AWARE2ALL

D1.1 CRITICAL ACCIDENT SCENARIOS AND HIGH-LEVEL REQUIREMENTS

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About AWARE2ALL

Facing to the challenge of future highly automated vehicles, where occupants can freely orient themselves to engage in non-driving activities. This new environment prompts questions about how car occupants will actually sit, what activities they will engage in, and how they will be informed through the HMI to keep them in the loop if necessary.

AWARE2ALL aims to pave the way towards Highly Automated Vehicles (HAVs) deployment in traffic, by effectively addressing the changes in road safety and changes in the interaction of different road users caused by the emergence of HAV through the development of innovative technologies along with the corresponding assessment tools and methodologies.

AWARE2ALL will develop safety and HMI systems that will be interrelated through achieving a holistic understanding of the scene to ensure safe operation of the HAV. AWARE2ALL proposes a common conceptual universal safety framework for considering Human Machine Interaction (HMI). The project will be built on the results of projects funded under H2020 and other R&D programmes addressing the identification of new safety-critical situations and the most likely positions and postures considering the expected HAV applications.

The main objective of AWARE2ALL is to address the new safety challenges posed by the introduction of HAVs in mixed road traffic, through the development of inclusive and innovative safety (passive and active) and HMI (interior and exterior) systems that will consider the variety of population and will objectively demonstrate relevant improvements in mixed traffic safety.

AWARE2ALL includes 16 partners from 6 EU Member States (ES, DE, GR, NL, FR and SE) and 2 associated countries (TR, CS) and it is complemented by the International Advisory Board (IAB) representing key stakeholders that covers the full research and industrial development automotive value chain, more specifically in the CCAM field.

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Executive Summary

In the framework of AWARE2ALL, Work Package 1 aims to define the critical scenarios and safety aspects of the AWARE2ALL project. During the development of activity T1.1 and T1.2, potential future safety-critical situations and risks for occupants and Human Road Users (HRUs), will be evaluated to ensure the safety of Vulnerable Road Users (VRU) and occupants. For this purpose, the activity has been focused on identifying the new situations that the project will face, with the inclusion of Autonomous vehicles to the traffic, identifying appropriate measures and indicators to any potential hazards. This activity is the starting point of T1.3 that will develop the detailed project use cases, based on which the project developments and testing will be performed.

The Description of Action (DoA) describes this deliverable as: "This document will report the critical scenarios, their parameters and accident types identified in T1.1, and the safety risk analysis and high-level KPIs and high-level system requirements for the risk mitigation in T1.2. Linked to T1.1 and T1.2.".

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Acronyms and terms

Acronym	Meaning
AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
ALKS	Automated Lane Keeping Systems
ATD	Autonomous Test Driving
AVAS	Acoustic Vehicle Alerting System
CAV	Connected and Automated Vehicles
DDT	Dynamic Driving Task
DMS	Driver Monitoring Systems
eHMI	External Human-Machine Interface
HAVs	High Automated Vehicles
HDV	Human-driven Vehicle
HGV	Heavy Goods Vehicle
HMI	Human-Machine Interface
HRU	Human Road User
iHMI	Internal Human-Machine Interface
LiDAR	Laser Imaging Detection and Ranging
ODD	Operational Design Domain
OEDR	Object and Event Detection and Response
OEMS	Original Equipment Manufacture
OLED	Organic Light-Emitting Diode
OMS	Occupant Monitoring Systems

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SAE	Society of Automotive Engineers
SIA	Social Impact Assessment
SSH	Social Sciences and Humanities
VRU	Vulnerable Road User

1. Introduction

In the mobility sector and the automotive industry, technological breakthroughs are being made in the development of autonomous vehicles. The implementation of HAVs in transport networks provides great potential advantages regarding the safety and efficiency of mobility systems. However, this new paradigm also implies important challenges in terms of coexistence with other elements of the environment in mixed traffic areas. Addressing these challenges requires a holistic understanding of the scene.

Among the key elements interacting with HAVs are the human beings themselves, who are considered Human Road Users (HRUs). Regarding the study of the interaction between vehicle and HRUs, one of the key factors in the approach will be the inclusion of heterogenous population, including diversity of profiles that are not taken into consideration normally in the case studies, and we have encountered challenges that will need to be addressed for the inclusion in society.

Thanks to the new functionalities offered by autonomous vehicle technology, the system itself can take over the driving tasks, so that the role of driver is no longer necessary. In this new context, there are new activities that people can carry out inside vehicles. However, in some circumstances and depending on the level of autonomy of the vehicle, the system may require a person to take control. Therefore, it is very important to define these new situations and roles that occupants can play. It is necessary to investigate what new postures and actions should be considered and how the iHMI system can alert the occupants in case of need. The needs of people outside the vehicle, considered Vulnerable Road Users (VRUs), must also be considered.

In this first phase of the AWARE2ALL project, the aim is to identify the most critical scenarios and new types of accidents arising from the introduction of HAVs in a mixed traffic environment, as well as to define the safety parameters for humans, both inside and outside the vehicle.

This document compiles the research carried out in *T1.1 Critical scenarios and accident types* and *T1.2 Occupants and VRUs safety parameters identification and high-level system requirements with KPIs* within *WP1 Critical scenarios, new accident types, use cases and risks.*

The document's structure is composed of the following sections:

- **Section 1** introduces the AWARE2ALL overview and main objectives.
- In **Section 2**, the current context and challenges of HAVS are defined in the state of the art.
- **Section 3** defines the objectives and partners of each Demonstrator, which will be the development and final objective of AWARE2ALL.
- **Section 4** describes the methodology that will be followed for the critical scenarios and KPI definition.
- **Section 5** defines the parameters to be considered for defining the scenarios.
- **Section 6** provides a more detailed definition of the functional scenarios where the use cases will be carried out.

- **Section 7** highlights the new types of accidents that may occur due to the entry of HAVS on the road.
- **Section 8** focuses on the safety parameters to be considered for defining HAVS and the according requirements and KPIs.
- **Section 9** explains the workshops carried out during the task activities and feedback received.
- Finally, in **Section 10**, the conclusions drawn from the deliverable.

2. Current situation and challenges

To properly define the critical scenarios and the type of accidents we face with the introduction of the autonomous vehicle on the roads, it is necessary to first study the current market situation and analyze the challenges that will arise.

This first analysis will also help us to identify the occupants and VRUs safety parameters and the high-level requirements to be considered

2.1. Market introduction

Before diving into new accident types, it's important to consider what kind of vehicles are expected to be introduced on the market and when. This introduction is mainly dependent on the availability of technological solutions in combination with applicable regulations. Additionally, the expected benefits of these new vehicles will stimulate the introduction to start around certain use cases.

In this chapter the most important aspects of Connected and Automated Vehicles (CAVs) introductions will be discussed:

- Technological readiness
- Regulatory readiness
- Affordable solutions
- Economic benefits
- Social benefits

Before diving into describing the project's estimate on the market introduction of CAV, we should shortly recall the Society of Automotive Engineers (SAE) levels of automation [1] and take current developments in using these levels into account. SAE J3016 describes different levels of vehicle driving automation systems that perform part or all the dynamic driving task (DDT). It provides definitions for six levels of driving automation, also depicted in Figure 1. SAE Levels of Driving Automation:

- Level 0: No Driving Automation
- Level 1: Driver Assistance
- Level 2: Partial Driving Automation
- Level 3: Conditional Driving Automation
- Level 4: High Driving Automation
- Level 5: Full Driving Automation

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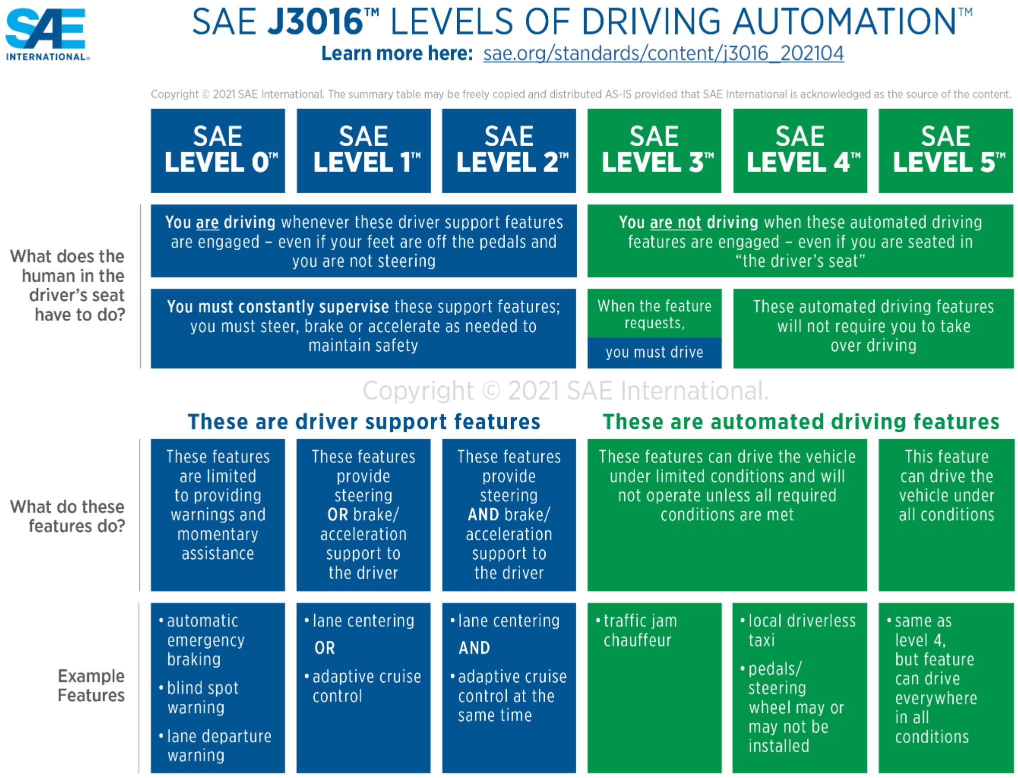

Figure 1. SAE Levels of Driving Automation [2]

The main pillars defining the levels are:

- Who/what performs the normal DDT (i.e., lateral, and longitudinal vehicle motion control)
- Who/what performs Object and Event Detection and Response (OEDR)
- If/who/what performs a fallback level in the event of system failure or reaching the end of operational conditions
- Complexity of the Operational Design Domain (ODD)

AWARE2ALL focusses on automated driving systems from L3 and higher.

2.1.1. Technology Readiness

Very high promises were made about the introduction and evolution of automated driving in the beginning of the century. However, the required technological evolution did not fulfil this promise. Only since last year, 2022, the first L3 systems are available in series production vehicles (Mercedes and Honda). Soon to be followed by e.g., Hyundai and Volvo Cars. The L3 systems are currently limited to lower speeds (up to 60 km/h), on well-defined highways in a traffic jam and under good weather conditions. Going towards higher speeds and even L4 automation systems will entail multiple complex challenges.

Therefore, OEMs are currently putting their development efforts and results in bridging the gap between L2 and L3 automation, resulting in so called L2+ automated vehicles [3]. These

L2+ vehicles are equipped with advanced L2 functionalities and will be able to drive automatically in a larger variety of situations, but with the need for the driver to monitor the driving task and most importantly: to take over control within a very short timeframe when automation fails. Removing the driver from the driving task and therefore completely relying on automation, makes the transition from level 2 to 3 or even higher automation levels complex. In L3 automated vehicles the system needs to be able to predict when the driver needs to take over and whether the driver is able to take over automation at all. These additional requirements, which are not applicable for L2 or L2+ automated vehicles, are complex challenges, which will probably not be solved within the coming years. Therefore, the trend has become to keep the driver in the loop, although the control itself will be more and more automated. In this way, OEMs can implement their results from L3 and L4 automation system development and have return on these development cost, while improving the driving experience using assistance systems.

In the European project L3Pilot, a large pilot of SAE L3 automated vehicles was performed on roads all across Europe. These so-called motorway and traffic jam chauffeurs were able to drive automatically on the road between other traffic participants, showing the readiness of these vehicles to enter the market. However, results show that these automated vehicles do not drive automatically for extended periods of time [4]. The European project Hi-Drive [5] will continue the research in a follow-up project where they aim to increase the ODD and find a widespread and continuous ODD on European roads.

Looking into the technology roadmap on CCAM of the ERTRAC Working Group: "Connectivity and Automated Driving", their vision on vehicles in 2050 includes 100% real-time connectivity on the relevant road network. All new vehicles will have a certain level of automation:

- Most shuttles, busses and delivery vehicles in cities operate autonomously, to a certain extend supported by a control center (i.e., L4-like)
- Personal transport is L4 on highways
- Support systems (i.e., L1/2) have evolved to give support in almost all driving scenarios to assure zero crashes and further reduction of emissions.

To reach this state, the main technical challenge is seen in situation awareness, in which AI has a big share. Future developments need to consider not only improvements in capabilities and trustworthiness but also the resources required, such as heavy computing which results in high power consumption and the necessary IT infrastructure.

As an implementation roadmap towards 2050, an incremental deployment view is given along implementation areas, mainly due to the complexity of probable scenarios in these areas:

- Highway and corridors
- Confined areas
- Urban mixed traffic
- Rural roads

2.1.2. Regulatory Readiness

The introduction of SEA L3 and higher levels of automated vehicles on the market is dependent on the regulations of these new systems. A distinction can be made between two different kinds of regulations: regulations pushing new ADAS to be integrated in vehicles entering the market and regulations allowing cars with higher automation systems to enter the road. An example of the first regulation is the new Vehicle General Safety Regulation [6] which requires OEMs to integrate several ADAS in new vehicle types from Summer 2022 and in new vehicles from July 2024.

The new Vehicle General Safety Regulation has come into force on July 6th, 2022. Since then, new vehicle types must be equipped with:

- Intelligent Speed Assist: a system which warns the driver if the speed limit is exceeded. This information is obtained via integrated cameras or GPS maps.
- Reversing detection with cameras or sensors.
- Attention warning in case of driver drowsiness: a system that measures the alertness of the driver and warns the driver if necessary.
- Emergency stop signal: a light signaling function to warn other road users in case of an emergency.
- Cybersecurity measures: measures to protect vehicles against criminals using electronic data.
- Emergency lane keeping assistance (Only vans and cars): a system which assists the driver in keeping a safe position with respect to the lane or road boundary and warns the driver in case of a lane departure.
- Advanced emergency braking (Only vans and cars): a system that detects a potential upcoming collision and automatically decelerates the vehicle.
- Event data recorders (Only vans and cars): a system to record critical crash-related parameters before and during a crash.
- Detection and warnings to prevent collisions with pedestrians or cyclists (Only busses and trucks)
- Tire pressure monitoring systems (Only busses and trucks)
- The following systems should be progressively in new vehicles between July 2024 and July 2029:
- Advanced driver distraction warning: a system which helps the driver to pay attention to the traffic situation and warns the driver when he/she is distracted.
- Safe and longer lasting tire performance
- Safety glass (cars and vans)
- Improved direct vision to better see cyclists and pedestrians (Busses and Trucks)
- Event data recorders (Busses and Trucks)

Making these systems mandatory will have a large impact on the number of vehicles on the road with these L2 automated systems. Bekkum et al. [7] estimated the share of vehicles equipped with automated lane keeping increasing in the Dutch Fleet from about 10% in 2021 to 80% in 2038. A penetration rate of 100% will probably be reached after 2050, when the complete fleet is replaced by new vehicles, see also Figure 2.

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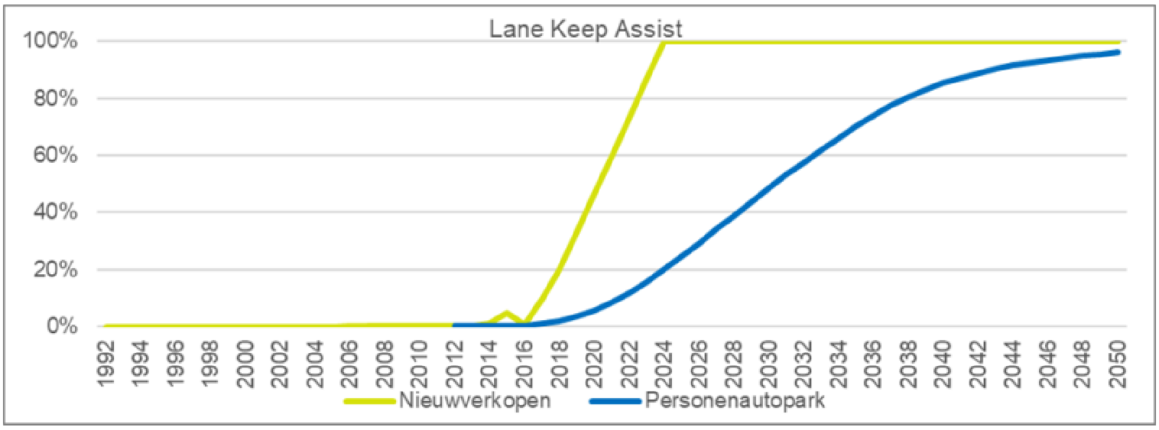

Figure 2. Development of penetration rate of automated vehicles in new sales (green line) and Dutch fleet (blue line)

With an increasing amount of level 2 automated vehicles on the road, these systems are expected to become more mature over time.

