEADSTART project defined testing and validation procedures of connected and automated driving functions including key enabling technologies (i.e., communications, cyber-security, positioning) by cross-linking of all test instances such as simulation, proving ground and real-world field tests to validate safety and security performance according to the needs of key user groups (technology developers, consumer testing groups and type approval authorities). The methodology was compiled based on a detailed state-of-the-art analysis. Moreover, a global network of experts and stakeholders was constantly involved in the development process by expert workshops and interviews.

3.2.2 PEGASUS Family

The PEGASUS project family is a German initiative funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK). The corresponding projects are PEGASUS (2016-2019), SET Level (2019-2022) and VVMethods (2019-2023) which are all part of an overall methodology for the safety assurance of automated driving functions.

The PEGASUS project aimed to establish a method that ensured the safety and reliability of highly automated driving functions, with the goal of providing a blueprint for future series development of such systems. The project focused on developing a standardized and widely accepted approach for testing these functions. This involved several subprojects that were closely connected and worked in collaboration towards a common goal. The overall method involved defining requirements based on existing knowledge and regulations, processing data to derive scenarios, preparing and processing data in a common database, testing and evaluating the highly automated driving function with various test instances, and creating a safety argumentation based on the test results to establish a safety statement. By following this approach, the project aimed to create a uniform and accepted method for testing highly automated driving functions.

The follow-up projects SET Level and VVMethods tackle the challenge to extend the PEGASUS method to urban traffic situations. In this context, VVMethods aims to develop an overall methodology and SET Level dealt with simulation technology, which is used in development and approval of automated vehicles.

3.2.3 StreetWise

StreetWise is a program led by TNO, the Netherlands Organization for Applied Scientific Research. The program is focused on developing methods for the safety assessment of AD systems for deployment in real-world environments.

In addition to the development of safety assessment methods, a TNO StreetWise pipeline is developed for the detection, identification and characterization of scenarios in large amounts of driving data, resulting from vehicles driving on the road with state-of-the-art sensor sets and data recording facilities.

The TNO StreetWise pipeline automatically processes driving data into activities, scenarios, parameters and statistics. New types of scenarios can be added quickly using the underlying framework. Python algorithms running in a cloud environment ensure flexibility and scalability. The pipeline is ready for connected vehicles as well (V2X, I2V). A web GUI provides easy access to the scenario database for extraction of OpenSCENARIO test cases, including the related Euro NCAP tests. Test automation is supported through an API, as successfully demonstrated with AVL ModelConnect, Vires VTD and Siemens Simcenter PreScan. Sensitive driving data can also be processed at the client's premises.

The objective of StreetWise is to develop methods and tools to support and accelerate the safe and responsible introduction of ADS technology onto the road. StreetWise considers the fast developments and innovations in automated driving such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, advanced sensors, and artificial intelligence (AI) algorithms. Assessment methods that are developed should be capable of dealing with such new innovations as well.

The core of the StreetWise method is a scenario database in which all parameterized traffic scenarios are stored. The scenarios have been identified from driving data collected from various fleets of data collection vehicles. Modelling scenarios in a parameterized way in computer-readable format provides the necessary input for smart simulation software and a means to calculate the residual risk of automated driving. TNO has developed its methodology such that it allows for building a collective scenario database among specific industrial partners who make their data available for this purpose, without exchanging sensitive driving data between the partners. This permits partners to scale up to a scenario catalogue that is complete for different cities, countries, and continents, without the need to run their own expensive testing or data collection campaigns in each of the regions.

3.2.4 Sakura

The SAKURA project (Safety Assurance KUdos for Reliable Autonomous vehicles) started in 2018 and is funded by the Ministry of Economy, Trade and Industry (METI) of Japan, under the strategies defined by the Committee on Business Discussions on Autonomous Driving Technologies.

The project develops scenario-based safety assurance methodologies, including a complete scenario generation process, tools and a scenario database linked to the SIP-adus Driving Intelligence Validation Platform (DIVP) virtual environment (https://divp.net/). The first phase of SAKURA, which ended in March 2021, focussed on harmonization of data acquisition, development of research methodologies, and coordination of standardization activities through joint efforts by the vehicle industry and traffic safety research institutions in Japan and abroad. Within this stage, the scope was limited to level 3 and higher systems and with a predominant focus on limited-access highways. The second phase, which commenced in April

2021 and is expected to last until 2025, builds on the outcomes of the first phase and extends the scope to urban areas with Urban vehicles (robotaxi) and shuttles.

