D3.4 Demo 4 System for on-time warning provisions to VRUs and drivers in critical conditions

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Executive summary

The SAFE-UP project aims to proactively address the novel safety challenges of the future mobility systems through the development of tools and innovative safety methods that lead to improvements in road transport safety.

Future mobility systems will rely on partially and fully automated vehicles to reduce traffic collisions and casualties by removing causal factors like driver distraction, fatigue or infractions and by reacting autonomously to emergency situations. On the other hand, they may introduce new collision risk factors or risky behaviours when interacting with other traffic participants.

SAFE-UP's Work Package 3 is handling the "Active safety systems for vehicle-VRU interaction" which is split to 3 demonstrators.

The first demonstrator of WP3 (Demo 2) handles the perception part of this active safety solution also in adverse weather conditions and will extend the object detection possibilities.

The second demonstrator of WP3 (Demo 3) is generating the active safety intervention (evasive manoeuvring).

The third demonstrator of WP3 (Demo 4) uses the C-ITS communication for exchanging information and generating warnings. The communication is established through four V2X modules implemented inside a vehicle, on a Road-Side Unit (RSU), on a VRU handheld device and on a bicycle On Board Unit (OBU).

This deliverable is a preliminary document that includes information collected and consolidated for the first version of Demo 4. The main focus for the work performed and reported in this Deliverable is divided in three layers:

1) **SCENARIOS:** Selecting and defining the scenarios and test runs for both pedestrian and cyclist conflicts, based on the developed knowledge of T2.1 (D2.6).
2) **DEVELOPMENT:** Developing the first prototypes of the Vehicle and VRU components of the Demo.
3) **VALIDATION:** Assessing the performance of the current developed subsystems on a) interoperability level, and b) on proving ground using a selected test scenario.

The updated and final version of this document will be available on Month 28 of the project (D3.7).

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List of abbreviations

Abbreviation	Meaning
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AV	Autonomous Vehicle
B-CL	Bicyclist crossing from left (D2.6)
B-CR	Bicyclist crossing from right (D2.6)
B-PCTurnL	Bicyclist in conflict with Passenger Car turning left (D2.6)
CAM	Cooperative Awareness Message
CBDA	Car to Bicycle Door-opening Adult (Euro NCAP)
CBNA	Car-to-Bicyclist Nearside Adult (Euro NCAP)
CBNAO	Car-to-Bicyclist Nearside Adult Obstructed (Euro NCAP)
CBTA	Car to Bicycle Turning Adult (Euro NCAP)
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CPNC	Car-to-Pedestrian Nearside Child (Euro NCAP)
DENM	Decentralized Environmental Notification Message
ECU	Electronic Control Unit
ETSI	European Telecommunications Standards Institute
Euro NCAP	European New Car Assessment Programme
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interface
IDAPT	IDIADA ADAS Platform Tool
IMU	Inertial Measurement Unit
ITS-G5	European implementation of WLANp based on IEEE 802.11p or extended IEEE 802.11bd
kph	kilometres per hour
KSI	Killed or Seriously Injured
LDM	Local Dynamic Map

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Abbreviation	Meaning
LSS	Lane Support Systems
LTE	Long Term Evolution
OBU	On Board Unit
P-CLwSO	Pedestrian crossing from left with sight obstruction (D2.6)
P-CRwSO	Pedestrian crossing from right with sight obstruction (D2.6)
P-PCTurnL	Pedestrian in conflict with Passenger Car turning left (D2.6)
RQ	Research Question
RSU	Road-side Unit
RTK	Real-time kinematic positioning
SAE	Society of Automotive Engineers
SOTA	State of the Art
V2X	Vehicle-to-Everything
VAM	VRU Awareness Message
VEH	Vehicle
VRU	Vulnerable Road User
WP	Work Package

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1 Introduction

1.1 The EU Project SAFE-UP

The SAFE-UP project aims to proactively address the novel safety challenges of the future road mobility environment by developing tools and innovative safety methods, leading to improvements in road transport safety.

Future mobility systems are expected to make use of vehicles with full or partial automation of the driving task, the so-called SAE L3/4/5 vehicles (SAE International, 2018). By supporting (or even replacing human) drivers during the driving task, such vehicles may help improve road safety by removing some of the known sources of collisions (e.g., driver distraction) or by taking control during critical situations (e.g. automated emergency braking). On the other hand, automated vehicles may introduce new collision risk factors (e.g., increased distraction during transition of control) or induce new risky behaviours in other traffic participants (Hamilton, 2019).