EuroNCAP is improving their protocols to assess higher levels of automation, as announced in their Vision 2030 [8]. They believe that assisted and automated technologies will play an increasingly important role in reducing traffic accidents and assessing these functionalities, including V2X-communication, will become even more important in fully automated vehicles. Their protocol, with penalties and rewards based on the performance of assisted driving technologies, will push OEMs and TIER1 suppliers to improve their systems further. EuroNCAP believes that it is highly likely that autonomous cars will be introduced in the next decade, although they foresee difficulties in standardizing test protocols for automated vehicles. Especially if automated functions are designed to operate within a certain ODD, which may differ from one vehicle type to another.

The UNECE has made large steps in the recent future with the UN-Regulation No. 157: uniform provisions concerning the approval of vehicles regarding Automated Lane Keeping Systems (ALKS). The ALKS regulation states that automated systems are allowed to control the lateral and longitudinal movements of the vehicle for extended periods of time without supervision of the driver. In other words, when the ALKS is active, the system should perform the driving task, including handling failures, without a driver monitoring these functions. However, the driver could decide to take back control at any time. The system may only be activated under certain conditions and on certain predefined roads, such as motorways without oncoming traffic or pedestrians. At first, the system is limited to only operate at speeds until 60km/h. Additionally, the regulation includes requirements for the HMI in the vehicle.

Although this regulation provides support for the assessment of higher levels of automation, it is often not specific enough to be used in the assessment of these vehicles by road authorities. The regulation provides requirements for the system, but no specific measures to be used in the assessment. For example, the regulation states that 'The means of deactivating the system shall provide protection against unintentional manual deactivation', but how to measure whether a button is pressed unintentionally, and which thresholds need to be met, is open for interpretation. In the coming years, road authorities are expected to concretize these requirements into measurable quantities, which Is needed for a standardized assessment of these vehicles on large scale.

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The ALKS regulation makes it possible to have the first L3 automated vehicles introduced on the road from Summer 2022. The Mercedes S-class is the first vehicle which is now driving on the German road with 'Drive Pilot': a system which is allowed to drive fully automated in stop-and-go traffic on the motorway below 60km/h, without supervision of the driver [9]. Other high-end vehicles are expected to follow in the coming years. This regulation can be seen as the first step into the regulation of higher levels of automated vehicles on the road.

2.1.3. Affordable solutions and related benefits

First, there are the different kinds of vehicles and their respective use. Different ownership, use and expectations of certain vehicle types lead to different expectations on automation and above all, different benefits. Following, a difference can be made on what is inside: people or freight.

For freight (a good overview of current status is given by Richard Bishop [10]): off road use cases are not within focus here (mining, construction, agriculture, logistic centers, etc.), as they typically are outside of the public domain and interaction with other road users are avoided, limited or orchestrated (e.g., via specific local rules). However, development from this area may transfer to automated driving. Currently there are many initiatives in 'late-stage' pilots, meaning that actual use of these kind of vehicles is close. The on public road automation of trucks is considered technically feasible, when the routes are known very well (drayage with short stretches on public road and hub to hub transport on the highway). Many trials are currently running or starting up with these L4 trucks in the US, mostly still with a safety driver (this is better than L2).

One special case of automated driving for HGV especially pursued in the recent years, has been platooning. Currently this technology is driven by non-conventional companies (see e.g., Locomotion [11]). The typical OEMs and suppliers seem to concentrate more upon L4 driving on yards/confined areas and in hub-to-hub operation (see e.g., the EU-project MODI [12]).

The use case is mainly driven by driver shortage and thus cost saving in that area, which may be quite significant. Moreover, compared to the whole cost of an HGV, the cost for the automation system is less in percentage than for instance for a private car.

For people: this can again be subdivided into private car, shared vehicle, public transport, and taxi. For a privately owned vehicle, the cost of automation will be relatively high, which will result in limited market uptake especially when the benefits are also limited (which depends on the level of automation): less driver stress, increased productivity. The shared autonomous vehicle may be cheaper but is less convenient and comfortable than a private one. It has the same expected benefits as for the privately owned automated vehicle.

Moreover, shared vehicles without L3/4 automation have been available for years already, but do not seem to have a large market share now. It has the same expected benefits as for the privately owned automated vehicle. For automated taxis and public transport, the benefit is mainly in saving driver cost.

2.1.4. Social benefits

CAVs are likely to have significant impacts on our society, providing multiple opportunities. In general, the impact of such technological innovation on the social dynamics is an ever changing

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and multi-faceted field of research and the analysis of socio-economic effects of CAVs is gradually growing attention, given its significance for both businesses and the life of citizens.

Wide socio-economic impacts can be already associated to these technologies, like an increase in safety (through reduced road accidents and human errors), an improved accessibility (not only for related to physical disabilities but in general for persons with limited transport access, opening up independent mobility and helping achieve better health, social and economic outcomes), a growth in productivity (by changes in the value of travel time) or a transformation of current transport-related jobs (e.g., professional drivers) [13].

To take fully advantage of such opportunities, local and transport authorities have the vital and necessary task to integrate CAVs in their transport and spatial plans, while a Social Impact Assessment (SIA) could also measure their influence on different social groups. This social aspect is often neglected in transport research, policy, and practice [14].

However, CAVs could also bring negative implications, as they could also strengthen inequality and/or social division, like in the case leading to different levels of services for different users or to a widening of the digital gap [15]. CAVs could also lead to traffic and emissions increase, because of safer travel, new users and new usage patterns mentioned above [16], as well as raise important ethical considerations and dilemmas [17].

To this extent, the analysis of their socio-economic implications remains an area to be explored, with further analysis required to cover the gaps, especially within the European Union, so that anticipatory strategic actions can be made with extensive knowledge of the possible consequences of adopting different measures.

In general, CAVs and CCAM bring new policy and regulatory challenges for both the European Commission and Member states on several areas, such as road safety, environment, competitiveness and jobs, societal and ethical issues, raising the need for the development of a new coherent legal framework for systems that do not yet exist, without obstructing innovation.

2.1.5. Wrapping it up

Ford CEO Jim Farley summarizes it quite well: “Profitable, fully autonomous vehicles at scale are a long way off” [18]. The Victoria Transport Policy Institute gives a good high-level overview for autonomous vehicle sales, fleet travel and benefits [19]: see Figure 3.

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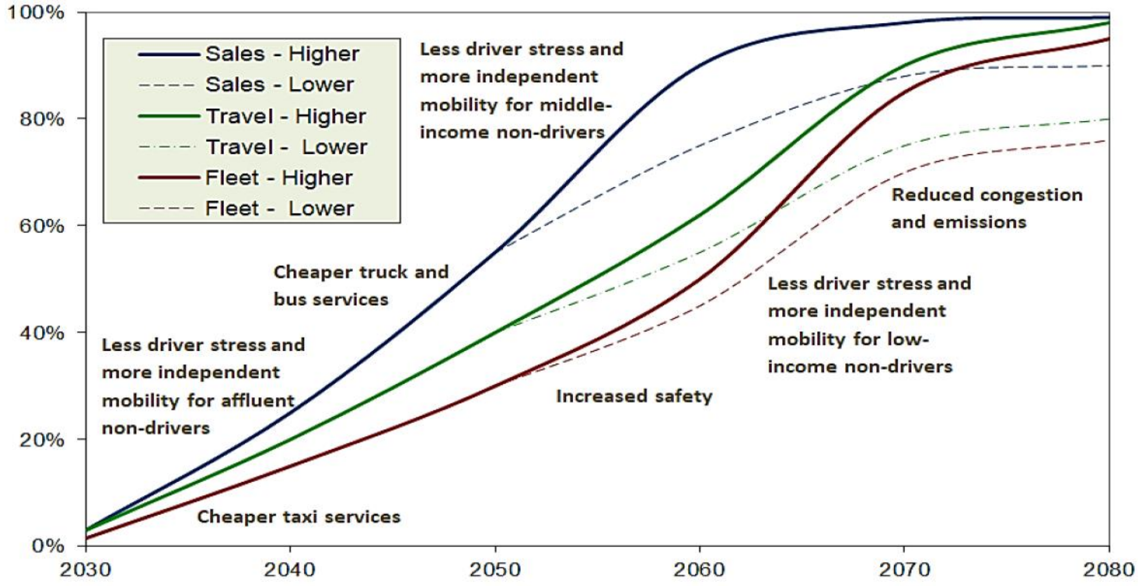

Figure 3. Autonomous vehicle sales, fleet travel and benefits [18]

The forerunner in development of automated driving currently is for HGVs, as benefits are most clear there. Probably followed by taxis (in the US) and public transport (Europe). Where latter also very much depends on governmental policies on car ownership, parking, etc.

Regarding cooperative driving, this seems to be quite out of the picture at most developers (OEMs, suppliers and new-commers). Many actions have been made to e.g., standardize the whole chain (e.g., for ITS-G5), now it awaits implementation. Where latter suffers from the penetration rate drawback (why investing in a communication device, when it cannot be used; there is no benefit for the first owner) on the one side and the high cost needed to update/implement the infrastructure on the other side. Lastly, to move forward into cooperative driving, i.e., cooperative world modelling (sharing observations) and cooperative maneuvering, the technology for quality of and trust in data needs a big leap forward.

2.2. Challenges

Operating a Highly Automated Vehicle (HAV) in mixed traffic is a complex task due to the interactions with often-unpredictable objects such as other road users like vehicles, pedestrians, cyclists, and animals. Despite many attempts to forecast the future penetration rates of HAVs, the bandwidth of these rates is very high due to the high level of uncertainty. An optimistic scenario considers a penetration of 15% by 2030 and 40% by 2040.

As with previous vehicle technologies, autonomous driving (AD) technologies will initially be expensive, thus shared autonomous vehicles, long-haul buses, and freight trucks can be considered as the first applications for HAV deployment in traffic. Shared vehicles provide the opportunity for independent mobility for people who cannot or should not drive, such as visually impaired people, but their uptake must be ensured with safety features that users are not familiar with.

HAVs are expected to improve road safety since human error contributes to approximately 90% of crashes [20]. They can also represent an alternative to high-risk drivers, such as senior drivers. However, AD technologies may introduce new risks, such as those derived from unconventional seating positions and occupant postures, and mixed traffic may present new safety-critical situations that must be properly identified and addressed. This can be done by allowing the vehicle to detect situations of risk in advance to avoid them and developing occupant protection mechanisms to reduce the impact in case of a non-avoidable accident.

A crucial factor to consider for the safe uptake of HAVs is efficient human-machine interfaces (HMI) to ensure that users can operate the vehicle when a handover is necessary. Communication with other road users can also improve safe operation, especially in mixed traffic.

An analysis of available data for 2020 [21] gives insight into current type of road users involved in fatal crashes, their locations, and the gender and age of victims. Overall, 52% of road traffic fatalities occurred on rural roads, versus 40% in urban areas and 8% on motorways. Car occupants (drivers and passengers) accounted for 43% of all road deaths while pedestrians made up 20%, users of powered-two-wheelers (motorbikes and mopeds) 18%, and cyclists 10% of total fatalities.

Within urban areas, the pattern is different, with pedestrians (37%) accounting for the largest share of victims. Users of powered two-wheelers made up 18%, and an increasing number of cyclists (14%) being killed, meaning that almost 70% of total fatalities in urban areas are vulnerable road users.

Men accounted for three out of four road deaths (77%). The elderly (65+) accounted for more than a quarter (28%) of all fatalities, although proportionally more young people are killed on the roads. While 12% of those killed on EU roads were aged between 18 and 24, this age group represents only 7% out of the EU population, meaning that young people are more likely to be involved in a fatal road collision.

To comprehensively address the issue of accidents involving autonomous vehicles, a systematic process will be undertaken, beginning with identifying the root cause of the accident. This process involves categorizing the cause into one of three categories: human error, autonomous vehicle errors, or interactions between the autonomous vehicle and its environment.

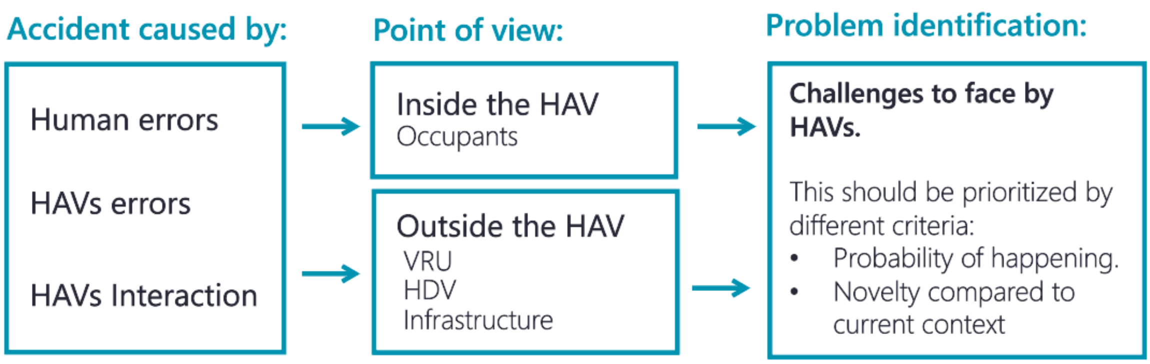

Figure 4. Causes of accidents and problem identification

It is essential to note that the classification of these causes depends on the perspective from which one views the situation. From the perspective of the vehicle's occupants, the cause may

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impact them directly, but from an external viewpoint, the surrounding users, other drivers, and even the infrastructure may be affected.

Once the cause of the accident and the relevant perspective to focus on have been determined, the specific types of challenges or problematic situations that the vehicle may encounter will be identified. From there, these situations will be prioritized.

2.2.1. Caused by Human errors

The outcome of human errors in the context of autonomous vehicles can be viewed from various perspectives, such as on the road, on the pavement, or inside the vehicle. These errors have the potential to affect multiple actors and represent significant challenges that need to be addressed by autonomous vehicle technology.

To effectively prioritize these challenges, we will consider criteria such as novelty and probability. By focusing on the most critical and relevant challenges, we can develop targeted solutions that address the root causes of human errors and enhance the safety and reliability of autonomous vehicles.

2.2.2. Caused by HAVs interaction problems

The interaction and communication of Highly Automated Vehicles (HAVs) with their surroundings can be categorized based on the interlocutors involved, namely: those on the road, those on the pavement, and those within the HAV itself.

Such errors in interaction and communication may pose challenges for various stakeholders, and it is imperative for HAVs to overcome these challenges. Prioritization of these challenges may be carried out based on the criteria of novelty and probability.

2.2.3. Caused by HAVs failures

HAVs are equipped with complex technology, including sensing and actuation systems that allow them to recognize the environment to steer the vehicle as safely as possible. This category includes possible failures of individual components, either in their own operation or in the communication between them.

In this research, this type of failure has not been considered because the aim of the project is not the development of the autonomous vehicle itself but the investigation of how it interacts with the elements of its environment, and more specifically with the HRUs.

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3. AWARE2ALL Demos

Four demonstrators are envisioned to validate the different technologies developed within the projects, mainly active and passive safety systems, i-HMI and e-HMI, in addition to Occupant Monitoring Systems (OMS). The distribution of the technologies through the demonstrators is shown in Table 1

Table 1. AWARE2ALL demonstrators

Demo #	Name	Test platform	Comments
Demo 1 (D1)	Passive safety	Virtual (Shuttle)	N/A
Demo 2 (D2)	Active safety	Physical (Shuttle)	No driver
Demo 3 (D3)	Active safety + iHMI + OMS	Hybrid (Vehicle)	Driver available
Demo 4 (D4)	eHMI	Physical (Vehicle)	N/A

3.1. DEMO 1 – Passive Safety

The virtual demonstrator D1 will show the simulation model of an L5-shuttle with 4 seats, two in driving direction and two rearwards facing. The new adaptive restraint system will be used for decreasing the injury behavior in all seating positions considering also handicapped people. The validation of the injury reduction potential as well as the impact of pre-crash actuation to the passenger's position and motion and the potential of crash-structure optimization versus active safety measures will be performed during crash simulation in urban driving conditions (main use case for L5-shuttle).