The scenario-based approach incorporates physics principles in order to address the limitations of existing approaches concerning evaluation scope sufficiency and explainability in emergencies. Scenarios are decomposed and structuralized logically in consideration of the physics of the AD system, incorporating perception, traffic situation, and operation related disturbances. In this way, a complete coverage of all the safety-relevant root causes for a given DDT can be provided. The SAKURA project scenario generation and safety evaluation process are based on an adaptation of the adopted definitions for function, logical, and concrete scenarios developed initially by the German PEGASUS project (see 3.2.2 above). Several other activities include field operation tests that collect sensor data to feedback complex scenarios back into the database.

3.2.5 Safety Pool

The Safety Pool™ Scenario Database (SPSD) is a secure repository of the test scenarios for Connected and Autonomous Vehicle (CAV) technologies. The SPSD was developed to support the development and verification and validation of CAV technologies. The SPSD has been created as part of a collaboration between WMG, University of Warwick, UK and Deepen AI. SPSD is also supported by the World Economic Forum as part of their Safe Drive Initiative and the UK's Centre for Connected & Autonomous Vehicles (CCAV).

The primary role of the SPSD is to accelerate the pace of ADS technology development by providing an extensive database of test scenarios which can be used for testing Automated Driving Technology via simulation and in the real-world.

It will achieve this by facilitating the sharing of scenarios between organisations, regulators, and researchers and by being an integral part of the CAM TestBedUK ecosystem - assisting organisations with testing their ADS on CAM Testbed UK and other international testbeds and on simulation platforms.

The SPSD promotes the sharing of scenarios by facilitating the publishing of scenarios to public libraries within the SPSD, whilst organisations also have the ability to store scenarios which are private to them in order to benefit from the test planning tools offered by the database. Users are able to access the SPSD via a Web Application and there is an Application Programming Interface (API) to allow organisations to connect their existing testing infrastructure to the database so that they can download scenarios to feed into their testing toolchain.

3.2.6 ADScene (Moove)

ADScene is an open initiative undertaken by two OEMs, Renault Group and Stellantis, to industrialize and complement research assets coming from research projects conducted in the French Institutes of Technologies, VEDECOM Institute (MOOVE projects), SystemX (SVA, 3SA, SVR projects), and SAM Project, the French automated mobility initiative funded by the Ministry of Economy, the Ministry of Transport, of France, under coordination or the PFA (French Automotive Platform). The history begins in 2019, with the publication of a PFA position paper on the safety of ADS where French automotive industry recommends to capitalize all relevant safety scenarios for ADS design & validation.

Scenario based assessment is a key component of the safety argument for next generation of automated driving functions. However, automotive industry, regulatory bodies and researchers need to share a common view of what is a state-of-the-art scenario database.

ADScene has a multi-partner precompetitive approach requested to generate such an industrial database, a scenario library for AD/ADAS leveraging research projects.

3.2.7 ArchitectECA2030

ArchitectECA2030 is a research project based at the Ostfalia University of Applied Sciences in Germany, focused on developing advanced technologies for the testing and validation of connected and automated driving systems. The project is funded by the German Federal Ministry of Education and Research (BMBF) and involves collaboration with several partners from the automotive industry and research institutions.

The main goal of ArchitectECA2030 is to develop a comprehensive testing and validation framework for connected and automated driving systems that can be used by automotive manufacturers and suppliers. The framework includes a range of simulation tools and hardware-in-the-loop (HIL) testing systems that can be used to validate the performance and safety of connected and automated vehicles in various driving scenarios.

ArchitectECA2030 also aims to develop advanced sensor technologies and algorithms for connected and automated driving systems, including lidar and radar sensors, camera systems, and machine learning algorithms. These technologies are designed to improve the accuracy and reliability of vehicle sensing systems, which is critical for the safe operation of connected and automated vehicles.

Overall, ArchitectECA2030 is an important research project that aims to address some of the key challenges facing the development and deployment of connected and automated driving systems. The project's focus on advanced testing and validation tools and technologies is essential for ensuring the safety and reliability of these systems, which will be critical for the widespread adoption of connected and automated vehicles in the future.