The true impact of vehicle automation technologies on road safety will become apparent in the decades to come, as it depends on social and market trends that are difficult to forecast (like technological developments in sensors for automated vehicles, market penetration and acceptance of automation technologies, etc.).

The work of Work Package (WP) 3 of the SAFE-UP project will extend the active safety system possibilities with the objective to reduce the number of fatal injuries and serious injuries in future traffic scenarios, defined by WP2.

This overall target is divided in several tasks. Task 3.1 is describing the active safety system requirements and architecture as well as the risk assessment methodology. In Task 3.2 the perception system is developed and shown in Demo 2 vehicle with research sensor configurations and in Demo 3 vehicle with a sensor configuration closer to serial applications. Task 3.3 is generating the software architecture and the corresponding algorithm, which are then implemented inside the active safety system. Task 3.4 will use the algorithm of Task 3.3 and build up the Demo 3 vehicle for evasive manoeuvring. In Task 3.5 the Demo 4 components are developed addressing the potential of connectivity in enhancing vehicle perception and VRU safety. Task 3.6 collects all three demo performance verification data and consolidates the final performance review as an output to WP5.

1.2 Objective of this Report

This report presents a summary of the actual (initial) status of the Demonstrator 4, which in a nutshell includes:

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- Updates of the overall system, vehicle subsystem and VRU subsystem architectures preliminary defined in D3.1 (Nikolaou & Panou, 2021).
- Status of Vehicle and VRU device components.
- Scenarios selection based on D2.6 findings (Bálint, et al., 2021).
- Interoperability validation between V2X vehicle unit and VRU device unit.
- Preliminary demo testing focusing on the validation of the fusion implementation with on-board sensors (camera, LiDAR and RADAR) before V2X and the validation of the AEB implementation focusing on one selected testing scenario (Demo_4_02).
- Next steps towards final implementation of the demonstrator.

1.3 Report Organization

The report is organised as follows: **Section 2** presents the overview of Demo 4 scope (Section 2.1), as well as an update of the research questions (Section 2.2) preliminary identified in D5.1 (Mensa, et al., 2021). **Section 3** includes the updates of the overall demo architecture, as well as of its three main components; vehicle component (Section 3.1), VRU component (Section 3.2) and RSU component (Section 3.3), which were preliminary defined in D3.1 (Nikolaou & Panou, 2021). In **Section 4**, the methodological approach towards the Demo 4 scenarios identification based on D2.6 findings (Bálint, et al., 2021) is presented (Section 4.1), resulting to four scenarios for pedestrians and three scenarios for cyclists (Section 4.2). Furthermore, the applicability of Demo 4 on future scenarios is also discussed (Section 4.3). **Section 5** describes the current development status for each of the three main components of Demo 4 (Sections 5.1.1-5.1.3), whereas **Section 6** presents the results of the preliminary validation tests regarding communication interoperability between the vehicle V2X unit and the VRU unit (Section 6.1), as well as the validation of the fusion of vehicle on-board sensors and the AEB implementation relevant to one selected testing scenario (Section 6.2). Finally, **Section 7** discusses the planning and next steps towards the final implementation of Demo 4, and **Section 8** summarises the outcomes of this report.

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2 Demo 4 Overview

2.1 Overall Demonstrator scope

The safety potential of the C-ITS technology in future road traffic ecosystems has been recognised both on technological and policy level by the European Commission. In compliance with the technological framework, the final report of the C-ITS platform highlights that collaborative perception of VRUs and drivers/vehicles is expected to harvest the expected safety benefits of C-ITS implementation, ensuring interoperability and fast deployment (European Commission, 2017). From the policy perspective, the update of the EU Road Safety Policy Framework 2021-2030 (European Commission, 2020) recognises that the goal set by the European Commission in 2010 on halving road fatalities by 2020 was not reached and the policy was extended to 2030, whereas still today around 70% of accidents in urban areas are involving VRUs and 25% are involving drivers (European Commission, 2021a). This updated road safety policy framework identifies that connectivity is expected to demonstrate tremendous road safety potential, which is in line with the recent recommendation by the EU Commissioner for Mobility and Transport that future initiatives should focus on the exploration of new technologies that will *“allow vehicles to ‘talk' to each other, to the road infrastructure, and to other road users”* (European Commission, 2021b).