Table 2. Main technologies per partners in Demo 1

Partner	Main technologies
DLR (Lead)	Passive safety virtual demonstrator model "UMV" with novel crash architecture for new scenarios
THI	Adaptive restraint system for different seating positions
ESI	Simulation tool support to link active safety (pre-crash) with passive safety parameters

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HUM	Support advanced ATD simulation for passive safety

3.2. DEMO 2 – Active Safety

This demonstrator features TECN shuttle (see **Error! Reference source not found.**), with L4 capabilities at low speeds, designed for functional safety. This advanced shuttle has been equipped with state-of-the-art perception and control strategies that enable it to perform critical maneuvers such as emergency braking and lateral obstacle avoidance.

One of its unique features is the ability to use the weight distribution of its passengers as input to optimize its response to emergencies. This information is processed by the control system to enhance the shuttle's ability to perform critical maneuvers and ensure the safety not only of the vehicle and other road users but also of the passengers inside the shuttle.

The objective of this demonstration is to highlight the immense potential of autonomous shuttles in enhancing the safety, efficiency, and sustainability of transportation.

Table 3. Main technologies per partners in Demo 2

Partner	Main technologies
TECN (Lead)	L4 Shuttle prototype Fallback strategies (longitudinal and lateral)
THI	Trajectory optimization based on risk evaluation (same as in Demo 3)

Figure 5. Shuttle with SAE L4 that will be used in the Demo 2.

3.3. DEMO 3 – Active Safety (with driver)

The objective of this demonstrator is to allow the monitoring of the driver state, and to propose an adapted HMI in terms of information quantity, sensory modalities, and their synchronization.

The demonstrator is also used to test multimodal HMI configurations. To do so, the cockpit is equipped with screens (cluster, central display, HUD, steering wheel, and mirrors), LEDs (side windows, windshield, steering wheel), speakers (cockpit + headrest), and driver's seat haptic actuators. Haptic feedback in the steering wheel can also be controlled using a Sensodrive motor.

Figure 6. Hybrid test platform for Demo 3

Table 4. Main technologies per partners in Demo 3

Partner	Main technologies
IRTSX (Lead)	Multi-level (L0-L4) vehicle 2 possible configurations: shared vehicle (with driver), autonomous shuttle (no driver)
TNO	Situational awareness estimation of the driver based on (at least) gaze behavior and predefined areas of interest
THI	Trajectory optimization based on risk evaluation (same as in Demo 2)
TECN	Haptic feedback via steering wheel and pedals Control strategies for take-over maneuvers and driver support

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GEST	Occupant monitoring systems to detect Seat Occupancy Hands On steering wheel (Body) Key points Body pose
VICOM	Driver monitoring systems, including distraction detection, drowsiness estimation and low-level feature extraction as face and body landmarks.
SYR	Define the specification of the system-wide state machine, as stated in T3.3 Contributor to HMI Android Automotive platform, as stated in T3.4 Lead the system verification, as stated in T3.4 Can contribute to iHMI SW design
CEA	Seat integrated haptic feedback

3.4. DEMO 4 – eHMI

This demonstrator will utilize a Seat Cupra (see Figure 7) to showcase the integration of out-of-vehicle perception and HRU safety mechanisms. The demonstrator will incorporate a Surround View System (SVS) with a multimodal communication interface with eHMI, along with AI-driven HRU diversity detection, attention recognition, and intention prediction mechanisms. In addition, the algorithms are designed to facilitate advanced detection of HRUs through the use of photorealistic synthetic data, thereby enabling a more comprehensive representation of VRUs. Moreover, an external visual and audio communication system will be implemented to efficiently communicate with VRUs.

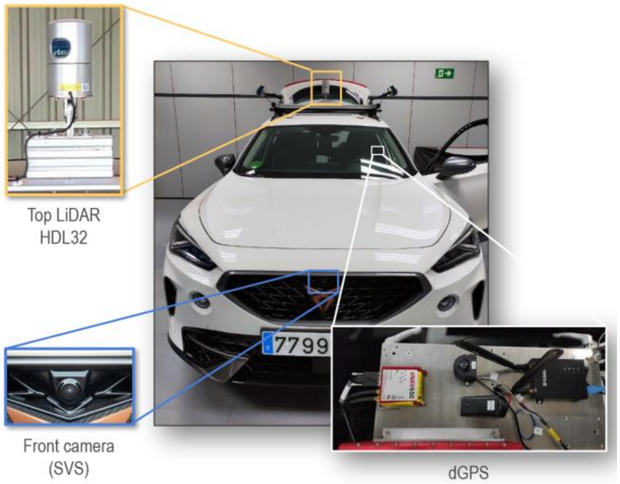

Figure 7. Real vehicle platform for Demo4

Table 5. Main technologies per partners in Demo 4

Partner	Main technologies
FICO (Lead)	Vehicle platform (SVS, Camera, LiDAR). Algorithms: HRU Diversity Detection, HRU Attention Detection, HRU Intention Prediction
FEKA	OLED TailLight
CAP	Development of AVAS system for eHMI based on sounds
CEA	AVAS with sound emitting panels
VICOM	Advanced detection of HRUs using photorealistic synthetic data

4. Current situation and challenges

AWARE2ALL is proposing an initial methodology for creating use cases to be implemented in the demonstrators. To achieve this, some basic concepts that will be used throughout the development of the project will first be defined, followed by a step-by-step layering of information to define the use cases.

4.1. AWARE2ALL Concepts

Within WP1 of AWARE2ALL, common concepts and terms are used that will be also adopted throughout the lifetime of the project. These are introduced below, with a short explanation for each one.

4.1.1. Use Case

What do we mean by the term 'use case'? There are different definitions that can be found, some of which are presented below. These can help understand the need of developing the Use Cases, as a tool for setting the requirements of a system, before its actual development or integration with existing technologies.

Use Cases can be defined as what happens when actors interact with the system. By recording all the way, the system is designed to be used we accumulate the requirements of the system. Therefore, a Use Case is a collection of possible sequences of interactions (scenarios) between the system under discussion and its users (or actors), relating to a particular goal [22] .

A Use Case is a description of a system's behavior, written from the point of view of a user who has given a command to the system to do something. A Use Case captures the visible sequence of events that a system goes through in response to a single stimulus. This means also that Use Cases only describe those things that a user can see, not the hidden mechanisms of the system [23] .

A Use Case, as a description of an actor's interaction with the system to be developed, is both a description of the system's user interface and an indirect description of some function that the system will provide. A set of Use Cases is a description of the system to be designed/built, the solution to the problem [24] .

A Use Case is a generalization of several scenarios. A Use Case represents a complete flow of events [25].

The project use cases will be developed and specified in Task 1.3.

4.1.2. Scenario

Scenarios cover the actions/tasks that a system can do, but also refer to those interactions that the system must be able to identify as invalid (e.g., error conditions, exceptions, and limitations). A use case is made up of one or multiple scenarios, depending on the complexity of the use case. Scenarios define the interaction level between user-system and consist of a stepwise sequence that is needed in order to achieve the goal; each step described in a scenario is a sub goal of the use case. As such, each sub-goal represents an autonomous action that is at the lowest level desired by our use case decomposition.

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4.1.3. User

A user might be anyone for whom a system/service is designed to be used by. Primarily, the user represents the end user or user groups that are defined through the Personas described in following sections. However, in many cases, there are several stakeholders that might be indirectly involved in a use case, such as organizations, private companies, public authorities, etc.

4.2. SSH Approach

The transformation of the current transportation system and the mobility practices, related also to the development of the CCAM, requires rebalancing the focus from the technical to the societal dimensions of this transport and mobility transition [26]. AWARE2ALL will extend the understanding of all the types of users and stakeholders involved and/or affected by the safety solutions that will be developed, therefore ensuring, and enhancing the inclusion of social groups that are vulnerable to exclusion. To this extent, central to AWARE2ALL approach is a philosophy of putting citizens in the center, by opening up the research process to facilitate an iterative process of understanding and collaboration among researchers, stakeholders and citizens and by adopting SSH principles and practices of "co-creation" and "inclusive methodology" in both research and validation activities.

Within the work implemented in WP1 so far and in T1.1 in particular, the integration of the SSH approach has been already applied both during the identification of the critical scenarios, regarding the interaction of HAVs with human road users (HRUs) in mixed road environments, but mainly during the definition of the user profiles that will be considered in the AWARE2ALL technical activities and the project's demos, ensuring the inclusion of different social groups, such as persons with disabilities (e.g., loss of upper limb, spinal cord injury, blindness, loss of lower limb), elderly, IT illiterate, etc. Emphasis has been also provided to the consideration of gender balance but also of different ethnicities, in an effort to address the limitation of various AI programs (e.g., facial recognition programs) to recognize persons that are not Caucasians and of white skin [27]. The outcomes of this work, both the definition of the critical scenarios and the user profiles have been presented and verified in a dedicated workshop that took place in M4, with the (virtual) participation of xx persons.

Moreover, the outcomes of T1.1 and T1.2 will be integrated in the definition of the project's Use Cases and related scenarios, ensuring also a strong SSH-based approach, through the organization of a dedicated workshop in M8 by CERTH, in order to get the feedback of end users, representing different clusters (drivers, elderly, disabled). During the workshop, participants will be asked to provide their feedback, propose modifications to the use cases and their prioritization, or even propose new ones.

4.3. Critical scenario definition process

The methodology for creating scenarios and use cases that will serve as the foundation for the project will involve careful consideration and analysis of all relevant actors involved, including autonomous vehicles, HRUs, occupants, and other vehicles. The analysis will also consider their respective locations and the surrounding conditions.

The starting point will be to identify all the parameters that will influence the scenarios and use cases. These parameters may include the type of autonomous vehicle, the road conditions, the

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weather, the time of day, and the actions of other vehicles and pedestrians. Once all these parameters have been identified, the scenarios will be defined from a high level of abstraction to a more detailed definition of the actors and values of the parameters.

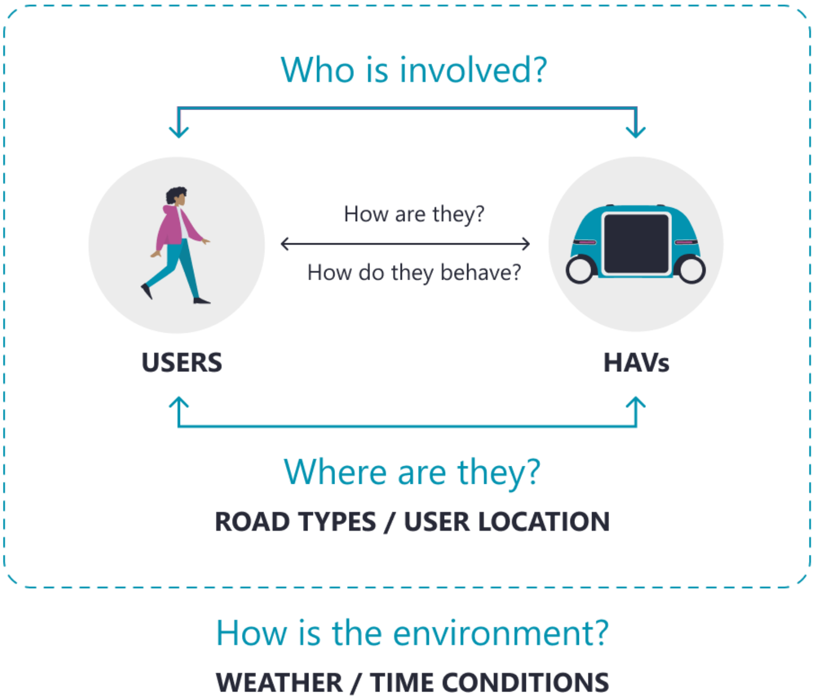

Figure 8. Critical scenario definition methodology

The scenarios and use cases will be developed based on real-world driving situations, considering the various factors that can affect the behavior of the autonomous vehicles and their interaction with other vehicles and people. For example, a scenario may involve an autonomous vehicle navigating through a crowded city street during rush hour, where pedestrians are crossing the street and other vehicles are changing lanes.

Ultimately, the goal of this methodology is to create scenarios and use cases that provide a robust and comprehensive framework for the development of autonomous vehicle technology. By carefully considering all the parameters and relevant actors involved, the resulting scenarios and use cases will enable the safe and efficient operation of autonomous vehicles in a wide range of real-world situations.

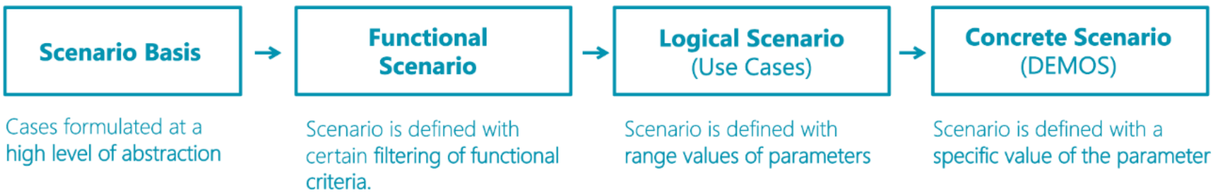

Figure 9. Scenario definition process

The process of defining the scenarios will entail a progression from a high level of abstraction. In subsequent steps, we will gradually define the various types of roads, including their associated conditions and circumstances. As the process continues, the range values of

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parameters will be defined incrementally until we achieve highly specific scenarios with values assigned to each parameter.

As can be seen in Figure 9 the first step is to define the basis of the scenarios and secondly to define the functional scenarios. These two steps will be carried out within T1.1 and T1.2, the content of which is explained in the following sections.

The third step will be to define the Logical Scenarios, detailing the use cases that will be worked on throughout the project, this part will be carried out as part of the work of T1.3.

Finally, specific scenarios will be defined, detailing specific parameters to be tested in the Demos. This task will be carried out in collaboration with the demo leaders and participants of WP2, WP3 and WP4.

4.4. KPIs definition process

For evaluating the effect of the safety systems at critical scenarios KPIs needs to be defined. As first step, all partners are distributing metrics for passive and active safety. These collected metrices are assigned to active safety, influencing the pre-crash scenarios and / or the passive safety, influencing the in-crash behavior, as well as to assign it to the different demonstrators of this project.

For each assigned metric, a prioritization per demonstrator and the assignment to use cases will be done. Looking at demonstrator level on the different use-cases, a specific definition of KPIs from highest prioritization metrics will be done.

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5. Parameters for Scenario definition

A scenario for an autonomous vehicle describes a hypothetical situation that illustrates how the vehicle interacts with its surroundings, Human Road Users (HRU), Human-Driven Vehicles (HDV), types of road infrastructure, and environmental conditions.

The User Persona represent the diversity of the population that will interact at some level with the autonomous vehicle. Human Road Users, including occupants and VRUs, and Human-Driven Vehicles, such as cars, are essential to consider as they share the road with the autonomous vehicle.

The vehicle's performance in various types of road infrastructure, including highways, urban roads, and rural roads, is also a crucial factor in the scenario. Additionally, environmental conditions such as weather, lighting, and road conditions can impact the vehicle's operation and performance.

Creating and testing scenarios is essential to ensuring the safety and effectiveness of autonomous vehicles on the road. By considering all relevant parameters in the design and testing phase, teams can identify and address potential issues before the vehicle is deployed in real-world situations, leading to more efficient and safer autonomous vehicles.

5.1. User Persona Definition

Creating User Personas that represent diverse populations is particularly crucial for a project on safety and communication with autonomous vehicles. User Personas that account for the diversity of the population can help to identify the specific needs and preferences of different user groups, such as those with physical or sensory disabilities. By understanding the unique challenges faced by diverse populations, AWARE2ALL can develop autonomous vehicle technology that is safe, accessible, and easy to use for everyone. Overall, creating inclusive User Personas helps to ensure that autonomous vehicle technology meets the needs of all users and enhances safety and communication on the road.