4 GAP ANALYSIS

The above-mentioned indicative research projects show that there is still a gap in the creation of a methodology leading to a robust safety assurance framework. Some create a code of practice that feeds interested stakeholders with preliminary basic data on safety on the CCAM realm (L3Pilot, Hi-Drive), others focus on safety aspects around unexpected events (Events) or uncertainty compared to human behavior (i4Driving), while others tend to create a predictive safety assessment framework concentrating on pre-crash and post-crash safety (V4Safety).

Given that not many global complete safety assurance frameworks exist yet (the South Australian Government has created a complete framework [7] that deals with aspects like ODD, risk assessment, remote operation/control, security, functional safety, compliance, approval process, reporting), and that prestigious Research bodies do not propose such a framework (JRC approaches safety through the use of digital and smart tachographs [8], JARI focuses on aspects like traffic accident statistics, actual vehicles crash experiments, simulation test experiments, passive safety studies, safety evaluation of AVs [9]), it is evident that SUNRISE should explore existing methodologies and exploit any aspect that may be used in the project's methodology. For any other missing parts, novel elements shall be included based on the analysis from the four stakeholder groups and the experience gained by the project partners.

4.1 Homologation Technical Service Analysis

The Homologation process of an AD vehicle requires a new approach when compared to regular vehicles. The validation of these technologies is not only limited to the internal procedures of the manufacturers in order to provide a safe product, but to the official type approval as well. Requirements identified for the Homologation Technical Service use case, have been compared with other project approaches.

During HEADSTART project, several AD use cases were studied. For the testing and homologation procedures, some bases were established regarding the procedure and steps to follow. Theoretical provisions were developed on the querying procedure for the database to return "logical scenarios", even though this was not demonstrated. On the validation side, demonstrations on virtual validation and proving ground validation were executed almost completely. HEADSTART project did not consider any type of monitoring procedure. It would be for SUNRISE to define and demonstrate how a continuous monitoring of CCAM vehicles will be a key factor for a real deployment scenario.

On PEGASUS projects a clear safety argumentation process for AD has been under development. Starting with the requirements definition, the PEGASUS methodology, considers simulation validation. This virtual testing shall be accompanied with test track validation in those edge/critical cases. Tests with a high relevance regarding drive dynamics and real sensor performance should be executed on proving grounds. Within field tests, the behaviour of the driving features gets tested and the major target is to find "surprises" (i.e., new scenarios, new parameters). It is expected that in-service vehicle data will provide robustness to the process.

For STREETWISE project, a Proof-of-Concept scenario database has been developed that currently contains mainly motorway scenarios in 10 different categories, which have been identified from more than 110.000 km of driving on Dutch, German and Austrian roads. TNO has developed the StreetWise methodology such that it allows for building a collective scenario database among specific industrial partners who make their data available for this purpose, without exchanging sensitive driving data between the partners. For validation, TNO works together with its partners in StreetWise that perform the actual data collection. For each collected dataset, a part of data is manually tagged to compute recall and precision of the StreetWise scenario identification algorithms. This provides valuable inputs, not only for the partners in StreetWise but also for Homologation Technical Services and Type Approval Authorities.

TNO considers a scenario database that is complete (describes real-world scenarios well) and that can be used to provide high coverage of specific ODDs (provides a complete description of the ODD and beyond) as a key important factor for a valuable and reliable safety argumentation according to UN-ECE's multi-pillar approach.

In the SAKURA project, no provision on SCDB and querying has been identified. For the virtual validation, all logical test cases regarding scenario-based testing with high number of scenarios but low relevance on sensor performance should be virtually validated. Physical testing should be conducted on those pre-selected tests with high relevance on driving dynamics and sensor performance, or rare events hardly seen in open road. Open-road tests are identified as a high relevance regarding real system performance on a highly variating surrounding condition.

SAFTEY POOL project has already proposed the coverage range for scenario definition based on different standards, such as OpenSCENARIO. Moreover, some type of quality check for the scenarios has been defined, including semantical and synthetical revisions. System validation has been considered virtually, on test tracks, but also on public roads. Monitoring of AD vehicles is expected to continually add new scenarios to the data base based on near miss incidents. Even though SafetyPool considers the use of its scenarios for all the identified use cases above, no methodology outcome has been developed so it is for SUNRISE to provide it.