Demo 4, therefore, focuses on investigating the safety benefit of a communication framework referred to as C-ITS, considering all the possible communication interactions that can take place, such as timely warnings (to both VRU and driver), as well as actuation of vehicle safety systems. The primary focus is related to the provision of timely warnings which could support in avoiding safety-critical situations between passenger cars and VRUs (pedestrians and cyclists). However, since the approach should be considered on a holistic manner with primary focus on the reduction of KSI (Killed or Seriously Injured) figures, the triggering of active safety solutions by communication framework is also analysed. Nevertheless, this does not mean that Demo 4 aims at developing a new generation of active safety systems, but rather to understand a potential safety benefit of current active safety systems through enhanced C-ITS based perception.

Overall, it has to be considered that this Demo is not aiming at delivering a ready to use product, but rather to develop a prototype in order to assess the safety potential of the communication framework. The results of this work may be used for future integrated developments into the heart of vehicle decision systems, but also on overall Connected, Cooperative and Automated Mobility (CCAM) ecosystems fostering safe co-existence of traffic participants in future mixed traffic situations.

Furthermore, there are additional challenges that the Demo 4 will not be able to address and that should be considered for further research. Such challenges include, among others, the position accuracy of both VRUs and vehicles, the integration of standard signals from the communication environment to the vehicle and also the fact that tests will be performed in controlled environments. Due to testing in controlled environments, aspects such as false

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activations of the AEB VRU system and evaluation of the perception and acceptance of warning messages by the users, will not be properly addressed. Those challenges will be defined more concretely in the final deliverable of Demo 4.

2.2 Research Questions

The identification of the research questions associated with Demo 4, will facilitate the assessment of the safety effectiveness of the Demo, as well as allow to better specify both its focus and the targeted achievements.

In D5.1 (Mensa, et al., 2021), two initial research questions for Demo 4 were drafted. Since however, the Demo 4 work was launched after the submission of D5.1, there is a need to update those research questions, in order to better fit Demo 4 scope and measurable targets.

Based on both the Demo 4 focus explained in Section 2.1 and the considerations above, the proposed research questions for Demo 4 are updated as follows:

- **RQ 1:** "What is the safety benefit of a VRU C-ITS warning system on connected VRUs in supporting them to mitigate safety-critical events with passenger cars, triggered by a radio signal based (OBU, VRU-smart device) communication and detection system, in terms of KSI injury reduction on EU level in 2025 compared to the 2016 numbers for Car to VRU collisions on urban roads?"
- **RQ 2:** "What is the safety benefit of a VRU C-ITS warning system on vehicle drivers in supporting them to mitigate safety-critical events with connected and non-connected VRUs, triggered by a radio signal based (OBU, RSU, VRU-smart device) communication and detection system, in terms of KSI injury reduction on EU level in 2025 compared to the 2016 numbers for Car to VRU collisions on urban roads?"
- **RQ 3:** "What is the safety benefit of a vehicle equipped with an active safety system (e.g. AEB) that is enhanced by a radio signal based (OBU, RSU, VRU-smart device) communication and detection system, in terms of KSI injury reduction in EU urban roads in 2025 compared to the 2016 numbers and the same safety system with SOTA VRU detection system?

It should be noted that in the SAFE-UP Grant Agreement the safety impact numbers associated with Demo 4 are measured in MAIS5+. However, the Demo 4 team after following the recommendation of the T2.1 accidentology experts and authors of D2.6, decided to adapt to KSI numbers instead. This allows to better align the Demo 4 scenarios with D2.6 findings (see Section 4), in order for the results to be comparable.

The above updated research questions are also referenced in D5.2 (as an update to D5.1) for coherence purposes, as its submission date coincides with the submission date of this report.

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3 Architecture

The initial version of the Demo 4 architecture was presented in D3.1 (Nikolaou & Panou, 2021), and its update is presented in this section. The architecture of this demonstrator reflects the need to interconnect the infrastructure, VRUs and vehicles all together to prove the potential benefit of the V2X technology by assessing on-time warnings to drivers and VRUs on risky situations, as well as evaluating the performance of an in-vehicle active safety system compared to the State-of-the-Art (SOTA) without V2X technology.

The updated version of the architecture is available in Figure 1, where the functional architecture of the three main Demo 4 components is shown, as well as their interaction channel via V2X.

Every component has its own sensors (green boxes in Figure 1), which are a combination of perception capabilities (V2X, cameras, LiDARs, etc.) and local systems (GNSS, IMU, etc.). The former feed the internal perception system, in order to be able to create a map of the surroundings, including other vehicles, pedestrians, roadside systems, etc.