Presented below are the User Personas developed for the AWARE2ALL project. Collectively, these personas encompass functional, age, gender, and ethnic diversities, thereby representing the user profiles elaborate below.

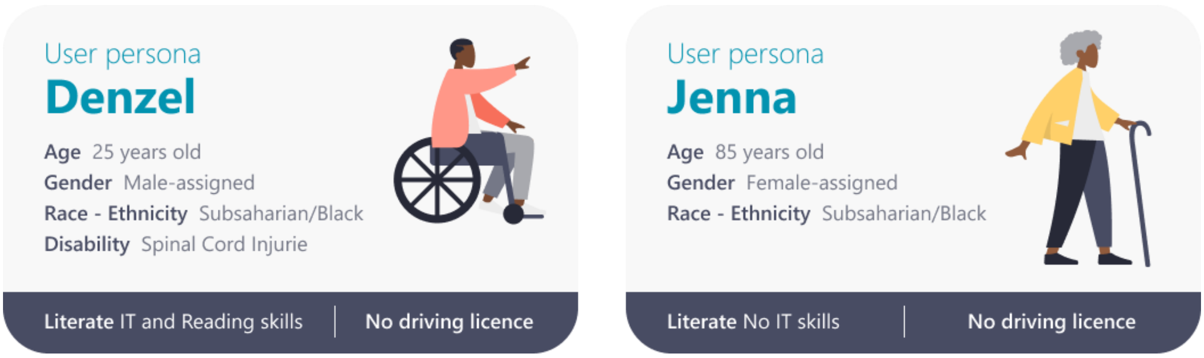

Figure 10. Denzel and Jenna user-persona

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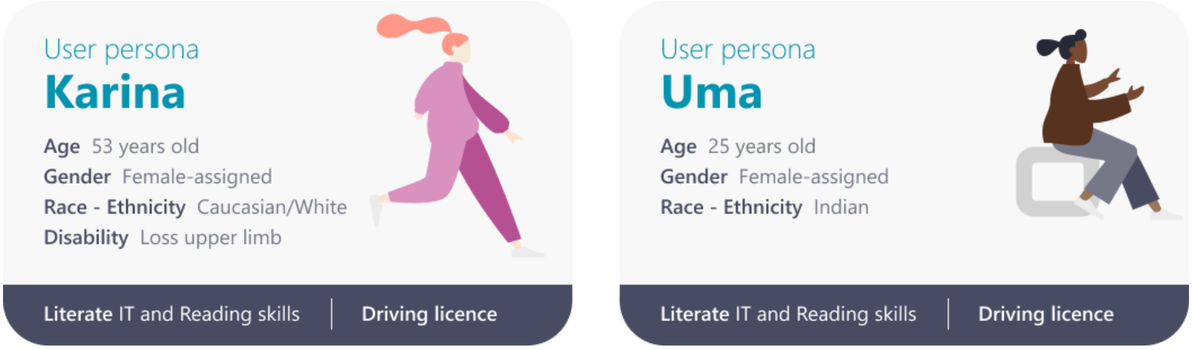

Figure 11. Karina and Uma user-persona

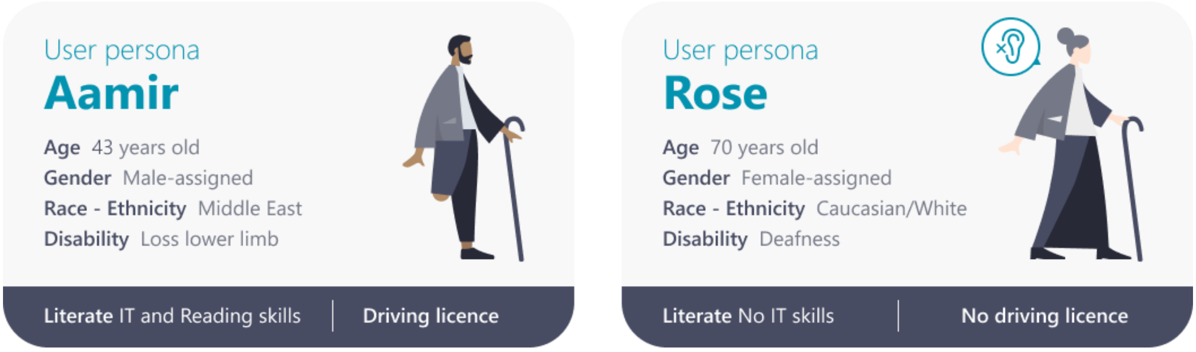

Figure 12. Aamir and Rose user-persona

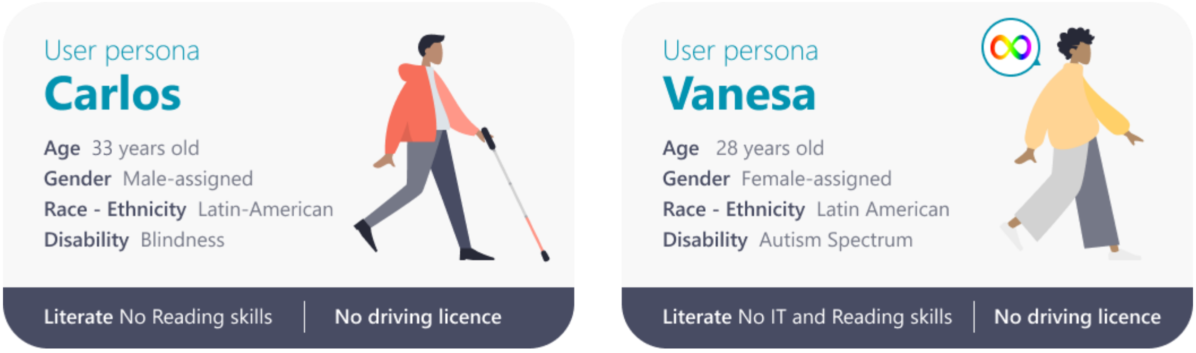

Figure 13. Carlos and Vanesa user-persona

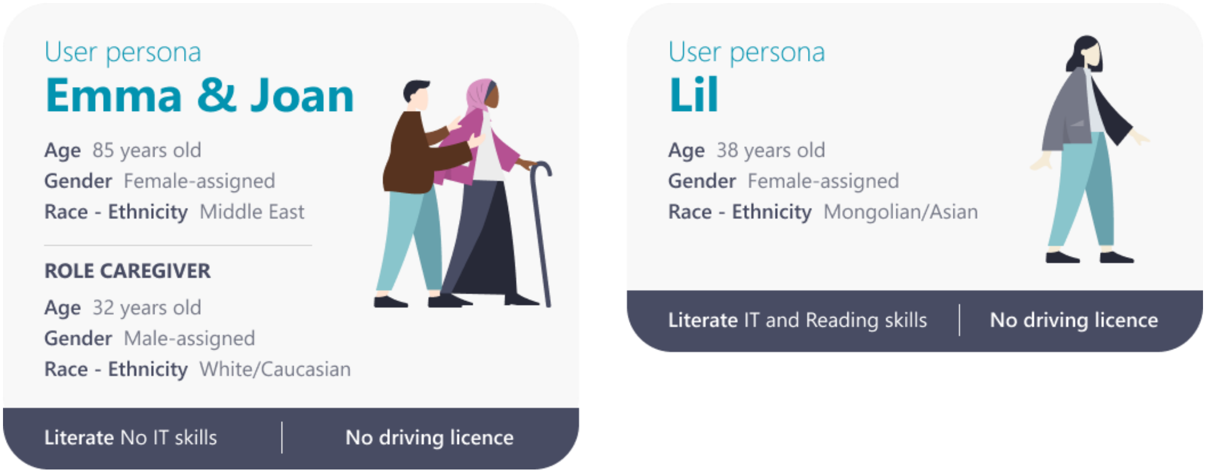

Figure 14. Emma & Joan and Lil user-persona

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To delineate the User Persona for the project, the primary step is to establish the various types of user profiles and comprehend the obstacles they may confront. User personas embody attributes of different user profiles, and each user persona may be assigned to one or more scenarios or various roles.

In order to achieve this, functional diversity has been scrutinized, comprising physical impediments such as the loss of a limb (upper or lower) or being confined to a wheelchair, sensory challenges such as blindness, deafness, or mutism, and psychological or neurological hindrances such as autism, dementia or Parkinson's disease. The age has been categorized into three ranges: 18 to 30 years, 30 to 65 years, and over 65 years. Additionally, the genders have been considered, namely male-assigned, female-assigned, and neutral, as well as race or ethnicity, including Sub-Saharan African, Indian, Middle Eastern, Latin Hispanic, and White/Caucasian. The classification used to analyze the user profiles considered is detailed below:

Functional diversity

Understanding the needs and difficulties of individuals with functional diversity is critical when developing new systems of security and communication in autonomous vehicles. It is imperative to ensure that these new technologies are accessible to everyone, regardless of ability.

The development of accessible autonomous vehicles requires the incorporation of accessibility options into the design of the technology. This can be achieved through working with disability advocacy groups, conducting user testing with individuals with disabilities, and integrating accessibility features into the system.

Accessibility is a key pillar in the development of autonomous vehicles, as it ensures that the technology is usable by everyone. The lack of accessibility features in current systems presents a significant challenge for individuals with disabilities, which must be addressed to make autonomous vehicles truly accessible.

Table 6. Functional Diversity [28]

Functional Diversity		Description
Physical	Loss Upper Limb	Permanent loss by physical separation of a hand at or above the wrist. Includes permanent total and irrecoverable loss of use of hand or arm.
	Loss Lower Limb	Permanent loss by physical separation of a foot at or above the ankle. Includes permanent total and irrecoverable loss of use of leg.

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	Spinal Cord Injuries - Wheelchair	Spinal cord injury refers to damage to the spinal cord resulting from trauma or from disease or degeneration (e.g., cancer). Symptoms depend on the severity of injury and its location on the spinal cord. Symptoms may include partial or complete loss of sensory function or motor control of arms, legs and/or body.
Sensory	Deafness + Hearing Loss	If they are not able to hear as well as someone with normal hearing, meaning hearing thresholds of 20 dB or better in both ears. It can be mild, moderate, moderately severe, severe, or profound, and can affect one or both ears.
	Blindness + Low Vision	The International Classification of Diseases classifies vision impairment into two groups, distance and near presenting vision impairment. Distance vision impairment: • Mild – visual acuity worse than 6/12 to 6/18 • Moderate – visual acuity worse than 6/18 to 6/60 • Severe – visual acuity worse than 6/60 to 3/60 • Blindness – visual acuity worse than 3/60 Near vision impairment: • Near visual acuity worse than N6 or M.08 at 40cm.
	Impairment of speech + Mutism + Aphasia	Absence of speech while conserving or maintaining the ability to hear the speech of others. It may not be a permanent condition, as muteness can be caused or manifest due to several different phenomena, such as physiological injury, illness, medical side effects, psychological trauma, developmental disorders, or neurological disorders. A specific physical disability or communication disorder can be more easily diagnosed. Loss of previously normal speech (aphasia) can be due to accidents, disease, or surgical complication; it is rarely for psychological reasons.

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Mental	Autism Disorder (ASD)	Autism spectrum disorders (ASD) are a diverse group of conditions. They are characterized by some degree of difficulty with social interaction and communication. Other characteristics are atypical patterns of activities and behaviors, such as difficulty with transition from one activity to another, a focus on details and unusual reactions to sensations.
	Dementia	Dementia is a syndrome – usually of a chronic or progressive nature – that leads to deterioration in cognitive function (i.e., the ability to process thought) beyond what might be expected from the usual consequences of biological ageing. It affects memory, thinking, orientation, comprehension, calculation, learning capacity, language, and judgement. Consciousness is not affected. The impairment in cognitive function is commonly accompanied, and occasionally preceded, by changes in mood, emotional control, behavior, or motivation.
	Parkinson´s Disease	Parkinson's disease is a brain disorder that causes unintended or uncontrollable movements, such as shaking, stiffness, and difficulty with balance and coordination. Symptoms usually begin gradually and worsen over time. As the disease progresses, people may have difficulty walking and talking.

Age diversity

Age is an important factor to consider when developing autonomous vehicles. Elderly pedestrians, for example, may have physical limitations that affect their use of these vehicles [29]. Compared to adults, elderly individuals tend to walk slower and have a more varied walking pattern, which may make it more difficult for them to interact with autonomous vehicles.

Moreover, elderly individuals may have difficulty accurately assessing the speed of vehicles, making them more vulnerable to accidents. This highlights the need for autonomous vehicles to be designed with safety features that consider the unique needs of different age groups.

To ensure the safety and accessibility of autonomous vehicles for all age groups, it is important to conduct thorough testing and evaluation of these vehicles with individuals of all ages. This can help identify any potential issues or challenges that may arise for certain age groups and inform the development of accessibility features and safety protocols.

Table 7. Age Diversity

Age Diversity	Description
18 -30 Years Old	They have come of age and are therefore considered independent, self-sufficient, and responsible. However, sometimes profiles of this age behave in a reckless and confident manner.
30 – 65 Years Old	Attained the age of majority and is therefore regarded as independent, self-sufficient, and responsible.
+ 65 Years Old	Common conditions in older age include hearing loss, cataracts, and refractive errors, back and neck pain and osteoarthritis, chronic obstructive pulmonary disease, diabetes, depression, and dementia. As people age, they are more likely to experience several conditions at the same time. Older age is also characterized by the emergence of several complex health states commonly called geriatric syndromes. They are often the consequence of multiple underlying factors and include frailty, urinary incontinence, falls, delirium, and pressure ulcers.

Gender diversity

Gender can have a significant impact on the needs and uses of autonomous vehicles. Studies have shown that females, including those who identify as non-binary or gender-neutral, experience higher rates of injury and fatalities than males in vehicle crashes. Multiple studies conducted in Europe and the United States have found that women die and are seriously injured at higher rates than men in comparable crashes [30]. According to a 2019 study by the University of Virginia, women are 73% more likely than men to be severely injured and 17%-18.5% more likely than their male counterparts to be killed in comparable crashes, leading to an estimated 1,300 preventable deaths of women per year.

In addition to these gender disparities in crash safety, women and girls also face harassment in and around public transport daily. Women often change their travel patterns to avoid potential danger, which can have negative consequences for their work, education, and public life [31]. Furthermore, the banishment of private cars from cities may worsen the situation for women and girls globally, as they may face additional safety risks and transportation challenges.

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It is important to take into consideration these gender-based differences and challenges when designing and implementing autonomous vehicle technology. This includes developing safety features that are tailored to the specific needs and abilities of all genders, as well as creating an inclusive transportation system that addresses the unique concerns of all users, regardless of gender identity.

Table 8. Gender Diversity

Gender Diversity	Description
Female-assigned	• The differentiated anthropometry, reach, strength, and variability of the female-assigned body (also during pregnancy) must be considered. • Consequences of a car crash are often far deadlier than for men because of gender bias in crash testing practices. (73% more likely to be injured in a vehicle crash than are men-assigned). • Virtual assistants have difficulty understanding feminine voice commands. • Facial recognition works better for men than for women. To consider regarding gender/sexual identity: If differs from heterosexual-male, sexual harassment or assault on public transport is more likely to happen.
Neutral	To consider regarding gender/sexual identity. If gender identity or sexuality differs from heterosexual-male, sexual harassment or assault on public transport is more likely to happen.
Male-assigned	To consider regarding gender/sexual identity. If gender identity or sexuality differs from heterosexual-male, sexual harassment or assault on public transport is more likely to happen.

Race diversity

One of the main areas of concern is the potential for racial bias in perception technology. For example, the sensors used by autonomous vehicles to detect objects on the road may be more likely to miss or misidentify objects that are commonly associated with people of color [32]. This could lead to accidents or other safety hazards if the vehicle fails to detect a pedestrian or other obstacle.

Another area of concern is the use of facial recognition technology in autonomous vehicles. There is evidence to suggest that facial recognition technology is more likely to misidentify people of color, leading to potential errors in passenger identification or authentication [33].

This could impact the safety and security of autonomous vehicles, as well as the ability of passengers to access and use them.

Additionally, there may be issues with communication between autonomous vehicles and people from different cultures. For example, there may be cultural or linguistic differences that could impact the ability of passengers to communicate with the vehicle, potentially leading to misunderstandings or other communication breakdowns. There may also be concerns around the design of the vehicle's interface, which may not be accessible or intuitive for people from diverse backgrounds.