ADSCENE, on its side, is a scenario library. It does have some scenarios specific to regulations such as UNR 157 ALKS or scenarios to comply authorizing the operation of automated road transport systems. However, ADScene library does not include all the scenarios needed to comply to a particular regulation. No methodology outcomes are provided for the homologation procedure on this project; however, it is expected that using an incident management process, the performance data is fed back into the safety argumentation process so to improve the performance of the AD technology.

On Architect ECA2030, scenario coverage and standards have been identified only in a theoretical basis. For system validation, it is expected the use of virtual tests always using certified simulation tool for specific ODD attributes. The physical tests should complete virtual test for those ODD attributes which can be represented in the real world. Finally, for real world testing, same KPIs’ as for virtual and physical tests shall be used.

Summarizing all of the above projects, we can list the current gaps as follows:

- In-Service monitoring for CCAM: not only the extend of the in-service compliance but also the management of the data generated.
- Scenario Data Base querying procedure is still a poor considered project through out all the benchmark projects.

4.2 Consumer Testing (Euro NCAP) Analysis

It has been conducted a comprehensive gap analysis study by contacting the responsible for each of the benchmarked projects (PEGASUS, Sakura, HEADSTART, ArchitectECA2030, StreetWise, ADScene) to compare the coverage of stakeholder requirements for EuroNCAP defined in section 2.

HEADSTART, defined a PoC for EuroNCAP for the highway pilot use case. In this project, some scenarios for NCAP assessment were proposed and it was analysed how simulation could complement the rating. However, this was just a theorical approach and was not implemented by any demonstrator in the project. The part of scenarios database for EuroNCAP purposes was not considered in this project.

PEGASUS Family, focussed on developing a framework for safety assurance, but EuroNCAP was not considered in the project.

Within StreetWise, a list of scenarios is detected from the recorded / provided data. Some of those scenarios are also represented in the EuroNCAP test suite, where they have specific parameter settings. Regarding the test allocation of scenarios into different platforms, StreetWise didn't work on it because it's focus is on scenario databases.

Sakura, had a similar contribution like the one on Streetwise by considering EuroNCAP in their database but not defined any specific test methodology for those purposes. It's important to remark that some metrics were defined for scenario assessment inspired on the ones used in ALKS regulation.

Safety Pool, is one of the projects where EuroNCAP has been more considered. Safety Pool can manage EuroNCAP scenarios in the database and it's providing logical parameter ranges for test execution. It's important to remark that it is not limited to scenarios catalogue because it has also defined evaluation criteria and metrics for testing purposes (both virtual and physical testing). However, is not a test manager tool and can't be used to create an evidence dossier for EuroNCAP purposes.

In ArchitectECA2030, the main contribution for EuroNCAP purposes was the definition of a methodology to allocate scenarios in virtual environment and defining metrics for its assessment. However, nothing related to scenario database was defined in this project, despite it was analysed how much coverage individual NCAP scenario generate within the certification / homologation process.

ADScene is considering EuroNCAP as one of their stakeholders and potentially it will be possible to use it for EuroNCAP purposes. However, at the moment it has been defined a theorical integration but not demonstrated in a PoC.

Based on our analysis of the consumer testing assessment for the SUNRISE Framework, we have identified several areas that require improvement. To enhance the methodology, we recommend integrating Euro NCAP (European New Car Assessment Programme) into the framework.

Firstly, there should be a clear alignment between the framework and Euro NCAP regarding the specific scenarios that need to be considered for vehicles with higher levels of automation. It is essential to determine how these scenarios should be managed within the scenario databases, ensuring that the framework adequately addresses the safety requirements outlined by Euro NCAP.

Additionally, the framework should establish a way to complement physical testing with virtual testing specifically for Euro NCAP purposes. This approach considers the limitations of the technical service in performing physical tests and aims to incorporate new metrics that integrate both physical and virtual testing environments. This will allow for a more comprehensive evaluation of vehicle safety, considering both real-world scenarios and virtual simulations.

By integrating Euro NCAP into the SUNRISE Framework in these ways, we can enhance the methodology's effectiveness and ensure that it aligns with established safety standards. This integration will enable a more robust assessment of vehicle safety, taking into account the evolving landscape of automated vehicles and the need for comprehensive testing methods.