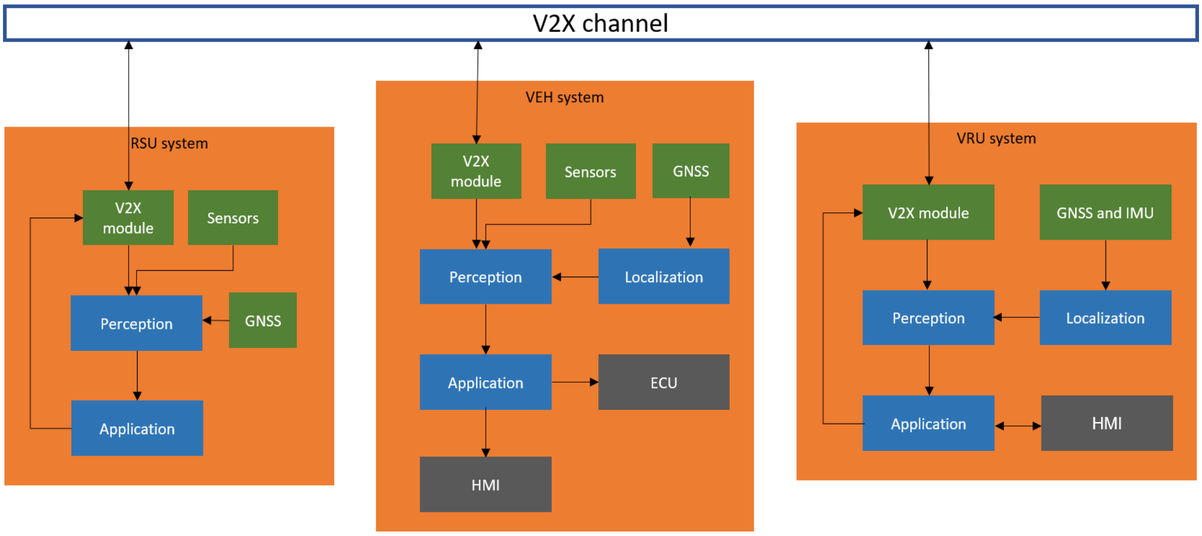

Figure 1: Demo 4 overall architecture (update from D3.1).

All components are able to communicate with each other, since they share the same technology and channel. However, based on the objectives of the Demo 4, some interactions might not be required to prove the performance of the safety systems.

For example, no information exchange is required between the RSU and the connected VRUs, since the RSU role is to detect non-connected VRUs via sensors and transmit this information to the vehicles. Therefore, the main interactions are between the VRU and the vehicles, and from the RSU to the vehicles.

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3.1 Vehicle component architecture

The vehicle is a key actor that uses V2X information to properly evaluate collision probabilities with nearby VRUs and proactively warn the driver and/or react automatically to minimise or avoid collision risk situations. The vehicle architecture's main concept (see Figure 2) is the link between the perception (including V2X) and the in-vehicle safety system ECU (AEB in this case).

A commercial vehicle from Toyota Motor Europe is going to be used for the final demonstrator, while an IDIADA AV vehicle is being used for the intermediate demonstrator. In both cases, the architecture remains unchanged, considering that the internal ECU is standard for every vehicle.

The demo vehicle is equipped with an IDAPT (IDIADA ADAS Platform Tool) device, which is able to aggregate all perception sensors information from cameras, LiDAR, RADAR and V2X module and then fuse them. Once fused, the vehicle will need to determine whether the output objects represent a risk based on its own positioning and dynamics data. Algorithms with different objectives are expected to be executed; one for the risk calculation to warn the driver and another for the collision probability calculation to trigger the AEB if required (i.e. in case the driver is not responding or the time to react is too low). Both are expected to work independently with different trigger parameters despite having the same goal (collision probability calculation). They are both running on the Driving Function Unit but with different output, since one trigger the HMI and the other will trigger the braking system though the AEB ECU.