By exploring these issues and working to address them, AWARE2ALL can help to ensure that autonomous vehicles are safe, accessible, and equitable for all members of society.

Table 9. Race / Ethnicity Diversity

<table>
<tr><th colspan="3">Race / Ethnicity Diversity</th></tr>
<tr><td>Sub-Saharan African</td><td rowspan="3">• Face recognition and verification better on lighter subjects than on darker subjects.
• Standard models for the task of object detection, trained on standard datasets, appear to exhibit higher precision on lower Fitzpatrick skin types than higher skin types. This behavior appears on large images of pedestrians.
*Fitzpatrick Types IV, V, or VI.</td><td rowspan="6">Share physical characteristics, such as skin color or facial features. They may also share similar social or cultural identities and ancestral origins. There are many racial groups, and a person may belong to or identify with more than one group.

To consider regarding ethnicity.
• Races other than Caucasian are likely to suffer more racism or assault on public transport.
• Semiotic differences of meaning in language and symbology may exist due to the dominant predominance of western culture</td></tr>
<tr><td>Indian</td></tr>
<tr><td>Middle East</td></tr>
<tr><td>Asian / Mongolian</td><td rowspan="2">• Driver monitoring systems incorrectly detect if a person with an epicanthic fold is distracted or has fallen asleep.</td></tr>
<tr><td>Latin/ Hispanic</td></tr>
<tr><td>White/ Caucasian</td><td></td></tr>
</table>

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**The Fitzpatrick skin type scale (Fitzpatrick, 1975), introduced to predict a person's predisposition to burning when exposed to UV light, measures several physical attributes of a person including skin, eye, and hair color, as well as a person's likelihood to freckle, burn, or tan. As a rule, categories 1-3 correspond to lighter skin tones than 4-6. This categorization aims to design a culture-independent measurement of skin's predisposition to burn, which correlates with the pigmentation of skin. Skin color labelled Fitzpatrick Types I, II, and III were grouped in a lighter category and faces labelled Fitzpatrick Types IV, V, and VI were grouped into a darker category. [34]*

5.2. Human Road User

When considering the parameters to define a scenario, it is important to consider the presence of HRU (all human involved in the scenario). In addition to analyzing what they are like and the difficulties they face in their daily lives (mentioned in the previous section, 4.1 User Person) we must identify what role they play in our scenario, where they are located and what activities they may be performing.

The two main HRU profiles are:

- Occupants, referring to the individuals inside the autonomous vehicle.
- Vulnerable road users, including non-motorized road users such as pedestrians and cyclists, as well as motorcyclists, scooters and people with disabilities or reduced mobility and orientation.

The classification and description of these HRU profiles are presented below.

Table 10. HRU - Occupants

HRU - Occupants		Description
Location /Position	Driver Seat	Depending on the level of autonomy of the vehicle, in case of an emergency it may be necessary for the driver to react and take control of the vehicle. If this is the case, only persons with a valid driving license may occupy this seat.
	Passenger Seat	Person travelling in the vehicle, usually on the driver's side. In the case of new vehicle configurations, this could be any person who does not assume the driving role.
	Wheelchair Seat	Place inside the vehicle adapted for people who use a wheelchair to move around. These seats have special space and safety features.
	Reduced Mobility Seat	These seats are aimed at people with reduced mobility, they have different characteristics in terms of size and comfort to meet the needs of this user profile.
Activities	Relaxing	· Eyes closed / napping · Listen to music · Looking through the window

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	Use of Device	· Use of Laptop · Use of Mobile · Reading a book · Use of Headphones
	Unauthorized behavior	· Out of position in forward normal sitting and reclined position · Standing during an emergency maneuver · Try to leave while being in a hazardous situation
	Abusive Interaction	· Verbal provocation · Physical altercation · Sexual harassment
	Driving	· Depending on SAE Level
	Sound / Noise Levels	· Loud talking · High noise levels · Use of headphones
Body Postures	Sit Down	On the floor
	Standing Up	
	On the seat	· Standard Position · Reclined position / Relax Position (Reclined seatback for larger angle between thigh and torso) · Fully reclining / Sleeping position

Table 11. HRU – Vulnerable Road Users (VRU)

HRU – Vulnerable Road Users (VRU)	
Types	Pedestrian (children not considered)
	Wheelchair (or other mobility aid)
	Bicycle

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	Scooter
	Motorcycle
Activities	Standing
	Walking
	Running
	Changing mind (Unpredictable change of user action. (E.g., from walking to running)
	Sitting down (in a bench or bus stop)
	Driving

5.3. Highly Automated Vehicle

The development of autonomous vehicles is a great challenge and change for society. The incorporation of this technology is not only due to its autonomy but also to the new interior positions available inside the vehicle. These positions allow occupants to perform various activities inside the vehicle. The integration of these novel features requires a significant change in the mindset of society, which must adapt to this new mode of transport. In addition, the introduction of autonomous vehicles requires the development of new regulatory measures and infrastructures to ensure the safety and efficiency of these vehicles. The emergence of autonomous vehicles represents a fundamental change in the transport landscape and will require the cooperation and adaptation of various stakeholders to ensure a smooth transition to this technology.

Table 12. Highly Automated Vehicle (HAV)

Highly Automated Vehicle (HAV)		
Type of vehicle	Shared	A shared vehicle can be private or public. · Shared-use vehicle systems consist of a fleet of vehicles that are used by several different people throughout the day. · Public transport systems include a variety of transit options such as buses, light rail, and metros. These systems are available to the public, may require payment of a fare, and operate at scheduled times.)

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	Shuttle	A vehicle or aircraft that travels regularly between two places carrying people.	
SAE Levels	0	No Driving Automation	
	1	Driving Assistance	
	2	Partial Driving Assistance	
	3	Conditional Driving Automation · Not driving when these automated driving features are engaged – even if seated in "the driver's seat". When features request MUST DRIVE. · Automated driving features will not require to take over driving. · These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met. · Examples: traffic jam chauffeur.	
	4	High Driving Automation · Not driving when these automated driving features are engaged – even if seated in "the driver's seat". · Automated driving features will not require to take over driving. · These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met. · Examples: traffic jam chauffeur, local driverless taxi, pedals/steering wheel may or may not be installed	
	5	Full Driving Automation	
Configuration	Interior	Rearward Facing	· Rearward facing at a seatback angle of 20 degrees (both pilot and copilot seats) · Front-right seat in rearward position to have a face-to-face configuration on the right side
		Forward Facing	· Standard Position (both pilot and copilot seats) · Forward facing at a seatback angle of 20 degrees (both pilot and copilot seats)
		Standing Up	· On the side of the vehicle, near the exit. Side grip · Centrally located. Upper grip.

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		Other	· Seats positioned at the sides of the vehicle, facing towards the middle (i.e. underground)
	Exterior	Access and exit	· Wheelchair Access · Auxiliary step to facilitate entry for people with movement difficulties.
		Shape (identification by HRUs)	· Symmetry exterior design (Front and Back)
	Capacity	Number of occupants	
Maneuvers	Stop	The vehicle is not moving	
	Overtake	Overtaking is about passing a slower moving vehicle in front of you. Signal correctly with the turn signals. This maneuver may include lane changes.	
	Changing Lanes	This maneuver is performed by moving from one lane to another, either left or right, to follow a given direction or to go to the desired destination. Signal correctly with your turn signals.	
	Merging into traffic	A merging maneuver can be done in several situations: when you are stationary or parked and when you are coming out of an access road or private road. There must be enough space and time to merge, signal your intention correctly with the indicators and carry out the maneuver without disturbing other road users.	
	Changing Direction	When making a right or left turn with your car, you are changing direction. This maneuver is done to leave the road you are driving on and go to a different one, or to leave it. Apart from signaling the turn with the appropriate indicator, you must stand as close as possible to the right-hand edge of the relevant lane if you are turning right or to the left-hand edge if you are turning left.	
	U-Turn	When making a U-turn, the direction in which one is travelling on the road is being changed. In other words, a U-turn is a 180º turn on the road, it is a maneuver to turn around and go back the way you came.	

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	Parking	Parking is a voluntary immobilization lasting more than two minutes. Types: in line, in battery. Signal the maneuver with the indicators and the reversing light when necessary.
	Reverse	Reversing is a maneuver that allows the vehicle to move backwards without reversing.

5.4. Road Types and Infrastructure

Europe has a diverse road network, including motorways or highways, rural roads, and urban roads. Each type of road presents different challenges and requires different considerations for autonomous vehicles.

Motorways or highways are designed for high-speed travel and are typically multi-lane. They are relatively predictable and straightforward, with well-marked lanes and limited pedestrian or bicycle traffic. Autonomous vehicles on highways must be equipped with advanced sensors and software to detect and avoid other vehicles, as well as traffic signs and lane markings.

Rural roads are narrow, winding and often lack markings or signage. They may also have unexpected obstacles, such as animals or farm machinery. Autonomous vehicles designed for rural roads must be able to overcome these challenges, using advanced mapping and sensor technology to detect and avoid obstacles.

Urban roads present the most complex challenges for autonomous vehicles. They are crowded, with a wide variety of vehicles, pedestrians and cyclists sharing the same space. In addition, urban roads often have complex traffic patterns, such as one-way streets and roundabouts. Autonomous vehicles in urban areas must be able to anticipate the movements of other road users and adapt to changing conditions.

To create effective use cases for autonomous vehicles on European roads, is necessary to consider the specific challenges and requirements of each road type. Factors such as road width, speed limits and traffic density, as well as the availability of real-time data and connectivity infrastructure must be considered. The type of road will be part of the first step in the definition of scenarios, as already indicated in Figure 9. Scenario definition process

Table 13 Road and Infrastructure

Road and Infrastructure		
HIGHWAY (<100 km/h)	High-speed roads. The speed limit is generally 130km/h and there is a hard shoulder, an often slightly narrower lane next to lane 1, which is usually only to be used in cases of an emergency.	Traffic Lane / Merging Lane
		Shoulder

	It is common, especially at city entrances, for one of the lanes to be used only by public transport, taxis, or high-occupancy vehicles.	Traffic Sign / Visual Panel
RURAL ROAD (80-100 km/h)	Slower speeds, opposite direction lines. Wide shoulder where pedestrians and cyclists could walk/ride.	Traffic Lane / Merging Lane
		Bike Lane
		Shoulder / Footpath
		Pedestrian Crossing
		Traffic lights / Traffic Sign / Visual Panels
		Bus Stop
URBAN ROAD (30-50 km/h)	Urban areas with heavy traffic. The speed limit is between 30 and 50 km.	Traffic Lane
		Bike Lane
		Footpath
		Pedestrian Crossing
		Traffic lights / Traffic Sign / Visual Panels
		Bus Stop
SLOW TRAFFIC (< 30km/h)	· Urban areas with a speed limit lower than 30 km. · Areas of a city or town reserved for pedestrian-only use and in which most or all automobile traffic is prohibited.	Traffic Lane
		Bike Lane
		Footpath
		Pedestrian Crossing
		Traffic lights / Traffic Sign / Visual Panels
		Bus Stop

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5.5. Environment conditions

Environmental conditions can affect the safety and efficiency of driving on different types of roads, such as motorways, rural roads, and urban roads. Adverse weather conditions, such as fog, rain, or snow, can affect visibility and traction and influence the behavior of both human and autonomous drivers. [35]

AWARE2ALL must take these environmental factors into account when creating use cases, incorporating advanced technologies such as sensors, mapping systems and driver assistance systems to ensure safe and efficient operation in varying conditions.

Table 14 Environment conditions

Environment Conditions		
Light Conditions	Daytime	Natural light from the sun, or the period during a day when there is light. To consider about autonomous driving tech: · Cameras suffer the same limitations as human eyes when faced with bright sunlight, glare, or nighttime conditions.
	Night-Time	The time in every 24-hour period when it is dark. To consider about autonomous driving tech: · Cameras suffer the same limitations as human eyes when faced with bright sunlight, glare, or nighttime conditions.
Weather Conditions	Rain	To consider about driving conditions: · Risk of aquaplaning. · Avoid hard braking. Brake gradually. · Maintain a greater braking distance between your car and the vehicle in front of you, especially in conditions like rain, ice and snow; leave as much as ten times the usual recommended gap. To consider about autonomous driving tech: · High-resolution lidars struggle in rain, fog, and snow. Radars can punch through bad weather but deliver less detailed information.

	Fog	To consider about driving conditions: · Drive with low beams and fog lights. · Reduce speed. To consider about autonomous driving tech: · High-resolution lidars struggle in rain, fog, and snow. Radars can punch through bad weather but deliver less detailed information.
	Snow	To consider about driving conditions: · Reduce speed. · If visibility drops below 100m, turn on fog lights. To consider about autonomous driving tech: · High-resolution lidars struggle in rain, fog, and snow. Radars can punch through bad weather but deliver less detailed information.
	Wind	To consider about driving conditions: · Vehicle stability could be reduced. To consider about autonomous driving tech: · Possible problems in object detection.
Temperature Conditions	Icy-Road Temperatures below 0º Celsius	To consider about driving conditions: · Gently accelerate the vehicle using low revs and shift to a higher gear as quickly as possible. · Low speed to avoid fishtailing or sliding. To reduce the chances of the wheels slipping, use the second gear instead of the first gear. To consider about autonomous driving tech: · High-resolution lidars struggle in rain, fog, and snow. Radars can punch through bad weather but deliver less detailed information.

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	High Temperatures	To consider about driving conditions: · Human health issues: Occupants or VRUs (dizzy turn or heat stress)

6. Functional Scenario definition

Once all the parameters that exist and can affect a mixed traffic context have been defined, we begin to specify the actors, actions and causes of these critical scenarios.

To achieve this, we will first establish a baseline scenario, on which we will overlay additional information.

6.1. Scenario Basis

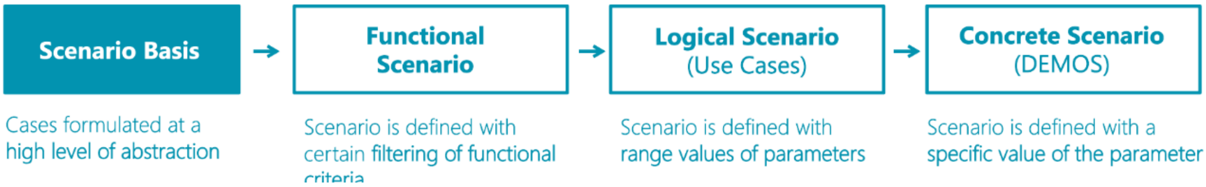

Figure 15. Scenario definition process, Scenario Basis step

As can be seen in Figure 15, as a first step in the definition of scenarios, a set of base scenarios has been defined. Four types of roads on which the autonomous vehicle can operate have been taken as a basis [36], as we can see below in Figure 16 .

- Highways (High Speed) A road that has separate carriageways for each direction of traffic and limited access from land on either side. Generally, have a speed limit between 120 or 130 km/h.
- Rural Road Two-way roads linking villages or small towns, usually in rural areas with low traffic density. The general speed limit on this type of road is 80 or 90 km/h.
- Urban Road Roads that are located within a locality, be it a town or a city. These roads include traffic rules and infrastructure adapted to the characteristics of a denser traffic environment. Normally, the speed limit does not exceed 50 km/h.
- City Traffic (Slow speed) These types of roads are in urban areas, are usually one-way and require a speed limit of about 30 km/h due to the influx of VRUs and are often very congested environments.