4.3 OEM Analysis

HEADSTART is the predecessor to SUNRISE. Its main objective was to find solutions for testing automated vehicles safety in three different scenarios: Traffic jam pilot, platooning and highway pilot. SUNRISE should target more a common safety approach than different specific solutions oriented to different scenarios with their corresponding proof of concept. Validation or verification methodologies connected to a specific database for definition/generation of test scenarios are not found in HEADSTART. SUNRISE should cover this gap, proposing a general validation/verification methodology able to get tests for virtual and physical testing when defining an ODD and thanks to the existence of a common data framework. Finally, SUNRISE should also target different scenarios, highway and urban, with key technology for AVs: Perception and decision-making system and corresponding sensors.

PEGASUS is a method that ensures safety of automated driving functions. Its focus was on the generation/definition of requirements based on different databases such regulations, field operational testing, user studies, … However, there is not a standardized way in how to input these data depending on the different possible stakeholders. SUNRISE should cover the gap gathering data from different stakeholders and finding a standard way to integrate those. From the OEM perspective, it is also key to not only focus on virtual testing, but perform physical testing with high relevance for vehicle dynamics, real sensor and algorithm performance.

STREETWISE develops methods and tools for the safe and responsible introduction of AD technology on public roads. Scenarios are used to describe any situation that an ADS might encounter during its lifetime. Depending on the ODD (as described by the OEM), the relevant tests are generated based on the scenario database. Real data is used being able to generate automatically tests for the corresponding scenarios. However, this test generation is only specific for OEMs and connected to a specific database. SUNRISE should allow to do a similar thing with the SDCB host. New unsafe scenario identified by OEMs while validating/verifying AD functions should be communicated to the SCDB host as an extension of the ODD with the corresponding parameters, so new tests could be generated.

SAKURA targets a scenario-based safety assurance methodology with a focus in physical characteristics related to AD functions: Sufficiency of sensors, algorithm, and actuator related measures. However, this is linked to a specific virtual environment with no physical testing. Physical testing is extremely important to cover sensor and algorithm insufficiencies. SUNRISE should provide a tool connected to a general data framework allowing to generate virtual and physical tests for a specific ODD. It would be important to determine which tests are to be performed virtually and which can only be done physically.

SAFETY POOL is not a safety methodology, but a scenario database for connected and autonomous vehicles technologies. The idea is to provide a common database that could be used by different actors for free, using and populating the database with new scenarios. Scenarios and ODDs are defined based on data and knowledge: accident data, insurance claim, telematics, real-world deployment, system analytical hazard analysis, system's behaviour, ontological modelling, standards/regulations/guidelines, and the rules of the road. SUNRISE should include all these possible stakeholders but keeping in mind than input and output to the database should be standardized. Another gap that should be covered by SUNRISE is definition of tests for virtual and physical testing, and to which specific sensors and algorithm the mentioned tests are related to.

ARQUITECTECA2030 is also a testing framework for connected and automated driving systems, including a range of simulation tools and being connected to a general database (they mentioned SAFETYPOOL as example). However, it only covers virtual testing, physical testing activities are not really in the scope of the project, except for some HIL proof-of concept. SUNRISE should cover physical testing, and this is extremely important to detect sensors and algorithm insufficiencies.

ADSCENE is also a common scenarios database used for AD design and validation by OEM. ADSCENE is an ecosystem open to all stakeholders of ADAS and ADS design, validation and homologation process. In that purpose, ADSCENE intends to propose a common scenarios Library in shared containers that include regulatory scenarios. Those test cases are used in virtual environments for the moment without gathering safety related metrics. SUNRISE should be able to generate tests for physical tests, and it should define relevant standard safety metrics depending on the ODD and specific AD function (sensor and algorithm).

To conclude, SUNRISE could be seen as a combination of all these different projects. It should provide a safety approach connected to a data framework able to generate both virtual and physical tests classified by AD algorithm and sensors and with relevant standard safety metrics. The data framework should have a standard way of inputting and outputting data, and the option of extending an ODD should be available either extending the current parameters or adding new ones. Data should be available for all the different combination of sensors and AD algorithm that we can find nowadays in the market, specifying which tests can only be done physically.