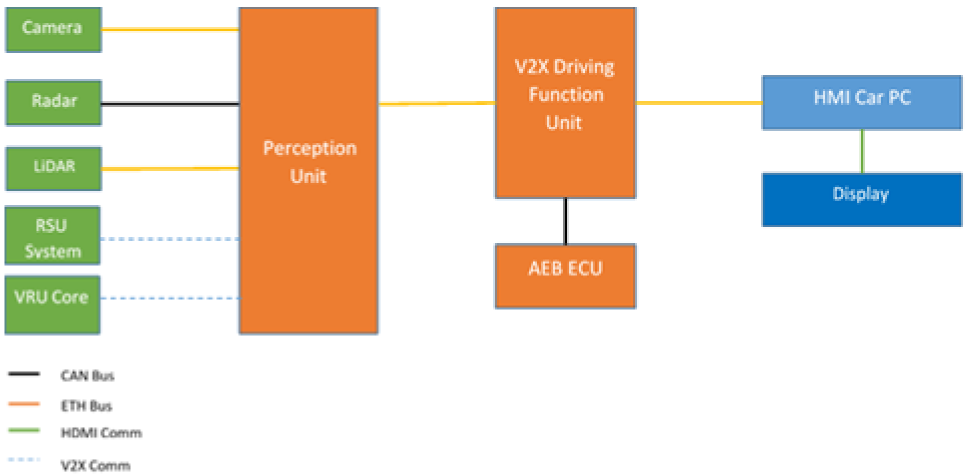

Figure 2: Vehicle demonstrator architecture.

3.2 VRU component architecture

In Demo 4, VRUs (pedestrians and cyclists) become active members of a C-ITS ecosystem with the exchange of V2X messages. The connectivity of a vulnerable road user can have a significant impact regarding traffic safety by increasing the awareness levels of all other ITS

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stations that are in range. Also, the received awareness and notification messages from other connected actors, enables the evaluation of dangerous situations by the device itself, making possible audio and visual alerts and warnings when a risky situation is predicted. For this scope a special prototype handheld device has been designed and developed. The VRU device architecture is presented in Figure 3.

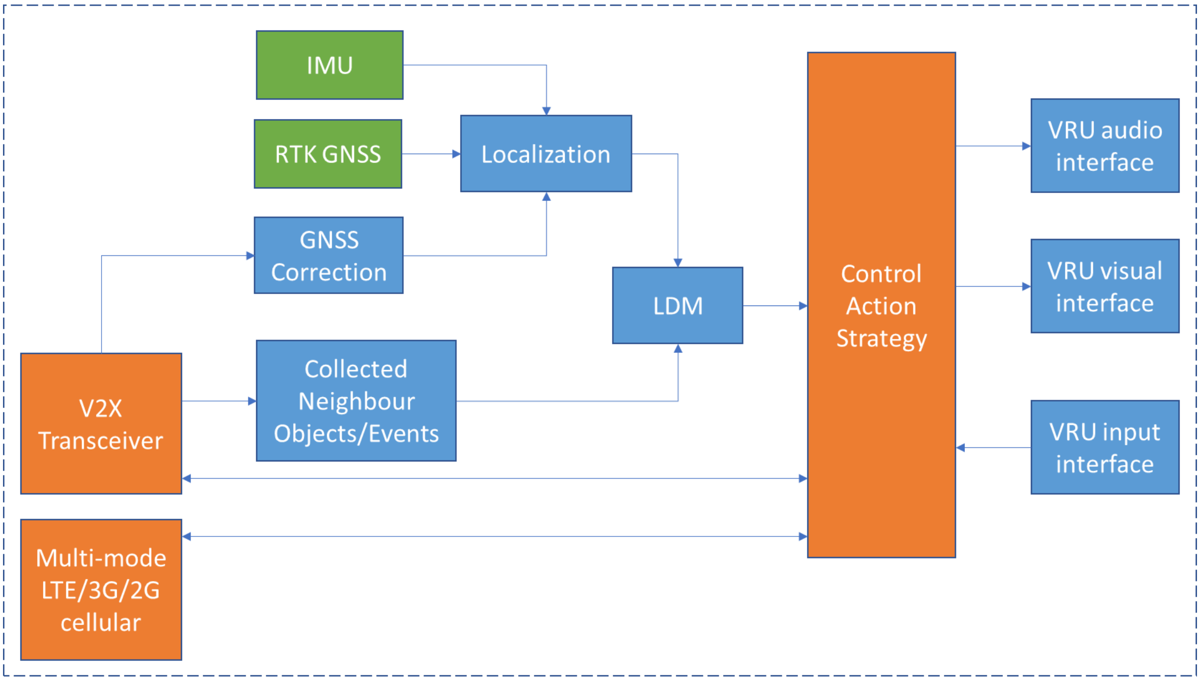

Figure 3: VRU device physical architecture.