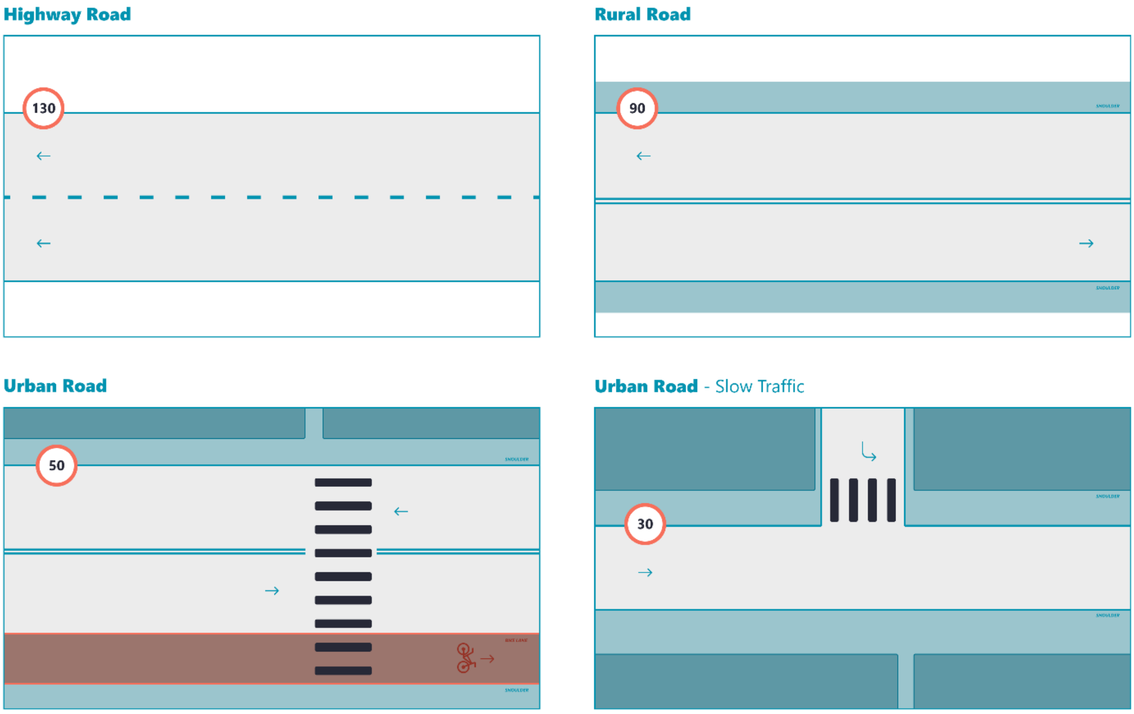

Figure 16. Scenario basis and road types

6.2. Functional Scenario

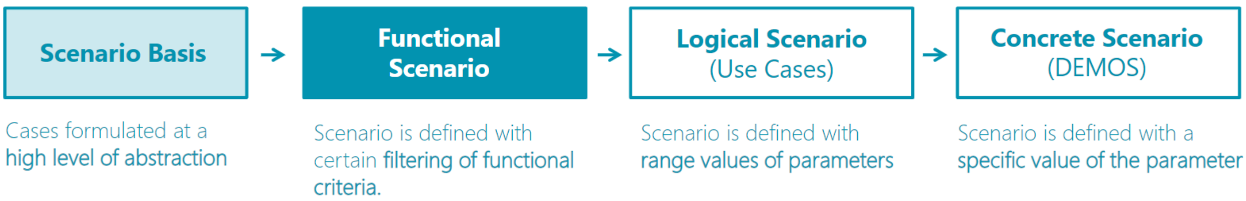

Figure 17. Scenario definition process, Functional Scenario step.

As shown in Figure 17, once the baseline scenarios have been established, we will proceed to define functional critical scenarios considering variations in the type of road and infrastructure, vehicles or VRUs involved. Several variations for each Basis Scenario are explained below:

6.2.1. Highway Scenarios

Standard Highway

This scenario shows a two-way carriageway, on which vehicles may travel at a maximum speed of approximately 80 or 90 km/h. In addition, this carriageway may contain a hard shoulder or pavement on which pedestrians or bicycles can circulate. In this type of scenario, the risk of an accident is increased because vehicles are travelling in the opposite direction, which increases the risk of overtaking. Pedestrians and bicycles can also be hit. Figure 18.

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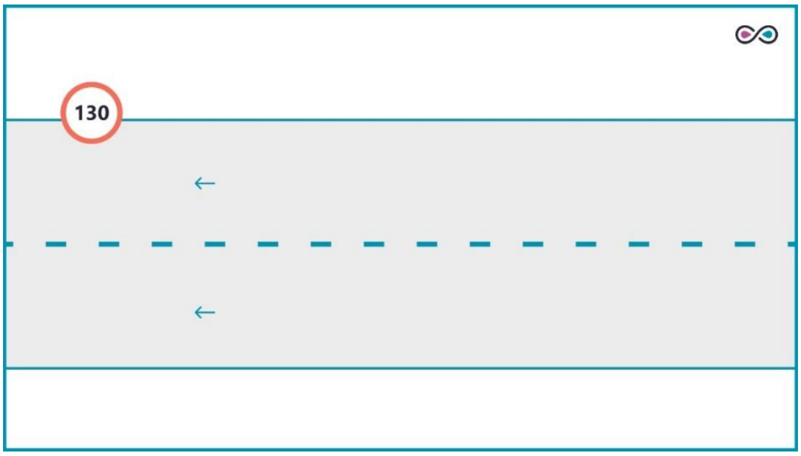

Figure 18. Standard highway

Merging into Highway

In this case, we see the same situation as above but with the addition of a merging lane on the right-hand side. In this scenario, there may be situations with a higher risk of accidents due to the possibility of vehicles merging at different speeds, and it may be necessary for vehicles already on the road to carry out maneuvers to allow merging. The level of attention or the degree of visibility are factors that may have an influence. Figure 19.

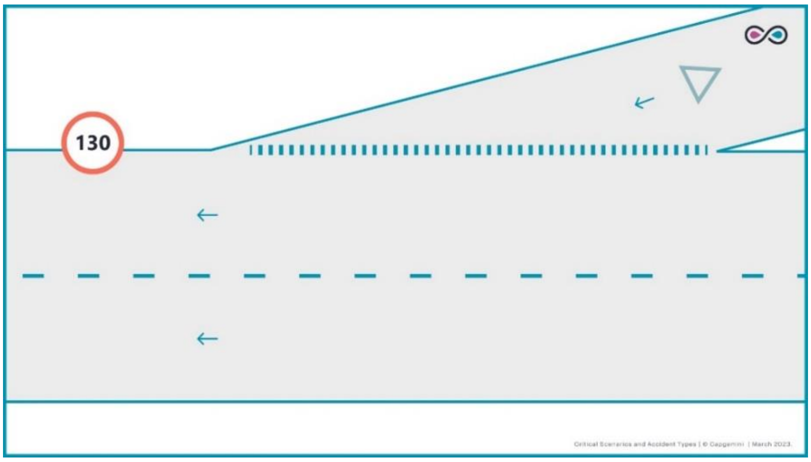

Figure 19. Merging into a highway

6.2.2. Rural Road Scenarios

Standard Rural Road

This scenario shows a two-way carriageway, on which vehicles may travel at a maximum speed of approximately 80 or 90 km/h. In addition, this carriageway may contain a hard shoulder or pavement on which pedestrians or bicycles can circulate. In this type of scenario, the risk of an accident is increased because vehicles are travelling in the opposite direction, which increases the risk of overtaking. Pedestrians and bicycles can also be hit. Figure 20.

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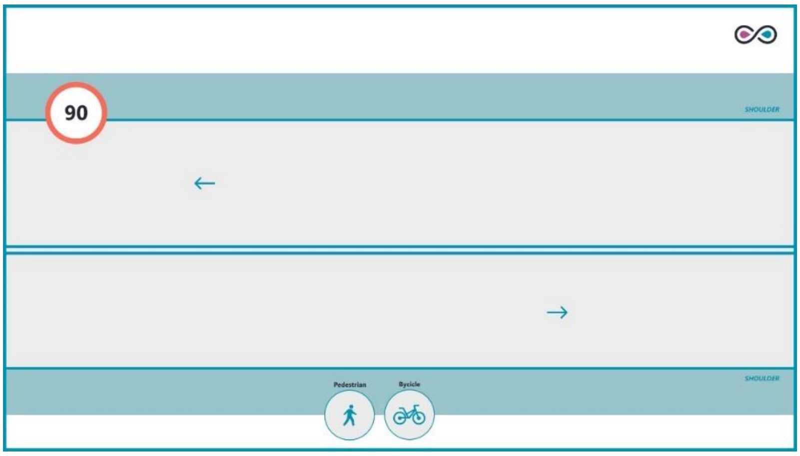

Figure 20. Standard Rural Road

Rural Road with Bus Stop

For this scenario a bus stop is added to the previous scene. It is important to consider the time it takes to slow down to park the bus, as well as to take into account people who may be waiting or who may encroach on the roadway to access an area of the vehicle at that time. Figure 21

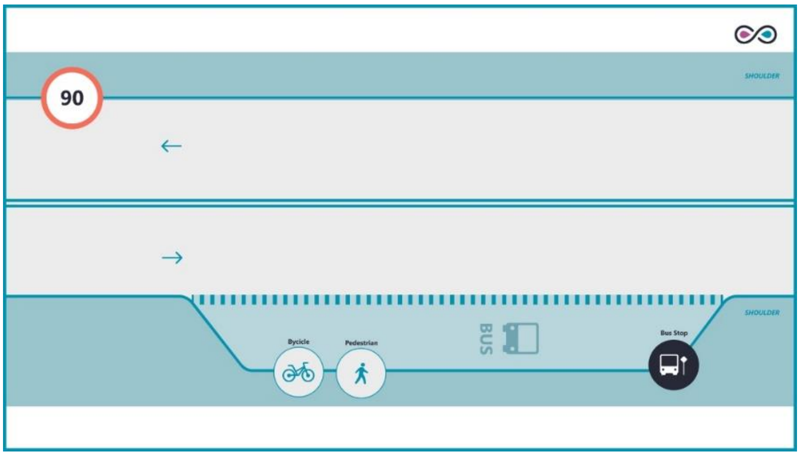

Figure 21. Standard with Bus stop

6.2.3. Urban Road Scenarios

Urban Road with Bike Lane

This first urban road scenario shows a two-way carriageway, pavements for pedestrians, a bike lane, and a pedestrian crossing. In urban areas, the complexity of the situation increases because there are many influencing elements which, if not well synchronized, can pose a risk of an accident. Figure 22.

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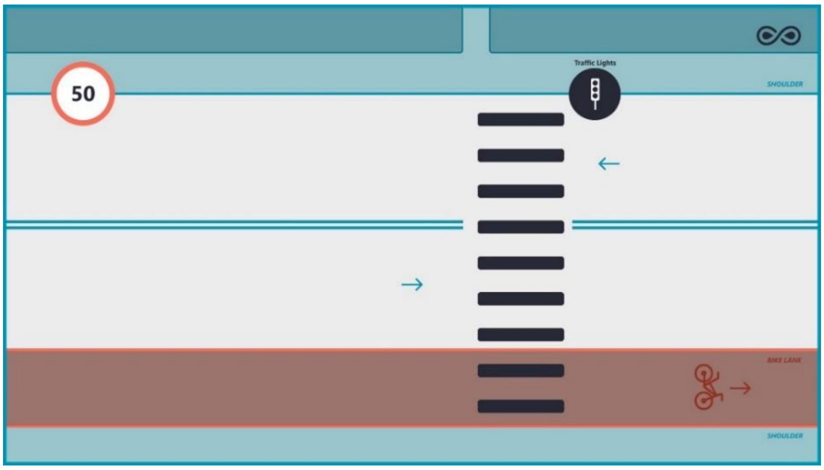

Figure 22. Urban Road with bike lane

Urban Road with Bus Lane

In this new situation, the cycle lane has been replaced by a bus lane. The resulting problems change considerably, because bicycles are considered VRUs and have a higher accident risk than buses, which are larger vehicles in which the occupants are more protected.

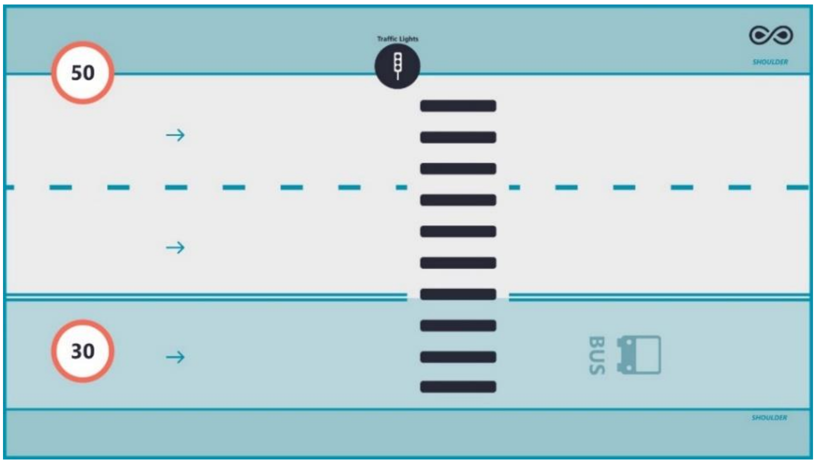

Figure 23. Urban Road with Bus Lane

Road Crossing

This is the most complex scenario within the Urban Roads scenarios. We have an intersection where vehicles can travel in several directions. In addition, on one side of the junction there is a pedestrian crossing with traffic lights.

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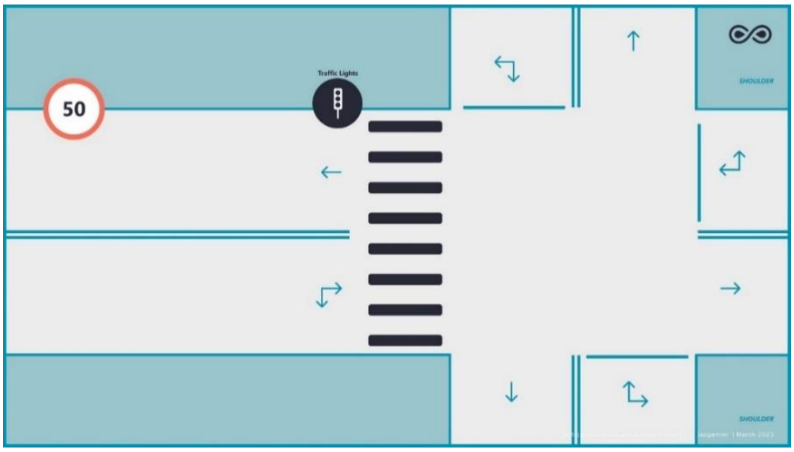

Figure 24. Road crossing

6.2.4. City Traffic Scenarios

Slow Traffic

In this first situation within this category, there is a single lane in which a maximum speed of 30 km/h is allowed. On the right-hand side, there is another lane on the right-hand side of the road which has a pedestrian crossing at the intersection.

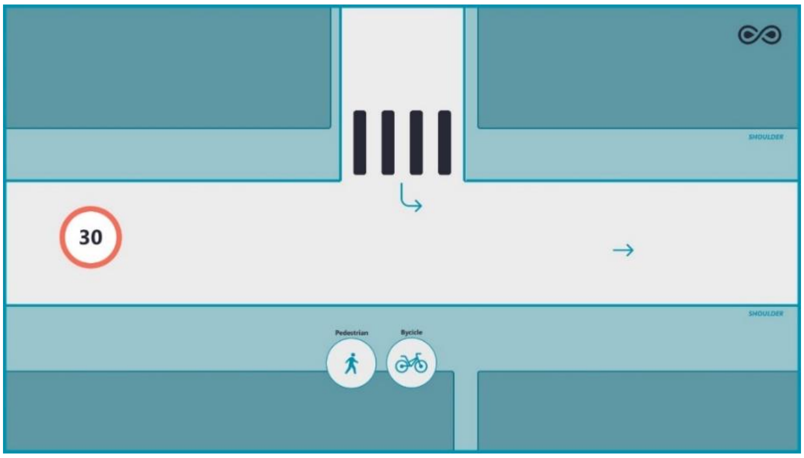

Figure 25. Urban Road Slow Traffic

Pedestrian Road

Finally, we have a pedestrian roadway where pedestrians and other VRUs such as bicycles or electric scooters can circulate. Only authorized vehicles can circulate on this type of roadway. The lanes for each vehicle are not delimited, which can lead to unpredictable risk situations in case an authorized vehicle circulates in this environment.

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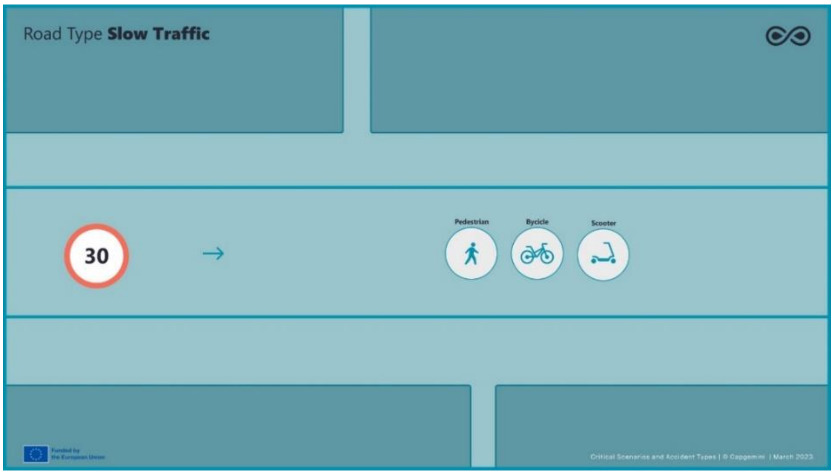

Figure 26. Pedestrian Road

7. Critical Accident types

New types of accidents can occur when autonomous vehicles (HAVs) are introduced to our roads, caused by human errors, HAVs errors, and infrastructure errors.