4.4 SCDB Host Analysis

The steps to be taken follow from the description of the state-of-the-art of Scenario Databases as provided in Chapter 3 and the application of the scenario databases as envisioned by SUNRISE, as discussed in the use cases for the SCDB-host in Section 2.2. This considers the following aspects:

1. The content of the scenario database (what information is contained in a scenario database):

    - To enable statistical analyses regarding completeness of scenarios or coverage of an ODD, based on inputs from multiple scenario databases hosted by different organisations, SUNRISE needs to support the harmonization of scenario descriptions and scenario parameterizations. Also, uniformity in the tags attributed to the concrete scenarios stored in the scenario database will drastically simplify the selection of scenarios from multiple scenario databases covering different regional areas. This includes a harmonization on the geographic location of the collection of scenarios, e.g., based on GPS positions.

    - It is also important to consider what information is used for identifying and characterizing scenarios in a database and what information is associated with each of the scenarios. For statistical analyses (e.g., to determine positive risk balance), it should be known what the exposure is of each 'concrete' scenario. In other words, how often does a scenario (within specific parameter ranges) occur on the road. Hence, such information should be available in the data. As an example, consider the collection of events by an event data recorder (EDR). An EDR does not continuously record data from a trip, but only stores those events (with a certain duration before and after an event) based on predefined triggers and thresholds. How to include other types of information (e.g., using EDR) into a scenario database should be determined in SUNRISE.

    - The outcomes of assessment based on scenarios in the database depend on the level of completeness of the database, or more precisely, in the completeness achieved by the combination of scenario databases for a given ODD. Consequently, it should be possible to calculate a metric for completeness of the scenarios for a given ODD considering the fact that scenarios might be extracted from different databases. It should be reported to the user, what part of the ODD is not represented well in case of insufficient completeness.

2. The architecture of the scenario database (how information is contained in a scenario database):

    - It is common practice to determine the set of test cases for safety assessment based on the scenarios that are relevant for the ODD of the CCAM system. It is foreseen that a single scenario database might not contain all scenarios to cover the ODD well. In other words, more than one scenario database is required to have sufficient completeness of scenarios for a given ODD. The architecture of a scenario database should allow searching and providing selections of scenarios that can be combined with selections of scenarios from other databases.

    - Search requests should be understood in the same way by the various scenario databases, and it should be possible to combine the output of selections of scenarios from different databases.

    - This does not only put requirements to the architecture of the scenario databases, but also puts constraints to the development of the 'federation layer', and the interfaces between the federation layer and each of the participating scenario databases.

5 CONCLUSIONS

5.1 Requirements for the SUNRISE SAF

This section summarizes the key requirements that must be considered during the framework's technical development, focusing on data management, scenario definition and coverage, simulation and testing methodologies, and monitoring systems. These requirements aim to address the needs identified from each stakeholder and provide a standardized framework that covers all their request. By emphasizing the technical aspects, SUNRISE aims to provide these stakeholders with the necessary tools and guidelines to contribute to the safe integration of autonomous driving technologies.

ID	Title	Description
UC_Homologation_001	Scenario Requirements for SCDB	Assessment of the most critical scenarios to be performed by a technical service in order to identify worst case scenarios to be tested.
UC_Homologation_002	Audit & Assessment Simulation	Virtual tests and simulations help to speed up and lower costs of the safety validation process. Therefore, any possible scenario that can be validated on virtual simulation tools shall be performed on this way
UC_Homologation_003	Audit & Assessment Physical Certification Test	Some functions need physical tests to be validated, therefore, worst case scenarios shall be reproduced and studied in physical test tracks.
UC_Homologation_004	Audit & Assessment Open Road Tests	AV on open road service led to a new horizon of possible scenarios which cannot be feasibly reproduced in test tracks nor simulation. Therefore, a real-world operation step on the safety validation process is needed. This step may provide new unexpected situations which were not reproduced on the test

		tracks and help to provide a clear view of the behaviour of the AV on real mixed traffic conditions
UC_Homologation_005	Monitoring	Following the EU 2018/858, vehicles under commercialization must follow market surveillance standards. Therefore, a monitoring process is to be defined for AV.

Table 3 Requirements for Homologation Technical Service

ID	Title	Description
UC_EuroNCAP_001	Scenario identification	The number of scenarios increases exponentially for high levels of automation and to have a test matrix covering all test cases is not feasible. It's necessary to have a methodology for defining test cases based in databases.
UC_EuroNCAP_002	Evidence dossier audit	Many test cases can't be replicated in proving grounds and it's necessary to give to the OEM room for demonstrating the proper performance of their systems by creating evidence dossiers.
UC_EuroNCAP_003	Select scenarios for virtual testing	Number of scenarios for high levels of automation is huge and virtual testing could be a good methodology for demonstrating the proper performance of the systems without the need of proving grounds.
UC_EuroNCAP_004	Metrics Assessment with new virtual methods	With the introduction of virtual methods, it's necessary to define specific evaluation criteria for EuroNCAP assessment due to limitations in correlation with real world testing.