While HAVs are designed to reduce accidents caused by human error, accidents may still occur due to errors made by the AVs themselves, as well as infrastructure issues. HAVs can experience software glitches or sensor malfunctions, leading to accidents. Pedestrians and other drivers can also behave unpredictably or fail to follow traffic rules, contributing to accidents. Poorly maintained roads or inadequate signage can pose challenges for HAVs, which may not be able to respond to situations where infrastructure or communication technology fails.

It is essential to address these new types of accidents through improved vehicle design, infrastructure upgrades, and comprehensive safety regulations to ensure that they are introduced safely and effectively. Highlights the importance of understanding the causes of accidents involving HAVs, as well as the need for reliable testing methods and a comprehensive safety framework.

AWARE2ALL will address the developing a safety-oriented design methodology, enhancing the adaptability of HAVs to complex traffic situations, and improving their ability to communicate with other road users. By addressing these challenges, HAVs can contribute to improved road safety and efficiency.

7.1. Critical Accidents Caused by Human errors

New types of accidents can occur when introducing autonomous vehicles (AVs) in traffic, caused by human errors both inside and outside the AVs or by human road users.

According to the European Transport Safety Council (ETSC) reported that 90% of all accidents on European roads are caused by human error, such as speeding, distraction, and failure to keep a safe distance. While HAVs can reduce accidents caused by human error, it is important to consider the behavior of other road users.

Some of the types of accidents caused by human drivers in interactions with AVs can include:

- Rear-end collisions: When human drivers follow AVs too closely or fail to anticipate an AV's sudden stop, they may cause a rear-end collision.
- Failure to yield: Human drivers may not correctly interpret the behavior of an AV, resulting in a failure to yield when necessary.
- Improper lane changes: Human drivers may not properly anticipate the movement of an AV, leading to an improper lane change and potential collision.

Below is the classification of human errors that can lead to accidents based on their location within the scenario: HDV and VRU driving (Table 15), HRU not driving (

Table 16), or occupants inside the autonomous vehicle (

Table 17).

Table 15. Errors made by: HDV and VRU Circulating

Errors made by: HDV and VRU Circulating
Influence of drugs/alcohol
Traffic signs and sign violation
Pedestrian violation
Following too closely
Improper turning
Fainting / heat stroke
Other/unknown: unsafe lane change, improper passing, wrong side of the road, unsafe starting or backing

Table 16. Challenges face by: VRU NOT Circulating

Challenges face by: VRU NOT Circulating
Need to know when a vehicle is driving autonomously
Lack of confidence: not trusting the actions it will carry out or whether it will carry them out correctly.
Experience danger when drivers are focusing on other tasks instead of driving.
Imitation is another social factor that defines human behavior. Law-violating increases the likelihood of other pedestrians to do so.

Table 17. Errors made by: Occupants

Errors made by: Occupants
Violent act / harassment inside.
Loosen the belt to pick something up.
Change positions.

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Spilling substances
Feeling unwell or fainting (in a standing up position is more dangerous).
Falling sleep
Misunderstanding or non-comprehension of HVAs signals/HMI.

7.2. Critical Accidents Caused by HAVs Interaction

Accidents caused by the interaction between autonomous vehicles and humans are a concern as HAV technology continues to develop. According to a report by the National Highway Traffic Safety Administration [37] , misunderstandings of hand signals or gestures, pedestrian interactions, and communication failures are examples of potential accidents caused by HAV-human interactions. In 2019, 36% of HAV accidents were due to interaction with other road users. AWARE2ALL will focus on developing communication protocols and improving HAV technology to reduce the risk of these accidents.

Some types of accidents that can occur due to interactions between HAVs and human include:

- Misunderstanding hand signals or gestures: Human drivers may make hand signals or gestures to signal their intent to other drivers. HAVs may not be able to interpret these signals correctly, leading to confusion and potential accidents.
- Pedestrian interactions: HAVs must be able to detect and respond to pedestrians crossing the road or walking alongside the road. Human drivers may also have difficulty anticipating the movements of pedestrians.
- Failure to communicate: HAVs may not be able to communicate with human drivers in the same way that humans communicate with each other. This lack of communication can lead to confusion and potential accidents.

Table 18. Challenges faced by: HDV and VRU

Challenges faced by: HDV and VRU
Not identifying that it is a HAV correctly
Lack of confidence: not trusting the actions it will carry out or whether it will carry them out correctly.
Not understanding the HAV's actions and intentions, which may lead to communication problems or accidents.
Following too closely
Improper turning
Fainting / heat stroke

Other/unknown: unsafe lane change, improper passing, wrong side of the road, unsafe starting or backing

Table 19. Challenges faced by: Occupants

Challenges faced by: Occupants
Safety perception inside the HAV might decrease when there is no driver maneuvering the vehicle.
Lack of confidence: not trusting the actions it will carry out or whether it will carry them out correctly.
Feeling of lack of control and comfort as occupants are not sure if the vehicle has understood the commands and final direction.

Table 20. Errors occurred to: Infrastructure

Errors occurred to: Infrastructure
Connectivity problems.
Traffic lights out, defective signals.
Traffic control is taken over by a civil guard giving physical signals that the HAV may not understand.

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8. Safety parameters identification and high-level system requirements with KPIs

In current road safety research, the safety of vehicle occupants and vulnerable road users (VRUs) and the development of effective safety systems are vital. To achieve the goal of comprehensive road safety for all road users, identifying relevant safety parameters and defining high-level system requirements using safety metrics is crucial. This Chapter begins with an in-depth analysis of novel safety parameters for occupants and VRUs. The study focuses on the systematic categorization of factors that influence the risk of interactions, crashes, and the severity of the resulting injuries. These include common safety parameters such as vehicle speed, the direction of travel, and communication capabilities between involved road users, even though they are not explicitly mentioned.

Based on this, high-level system requirements are discussed to optimize the identified safety parameters and minimize potential risk factors. Appropriate safety metrics are presented to continuously monitor and evaluate the effectiveness of these system requirements, covering both quantitative and qualitative aspects.

Finally, an integrative approach is developed that embeds the identified safety parameters and metrics into a comprehensive framework that considers the interactions between the different factors. This systematic approach forms the basis for further developing the technologies created by work packages 2-5. Furthermore, we deliver the most relevant safety metrics to the subsequent work packages as suggested KPIs that will be further calibrated throughout the project to adapt them to the given use cases while considering novel safety parameters described in 4.4 KPIs definition process.

8.1. Safety Parameters and Metrics for Occupants and VRUs

In order to evaluate the safety of a system, one needs to define safety parameters, metrics, and subsequent KPIs obtained from the given metrics. The following definitions explain the mentioned terms in a context. Safety parameters are measurable or observable factors directly related to road users' safety. They are part of safety metrics and are the basis for analyzing, evaluating, and optimizing road safety systems. Examples of safety parameters include vehicle speed, positions, accelerations, and others.

Safety metrics evaluate and monitor traffic safety systems' and strategies' performance and effectiveness. They provide an accurate analysis of transportation safety matters and assist in identifying areas for improvement and prioritizing safety initiatives. Safety metrics are typically related to technical aspects and are usually linked to, or consist of, the relevant safety parameters. Examples of safety metrics include accident rates, time to brake, and other aspects, as listed in Subchapter **Error! Reference source not found.**.

The project touches new types of risks originating from new configurations caused by automated driving. From the passive safety point of view the new configurations do have particular influence on the seating positions that the automated modes will allow e.g., rearward sitting positions in the first row of seats. Such configurations bring new risks which must be analyzed and quantified, since state-of-the-art seat belts and airbags are inefficient to provide

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optimized protection. On the other hand, from the point of view of passive safety of vulnerable road users the risks are comparable with those of vehicles with lower levels of automation. From this reason, the passive safety investigation is focused on the vehicle occupant safety. The passive safety in this project deals only with vehicle occupants since the requirements for VRU safety are different.

Safety Parameters

AWARE2ALL aims to integrate new marginal groups into safety assessment and safety development and based on this, to take measures to minimize the severity of accidents. Concerning highly automated vehicles, new accident severity parameters arise. These must consider both new seating positions and the diversity of the people involved to ensure a consistently high level of safety. The research considers combining different safety parameters in one or many safety metrics. Table 21 describes new safety parameters for subsequent integration into existing and new metrics. To limit the range of parameters, the focus is on technically measurable or observable parameters that provide new and extended safety metrics for the subsequent evaluation in the context of this project and the selected scenarios. From the point of view of active vehicle safety, every human life is to be weighted equally and defined as irreplaceable. In this context, it is irrelevant from an ethical and legal point of view whether the VRU is disabled or generally deviates from the "standard type." Table 21 describes the safety parameters related to the scenarios and their potential implementation in active and passive safety.

Table 21. List of safety parameters

	Unit	Active safety	Passive safety
Body height	[m]		X
Body weight	[kg]	X	X
User persona		X	X
Seat rotation	[°]		X
Seatback Angle	[°]		X
Occupants number		X	X
Body height	[m]		X
Body weight	[kg]	X	X
Occupant seating direction	[°]	X	X

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8.1.1. Active Safety Metrics

The function of active vehicle safety is to actively avoid accidents or high risks to protect passengers and external VRUs. To measure the criticality or severity of a collision, one uses the combined safety parameters in the form of safety metrics. In active vehicle safety, there are various metrics, also concerning different accident participants. Typically, the level of criticality increases directly or indirectly proportional to a metric, such as "time to collision." For different accident opponent classes, criticality differs in absolute terms by a higher or lower threshold or relative to the weighting of the numerical value of a given metric. The challenge in developing and evaluating active vehicle safety is, among other things, the relative weighting of individual safety parameters and the weighting of holistic safety metrics.

New metrics are applied when supplementary or completely new degrees of freedom are provided. The vehicle type used in AWARE2ALL is state-of-the-art and built based on existing metrics and their additions. The basis for list of relevant metrics of active vehicle safety is the literature research of [37] and subsequent supplementary sources: [38], [39], [40], [41].

From the above sources, the fundamental metrics result below in Table 22.

Table 22. Active safety metrics

Metric	Unit	Definition	Required Safety Parameters	Calculation Manner	Source
Time to Collison (TTC)	[s]	Time till collision between ego vehicle and obstacle if they continued their present trajectory and speed	• Trajectories • Speeds • Obstacle dimensions	Continues and instantaneous	[42]
Time to Steer (TTS)	[s]	Time till last point in time where a collision between ego vehicle and obstacle can be avoided by steering	• Trajectories • Speeds • Obstacle dimensions • Evasive steering trajectory	Aggregated single value within a time period	[43]

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Time to Break (TTB)	[s]	Time till last point in time where a Collison between ego vehicle and obstacle can be avoided by breaking	• Trajectories • Speeds • obstacle dimensions • Longitudinal stopping distance	Aggregated single value within a time period	[43]
Time to React (TTR)	[s]	Time till last point in time where a collision between ego vehicle and obstacle can be avoided by breaking or steering depending on which is later	• Trajectories • Speeds • obstacle dimensions • Evasive steering trajectory • Longitudinal stopping distance	Aggregated single value within a time period	[43]
Time Exposed Time to Collison (TET)	[s]	Absolute time a vehicle is below the defined threshold for the TTC calculation	• TTC time sequence • TTC time threshold • Total time period	Aggregated single value within a time period	[42]
Time Integrated Time to Collision (TIT)	[s]	Integral of the TTC-profile for the time it is under the threshold	• TTC time sequence • TTC time threshold • TTC curve • Total time period	Aggregated single value within a time period	[42]
Modified Time to Collison (MTTC)	[s]	Modified models which consider all longitudinal conflict scenarios based on TTC	• Velocities • Accelerations • Relative distances • Vehicle/ obstacle dimensions	Instantaneous	[44]
Post Encroachm ent Time (PET)	[s]	Time between a road user leaves an area of potential collision and	• Vehicle's detection times • Vehicle's dimensions • Vehicle's	Instantaneous	[44]

		another one enters the collision area	speeds • Vehicles' trajectories		
Time to Accident (TTA)	[s]	Remaining time to accident beginning in the moment where one participant starts an evasive action and continues it unchanged	• TTC • Evasive maneuver detection • Vehicles' trajectory	Instantaneous	[40]
Deceleration Rate to Avoid Collision (DRAC)	m/s^2	Differential velocity between a response vehicle and its corresponding lead vehicle divided by their closing time	• Velocities • Positions • Vehicle dimensions	Instantaneous	[45]
Crash Potential Index (CPI)		Probability that a vehicle's DRAC exceeds its maximum available deceleration rate (MADR) for a given time interval	• MADR distribution • DRAC	Aggregated value over time interval	[45]
Proportion of Stopping Distance (PSD)		Ratio between remaining distance to the potential point of collision and the minimum defined stopping distance	• Minimum stopping distance • Point of potential accident	Instantaneous	[45]
Potential Index for Collison with Urgent Deceleration	[m]	Distance between ego vehicle and other road user when both stop completely	• Relative distance in between • Deceleration rate • Reaction time	Instantaneous	[40]

System Failures		Total number of system failures	• Computer flags	Aggregated	
System Deactivations		Total number of system deactivation	• Computer flags	Aggregated	
Manual Take-overs (MTO)		Number of intended and unintended manual takeovers	• Computer flags	Aggregated	[39]
Take-over Time (TOT)	[s]	Elapsed time since take-over request is sent until the user gets full control of the vehicle	• Computer flags	Instantaneous	[39]
Time to Detention (TTD)	[s]	Elapsed time for an emergency braking	• Speed	Instantaneous	
Traveled Distance at Braking (TDB)	[m]	Traveled distance since the emergency braking maneuver is requested until null speed is reached	• Speed	Instantaneous	
Safety Perception		Mean of multiple subjective user experience poll evaluations	• User experience polls	Aggregated	
Driver reaction time	[s]	Time between an event occurs and the driver performs a driving action (steering or pressing a pedal)	• Computer flags	Aggregated single value within a time period	[39]
Number of crashes		Number of times the ego vehicle having a collision with an HRU.	• Ego vehicle and HRU positions	Aggregated	[39]

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Number of near misses		Number of times the ego vehicle having a passing by another HRU by an unsafe distance.	• Ego vehicle and HRU positions	Aggregated	[39]
Lateral error	[m]	Deviation between the actual trajectory of the vehicle and the expected one	• Vehicle position	Instantaneous	[38]
Angular error	[rad]	Orientation of the vehicle with respect to the trajectory	• Vehicle orientation	Instantaneous	[38]
Time to stable performan ce	[s]	Time elapsed since the take-over maneuver is requested until the driver has full control in the steady state.	• Computer flags	Aggregated single value within a time period	

8.1.2. Passive Safety Metrics

The function of passive safety systems is to protect and mitigate the injury to occupants and VRU in the event of an unavoidable collision. Internal and external structure, airbags and restraint systems constitute passive safety systems. The main priority of the structural elements of a passive safety system is to effectively reduce the kinetic energy of the collision in a controlled manner and minimize component intrusions into the occupant cell, thereby reducing the acceleration and forces experienced by the occupant. The crash pulse (acceleration and forces transferred through the vehicle) formed from the structural deformation stage feeds as input for restraint and airbag systems within the occupant cabin. Typically, the seat belt is the primary restraint system which restrains and positions the occupant for an optimal airbag deployment. Supplementary restraint system (SRS); airbag, reduces the rate of occupant's deceleration by providing a cushion effect and distributing the kinetic energy over a larger surface. The performance of passive safety systems is evaluated by performance metrics of the vehicle and key injury risk indicators of the occupant(s). The passive safety metrics are presented in Table 23 and **Error! Reference source not found.** for the vehicle and occupant respectively. The occupant metrics that are most significant to fatal and severe injuries are located in the head, neck and thoracic regions.

A combination of passive safety systems (seat belt and airbags) will be deployed when a crash is unavoidable to mitigate the injuries and crash severity. Typically, seat belt is a primary restraint system which restrains and positions the occupant for an optimal airbag deployment. Supplementary restraint system (SRS); airbag, reduces the rate of occupant's deceleration by

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providing a cushion effect and distributing the kinetic energy over a larger surface. The performance of the passive safety systems is evaluated by evaluating key injury level indicators. The passive safety metrics are listed in Table 23. However, the passive safety system related significant metrics are for head, neck, and thorax.

Vehicle-level passive safety metrics:

There are numerous methods and metrics to evaluate the structural performance of a vehicle and its components for crashworthiness assessment. However, due to the variation in performance requirements of a specific component (which is dependent on the restraint systems, load-cases and vehicle drivetrain and surrounding architecture), the structural crashworthiness is evaluated by metrics that utilize a holistic approach to crash assessment. For example, a longitudinal crash rail can be assessed by peak crush force, mean crush force and the energy absorbed on a component level, but the overall crush distance of the vehicle is utilized in the assessment criteria due to the interaction of components and systems throughout the crash phase. Table 23 presents key vehicle-system-level passive safety metrics assessable in longitudinal and lateral crash scenarios.

Table 23 Vehicle-system-level passive safety metrics

Metric	Unit	Definition	Required Safety Parameters
Acceleration Severity Index (ASI)	-	This index gives the potential for occupant risk in crash events (The limit ASI are the values, below which the risk of the passenger's injury is very low).	• Velocity Curves
Ridedown Efficiency (μ)	[%]	The ridedown efficiency is ratio of maximum ride down energy density to initial occupant kinetic energy.	• Initial Velocity of the Vehicle • Ridedown Energy Density • Acceleration curve
Velocity Change (ΔV)	m/s	Velocity change is defined as the maximum change in vehicle velocity during a collision event.	• Initial Velocity of the Vehicle • Closing Velocity
Crash Severity Index (CSI)		It is ratio of Barrier Equivalent Velocity (BEV) of subject vehicle to the closing speed.	• Barrier Equivalent Velocity • Closing Velocity • Stiffness and Mass ratio

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Crush Distance	m	Maximum deformation of the vehicle ascertained through crash phase (before restitution).	Maximum displacement (relative)
Passenger Compartment and system integrity	m	Maximum intrusion of components that form the occupant and system cells.	Maximum displacement (relative)

Occupant-level passive safety metrics:

The combination of vehicle structure performance and restraint system performance provides an overall outcome of injury risk to the occupant(s) of the vehicle. The metrics and their criteria depend on the crash scenario, the occupant positioning within the vehicle and the passive safety systems (such as airbags) employed within the occupant compartment. Therefore, Table 24 provides occupant level safety metrics for all considered scenarios [46].

Table 24 Occupant related passive safety metrics

Region	Metric	Unit	Definition	Required Safety parameters
Head				
	3ms Exceedance	m/s^2	Peak acceleration exceeding 3 ms window	Triaxial components of head acceleration
	Head Injury Criterion (HIC)	-	Measure of likelihood of a head injury as a function of acceleration	Aggregated head acceleration (time window for maximum value)
Neck				
	Tension	kN	Maximum tension observed throughout the neck at different time intervals throughout crash phase	
	Compression	kN	Maximum compression observed throughout the neck at different time intervals throughout crash phase	

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	Shear	kN	Maximum shear observed throughout the neck at different time intervals throughout crash phase.	
	Sagittal bending moment	Nm	Bending moment in the sagittal plane of the occupant exhibiting Flexion/Extension shape of the neck	
	Lateral Bending Moment	Nm	Maximum Lateral Bending Moment of the neck	
Thorax				
	Combined Thoracic Index (CTI)		CTI is the sum of normalized chest acceleration and the chest deflection.	• Maximum observed acceleration and deflection •Maximum allowable acceleration and deflection
	Viscous Criterion (VC)	m/s	Rate dependent viscous injury mechanism.	Maximum value
	Rib deflection	mm	Rb deflection of at least 3 positions in thoracic cavity.	Rib Locations
	Thoracic Trauma Index (TTI)	m/s^2	Injury prediction related to mean of maximum lateral acceleration of ribcage and the lower thoracic spine.	Maximum lateral acceleration of 4th and 8th rib and maximum lateral acceleration of T12 vertebrae.
	Rib Deflection rate	m/s	Maximum deflection rate of ribs.	
Spine				

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	T1 Acceleration	m/s^2	Acceleration components of the T1 Vertebrae.	
	T4 Acceleration	m/s^2	Acceleration components of T4 Vertebrae.	
	T8 Acceleration	m/s^2	Acceleration components of T8 Vertebrae.	
	T 12 Acceleration	m/s^2	Acceleration components of T12 Vertebrae.	
		m/s^2	C2 acceleration.	
		mm/ms^2	L1 acceleration.	
		kN	Spine axial force C2,T1 & L1 (check for laxity).	
		kN	Spine shear force C2, T1 & L1 (check for laxity).	
		kN	Lumbar forces.	
		Nm	Lumbar Moments.	
Pelvis				
	Rotation	°	Maximum rotation of the pelvis in relation to the spine.	
	Pelvic Forces	kN	Maximum forces recorded at the Pubic symphysis, Iliac & acetabulum.	
	Pelvic Acceleration	m/s^2	Maximum pelvic acceleration recorded at the Pubic symphysis.	
Legs				

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		kN	Femur axial forces.	
		kNm	Femur moments.	
		kN	Tibia forces.	
		kNm	Tibia moments.	
	Sliding Knee Joint	mm	Maximum knee Joint Displacement.	Displacement of the tibia with respect to the femur.

8.2. High-level System Requirements with KPIs

In this chapter, we address the safety challenge in the development of Highly Automated Vehicles (HAVs), where occupants can freely orient themselves and engage in non-driving activities, focusing on the requirements and performance evaluation. The first sub-chapter outlines high-level system requirements for active and passive safety, while the second sub-chapter discusses the methodology for selecting Key Performance Indicators (KPIs) to assess and evaluate the performance of these innovative seating systems. Throughout the chapter, we emphasize the importance of maintaining safety standards and accurately measuring improvements in the context of this novel seating configuration.

8.2.1. High-level System Requirements

A new reclined seating positions for cars, which offers increased relaxation and a more comfortable experience during long drives or autonomous vehicle operation, presents also new challenges and requirements to ensure the safety and well-being of occupants. A comprehensive list of high-level system requirements and key performance indicators (KPIs) to guide the design and implementation of reclined seating positions in cars while maintaining optimal safety standards is presented below. The requirements are organized into active safety, and passive safety, addressing the various factors involved in this new seating configuration in near accident, pre-crash and crash situations.

The high-level system requirements cover the general specifications of the automated vehicle functionalities independently of the specificity of each demonstrator. These requirements highly the main technologies to be developed within AWARE2ALL. Table 25 shows the requirements related to active safety, and Table 26 is the equivalent for passive safety systems.

Table 25. High-level system requirements for active safety systems

#	**Active safety high-level requirements**
1	System has to detect the state of the driver
2	System has to detect the state of the passengers

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3	System has to detect and classify VRUs
4	System has to detect surrounding obstacles
5	System has to perform longitudinal and lateral control of the vehicle
6	System has to communicate with the driver through multimodal HMI
7	System has to communicate with the passengers through multimodal HMI
8	System has to communicate with other road users through eHMI
9	System has to perform minimum risk maneuver
10	System has to issue take-over requests to the driver
11	System has to predict risk of collision
12	System has to detect and adjust to changing road conditions (e.g., wet, icy, rough terrain).
13	System has to recognize and respond to emergency situations (e.g., sudden braking, evasive maneuvers).

Table 26. High-level system requirements for passive safety systems

#	Passive safety high-level requirements
1	System should avoid occupant ejection in case of rollover or side-impact collisions.
2	System should avoid occupant body part excursion
5	System should be designed to prevent submarining (sliding under the seatbelt) in reclined positions during frontal collisions.
6	System should minimise risk of occupant limb impact with hard interior parts of the cabin. Energy-absorbing materials and structures in the seat design should be incorporated to minimize injury risk during collisions.
7	System should minimise risk of energy storage no integrity
8	System should minimise instantaneous and extended acceleration of the occupant
9	System should minimise forces experienced by the occupant during impact
10	System should adapt for different, relevant, user profiles with sensors to detect occupant's position and anthropometry and adjust restraint systems (e.g., seatbelt

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	tension, airbag deployment) accordingly for optimal protection for all passengers in various reclined positions.
11	System should maintain structural integrity of occupant cell
13	System has to monitor and adjust the reclined seating position and restrain system based on vehicle speed and driving conditions.
14	System should pre-tension the restraint system and adjust the seating position when impact is unavoidable (returning the seat to an upright position during a crash)
15	System should provide adequate head, neck, and spinal support for occupants in rear-facing and reclined positions, minimizing the risk of injury during a collision.
16	System should ensure proper positioning of side-impact airbags and curtain airbags to protect occupants in reclined and rear-facing positions.
17	System should minimize the risk of injury due to intrusion or deformation of vehicle structure in the event of a collision.
18	System should be designed to prevent luggage or other cargo from intruding into the occupant space during a collision.

8.2.2. KPI Definition

In the context of later development and evaluation stages, crucial safety metrics are employed to comprehensively assess the performance of newly developed systems. The evaluation process typically involves comparing the novel technology to an established baseline by utilizing one or more metrics to quantify the extent of improvement over the existing system. However, the challenge lies in navigating the vast array of available metrics and their intricate safety parameters.

To address this issue, it is common practice to focus on a selected group of vital metrics designated as Key Performance Indicators (KPIs). A possible assortment of metrics is presented in Table 22 and **Error! Reference source not found.**, where novel safety parameters have not been considered thus far. The methodology for identifying suitable KPIs revolves around examining well-established metrics from the literature.

These potential KPIs are then filtered based on their relevance to the defined use cases and are assessed for compatibility with the new safety parameters detailed in Table 21. The primary challenge is integrating these novel safety parameters into existing or newly developed safety metrics, thereby ensuring a valuable and meaningful quantification of improvements without imposing an excessive testing burden.

At this early stage of the project, it is not feasible to finalize the KPIs. As a result, the working group is concentrating on developing the methodology and preliminary selection process as a foundation for further work in work packages 2-5. This approach aims to deliver high-level KPIs that will effectively measure the performance and safety of the developed systems in a comprehensive and meaningful manner.

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9. Workshops

An extensive literature research is carried out during tasks T1.1 and 1.2. To share the knowledge and research, several workshops were held by THI and Capgemini, with different objectives for partners and external parties.

To synchronize progress and information, it was decided that the first workshop would be held jointly, while the second workshop would be held separately with more detailed objectives. Information regarding the objectives and results of these workshops can be found below.

9.1. Workshop1 – Overview task T1.1 and T1.2

This first workshop was aimed at partners involved in R&D initiatives in relation to the AWARE2ALL project to share with the other partners their knowledge on results, regulations, or standards in the field of research. This session was held jointly between task T1.1 and T1.2, and had the following objectives:

- **T1.1 Critical scenarios and accident types**

  Share the working methodology and defined parameters to establish the basis for critical scenarios and types of accidents. In addition, collect feedback from partners to refine the research conducted.

- **T1.2 Occupants & VRUs safety parameter identification and high-level system requirements with KPIs**

  Gather the relevant functional scenarios and prioritize the safety parameters for both active and passive safety systems. The results of the first workshop serve as the basis for the definition of the high-level system requirements and KPIs.

9.2. Workshop 2 – External workshop of T1.1

As part of the activity planned for task T1.1, a second workshop organized by CAP is envisaged. This session is called *Workshop 2: Critical scenarios and new accident types*. It was a workshop open to external parties, where the results of the initially defined scenarios and accident types were presented. The participation of external parties was supported by WP6 (C&D&E). The main objectives pursued were:

Share knowledge about critical scenarios and new accident types that occur when introducing autonomous vehicles in mixed traffic environments.

Gather feedback from the attendees (stakeholders and similar projects) to complete the work base and continue with the development of the AWARE2ALL project. The KPI was set as 20 participants.

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Figure 27. Workshop2: Critical Scenarios & New Accident Types

As can be seen in Figure 27, this meeting was held on 16 March 2023. To reach the widest possible audience, a dissemination campaign was carried out in collaboration with WP6 through the following actions:

- Sending e-mails to the different partners to contact experts.
- Publication of a post on LinkedIn and Twitter.

It resulted in the participation of 50 attendees, including people from other projects or organizations outside the AWARE2ALL project. At the end of the session a questionnaire was shared in order to collect feedback from the participants. This questionnaire asked about issues related to the selection of user-persona, the definition of functional scenarios and the identification of the main challenges and types of accidents to be considered.

The responses obtained correspond to different sectors, as shown in the graph below.

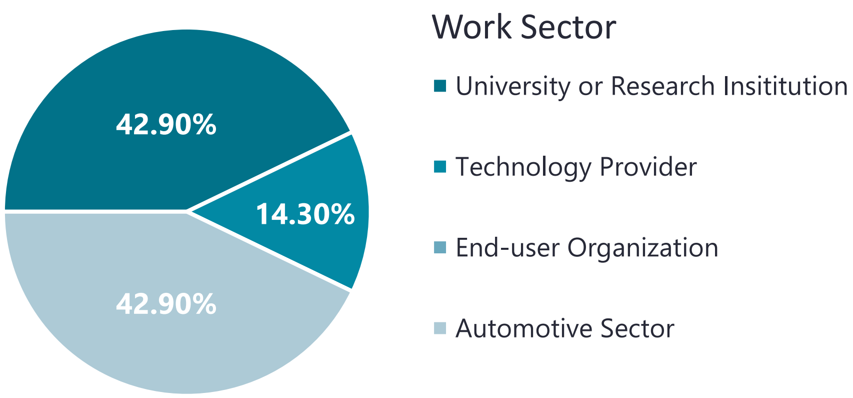

Figure 28. Graph of percentage of responses by sector.

The diversity of the user persona, including functional diversity, gender, age, and race, is positively validated by the responses.

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With regards to the challenges presented, the comments indicate the complexity of the challenge in achieving effective communication between human and machine, both with the occupants and with the people around them.

Finally, the variety of scenarios proposed as the basis for the creation of the use cases is validated by all the responses.

9.3. Workshop 2 – Second workshop T2.2

In order to allow the next work packages to define and adapt the KPIs according to their needs the metrics need to be evaluated regarding their relevance for each demonstrator. The second workshop for task T1.2 therefore aims to analyze the necessity of each metric for all the four demonstrators. We discussed using the metrics in the respective work packages concerning potential threshold values or existing empirical values from the literature. The goal was to connect the safety parameters and metrics for the demonstrators at an early stage. With the participants' previous experience, the possible impact of the new methodologies on the later evaluation was estimated and adapted with regard to this.

10. Conclusions

The introduction of Highly Automated Vehicles (HAV) to the market poses several challenges related to the diversity of the population and the changes in user behavior and traffic situations. The development of HAVs requires consideration of different use-cases and technologies to cater to the diverse needs of different user groups. This is crucial to ensure that the benefits of HAVs are available to all segments of the population, regardless of factors such as age, gender, and functional diversity.

The AWARE2ALL project aims to enable the evaluation of the impact of HAV-introduction on users not usually considered in the studies, and other traffic participants while expanding the Operational Design Domain (ODD) of HAVs. This project defines a set of metrics that are assigned to demonstrator technologies and proposes prioritization for the Key Performance Indicator (KPI) definition in the subsequent work packages.

One of the challenges of HAVs tackle in AWARE2ALL, is the effective communication between humans and machines. The human-machine interaction can be complex, especially when communicating with both occupants and people around them. This is crucial for ensuring the safety of everyone involved in the traffic system.

Furthermore, the introduction of HAVs to the market also requires consideration of the impact on the overall traffic situation. This includes the need for the HAVs to share the road with other vehicles and vulnerable road users such as pedestrians and bicyclists. The diversity of scenarios put forward in the AWARE2ALL project serves as the basis for the creation of use-cases that enable the evaluation of HAV-introduction in different traffic situations.

All these considerations have been taken into account as basis to define the critical accident scenarios and high-level requirements. Therefore, the current document highlights the need for diverse user representation, together with the functional scenarios considered, that will drive the validation of the AWARE2ALL technology in the divers demonstrators tackled in AWARE2ALL.

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