UC_EuroNCAP_005	Proving ground testing	If new testing methods like virtual testing can be used for NCAP assessment, this could have an impact in the way how physical testing is being defined until now.

Table 4 Requirements for Consumer testing (EuroNCAP)

ID	Title	Description
UC_OEM_001	Verification method (scenario and allocation assessment)	Systems design and software undergo physical and virtual testing under known scenarios so bugs can be found early in the development cycle. These bugs can be corrected before the validation phase.
UC_OEM_002	Virtual defects	Virtual tests and simulations help to speed up and lower costs of the verification process. Therefore, any possible scenario that can be validated on virtual simulation tools shall be performed on this way.
UC_OEM_003	Physical testing defects	Some functions need physical tests to be validated, therefore, worst case scenarios shall be reproduced and studied in physical test tracks.
UC_OEM_004	Access and method for scenarios database	Possible defects/failures are already included in a database so those could be already considered in the design process of an AV functionality, making the development faster and bug-free.
UC_OEM_005	Validation method	Validation is used to ensure that a system is free from any unreasonable risks due to unknown hazards. Validation is also used to identify failures that did not appear during the verification process.
UC_OEM_006	Demonstrate safety statistics	Knowing safety metrics by different OEMs allows to focus research and innovation work in the right direction – e.g., perception system is the one causing

		most of the disengagement when driving autonomously.
UC_OEM_007	Communicate "unknown safety scenarios"	It is important to communicate this new ODD where a specific AD system fails to perform correctly, so this can be considered by others in their design specifications, paving the way to failure free AVs. This communication should be done to the corresponding SCDB with a parameter range extension or creations of new parameters for a specific ODD.

Table 5 Requirements for OEM

ID	Title	Description
UC_SCDBhost_001	Adding scenarios to the SCDB	A generic scenario-based methodology is provided for the safety assessment of CCAM systems. For CCAM safety validation, the SCDB needs to be complete for the addressed ODD. This puts requirements to scenario ontology, the data to be processed, the way of describing the ODD, the way of generating tests and the way of addressing the SCDBs through the federation layer.
UC_SCDBhost_002	Development tests by the OEM/CCAM developer	Already in the development phase of CCAM functionality, it is important for the manufacturer to have insight into the expected ODD of the function, and the large variety of scenarios and parameter ranges within the ODD.
UC_SCDBhost_003	Homologation tests	The SUNRISE framework allows not only access to a collection of SCDBs, it also allows the homologation authority to audit the process from introducing scenarios into the database to the generation of test cases. With SCDB metrics related to completeness (e.g., for a specific regional

		area) and coverage (e.g., for a specific ODD), as developed within SUNRISE, the statistical relevance of the tests used in the safety assessment can be determined and shared with the homologation authority.
UC_SCDBhost_004	Scenario research for the EC	Through the SUNRISE federated access, it can be more easily arranged to perform a scenario analysis over a larger region of interest.

Table 6 Requirements for SCDB Host

5.2 Targets for the SUNRISE SAF from Homologation Technical Service

In terms of in-service monitoring for CCAM, none of the benchmark projects fully addressed this aspect. SUNRISE needs to define and demonstrate the importance of continuous monitoring for CCAM vehicles, not only in terms of compliance but also in managing the generated data. Effective in-service monitoring is crucial for ensuring the safety and performance of AD technologies throughout their operational lifecycle.

Another significant gap identified across the benchmark projects is the lack of focus on the querying procedure for scenario databases. While several projects developed comprehensive scenario databases, there is a need for a well-defined and standardized approach to query these databases efficiently. The querying procedure plays a vital role in retrieving relevant and applicable scenarios for validation and testing purposes during the homologation process.

To bridge these gaps and enhance the SUNRISE Safety Assurance Framework, it is crucial to:

- Define and demonstrate the value of in-service monitoring for CCAM vehicles, encompassing not only compliance but also effective management of generated data. This includes establishing protocols for data collection, analysis, and utilization to improve safety and performance.

- Develop a standardized and efficient querying procedure for scenario databases. This procedure should enable easy retrieval of relevant scenarios for validation and testing, ensuring comprehensive coverage of operational design domains (ODDs) and real-world driving conditions.

Addressing these gaps will contribute to the development of a robust and reliable safety assurance framework for AD homologation. By emphasizing in-service monitoring and refining the querying procedure for scenario databases, SUNRISE can enhance the overall safety, performance, and trustworthiness of CCAM vehicles as they undergo the necessary validation and approval processes.

5.3 Targets for the SUNRISE SAF from Consumer Testing

The gap analysis study of the benchmarked projects revealed that while some projects considered EuroNCAP as a stakeholder and had some contributions, the majority did not focus on it as one of their main topics of research and were more focused on homologation or SOTIF topics.

Several areas were identified for improvement in the consumer testing assessment for the SUNRISE Framework, and based on our analysis, we recommend that the framework takes actions to integrate EuroNCAP in the methodology. Specifically, it should be included a clear alignment of which scenarios need to be considered for EuroNCAP for higher levels of automation and how they should be managed by the scenario databases. Additionally, the framework should define a way to complement physical testing with virtual testing for NCAP purposes, taking into consideration the limitations of the technical service to perform such tests and including new metrics that integrate both test environments.

5.4 Targets for the SUNRISE SAF from OEM

One of the primary targets for SUNRISE is to move away from specific solutions oriented to different scenarios and instead focus on a common safety approach. While its predecessor project HEADSTART explored safety testing in specific scenarios such as Traffic Jam Chauffeur, Platooning or Highway Pilot, SUNRISE aims to provide a unified methodology that can be applied across a wide range of scenarios, including both highway and urban environments. By focusing on key technologies for autonomous vehicles, such as perception and decision-making systems, and their corresponding sensors, SUNRISE seeks to ensure a comprehensive approach to safety.

Another target for SUNRISE is the development of a general validation and verification methodology connected to a common data framework. Analysed projects like PEGASUS recognized the importance of gathering data from various stakeholders, including regulations, field operational testing, and user studies. SUNRISE intends to fill the gap by establishing a standardized way to gather and integrate data from different stakeholders, ensuring a collaborative and inclusive approach. This data framework will serve as a foundation for generating virtual and physical tests and defining relevant safety metrics.

The SUNRISE framework also aims to address the need for physical testing alongside virtual simulations. While projects like STREETWISE and ARQUITECTECA2030 focused primarily on virtual testing, SUNRISE recognizes the importance of real-world testing to uncover sensor and algorithm insufficiencies. By providing tools and methodologies for both virtual and physical testing, SUNRISE ensures a comprehensive evaluation of autonomous driving systems' performance and safety.

Moreover, SUNRISE targets the establishment of a standardized scenario database, building upon initiatives like SAFETY POOL or ADSCENE. The framework seeks to incorporate a wide range of stakeholders, including accident data, insurance claims, telematics, real-world deployment, and regulatory scenarios. By standardizing the input and output of data and defining tests for virtual and physical testing, SUNRISE aims to create a comprehensive and accessible resource for the autonomous driving community.

5.5 Targets for the SUNRISE SAF from SCDB host

In conclusion, the development of a comprehensive and harmonized scenario database is crucial for the testing and evaluation of Connected and Automated Mobility (CCAM) systems such as CCAM systems. The SUNRISE project emphasizes the importance of considering both the content and architecture of the scenario database to ensure its completeness and usability.

Regarding the content of the scenario database, harmonization of scenario descriptions and parameterizations is necessary to enable statistical analyses across multiple scenario databases from different organizations. Additionally, uniformity in scenario tags and the availability of exposure data for each scenario will simplify the selection and assessment of scenarios.

Regarding the architecture of the scenario database, it is essential to develop a federation layer that allows searching and combining selections of scenarios from multiple databases to achieve sufficient completeness for a given ODD. Consistency in search requests and interfaces between the federation layer and participating scenario databases is also critical.

Overall, the SUNRISE project emphasizes the need for collaboration and standardization among stakeholders involved in the development of scenario databases to ensure that CCAM systems are thoroughly tested and evaluated under realistic driving conditions, ultimately leading to increased safety on the roads.

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