It has to be stated however, that the parts reflected in the VRU architecture diagram are currently at a different stage of development maturity. This is described later within this report, in the development status section (Section 5.1.3).

The VRU device physical architecture may be slightly updated at the final version of Demo 4 for the cyclist case, depending on what will be available for the actual demonstration. Bicycle mounted sensors for speed, brake and steering wheel angle detection, can further increase the accuracy of bicycle awareness information.

3.3 RSU component architecture

The RSU role is to detect VRUs in its field of view and report this information to the nearby vehicles via V2X.

The RSU architecture contains a LiDAR and a Camera, the information of which will be fused using an IDAPT device to have a map of the VRUs (Pedestrians and Cyclists) nearby. Such detected "objects" will be reported immediately to the nearby vehicle using V2X communications. The RSU architecture is described in Figure 12 of D3.1 (Nikolaou & Panou, 2021).

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The RSU is under development at this stage of the project; hence it is not part of the intermediate demonstrator described in Section 5.

4 Scenario selection

When selecting the relevant scenarios, we need to consider the scope of the Demo 4 as well as the related Research Questions.

From the research questions (Section 2.2), two important aspects that have to be considered can already be identified. The first aspect is addressing the need to focus on scenarios which are related to KSI injuries. The second aspect is that from the RQ3, it is derived that the baseline case is a vehicle with an active safety system (e.g. AEB), with a SOTA VRU detection system. It should therefore be identified, which scenarios are aimed to be addressed nowadays by such systems. Those considerations will be analysed more concretely in the scenario selection method described in Section 4.1 below.

Additionally, as mentioned under D5.1, the Demo 4 scenarios shall focus on urban areas related to VRUs, with emphasis in non-designated crossings for pedestrians, as well as intersections for cyclists. Consideration of new interactions between VRUs and drivers will also be taken into account. Therefore, the scenario selection process will pay special attention at those contexts.

4.1 Scenario selection method

Considering the insights depicted above, the method defined to select the scenarios will take into account three specific inputs:

1. The accidentology results performed in SAFE-UP within D2.6 (Bálint, et al., 2021): This document provides the reference figures in terms of relevant passenger car to VRU collisions associated with serious injuries and fatalities (KSI). Based on this, Demo 4 will take into account the findings and recommendations made, for those scenarios relevant to C-ITS solutions.
2. The SOTA of active safety system with VRU detection, which is the baseline for the part of Demo 4 dealing with the triggering of active safety systems. This will be done by considering the (Euro NCAP, 2020) protocol which addresses not only the activation of AEB VRU systems but also the warnings provided to drivers.
3. C-ITS technology relevant cases, taking into account situations where communication may have a safety benefit potential, such as the case where there are obstructions that hinder the VRU visibility by a vehicle.

The first point provides a clear overview of the accident data, split by conflict situation (e.g. crossing, longitudinal) and type of VRU (cyclist, pedestrian).

The second point is providing what is the SOTA in terms of AEB VRU technology. It should be noted that this represents an innovation aspect compared to the SAFE-UP Grant

Agreement which referred to accident figures from 2016 and therefore could not reflect on what the effect of AEB VRU systems could be on such figures, since the penetration of such systems was not relevant at that time, considering that the first adoption of a Euro NCAP protocol for AEB VRU was in 2016 (Euro NCAP, 2015). The consideration of the Euro NCAP 2020 protocol scenario selection does not mean that Demo 4 scenarios shall go beyond the existing protocol, since it is possible that SOTA AEB VRU systems or SOTA VRU warning systems for drivers do not address fully all the scenarios in the protocol; however it provides a good reference on which scenarios current technologies are aiming to address.

Another important aspect regarding this second point is that some of the existing scenarios in the Euro NCAP 2020 protocol, may pose challenge for current technology in terms of sensor detection or the necessary time for a system to activate. As mentioned under the Section 2.1, the Demo 4 is not aiming at developing an updated AEB solution to replace the actual systems, since it is expected that technology will evolve and may improve today's limitations. That is why, Demo 4 will not just look at which scenarios are not addressed by SOTA AEB VRU in the current protocol, but mainly which ones are fundamentally challenging for AEB VRU systems, such as when there is a clear system limitation due to lack of field of view (e.g. obstruction cases) which is something that may be more difficult to address by system or/and sensor improvements.

Based on the three inputs mentioned above, the proposed method to define the scenarios to be addressed by SAFE-UP Demo 4 is shown in Figure 4.

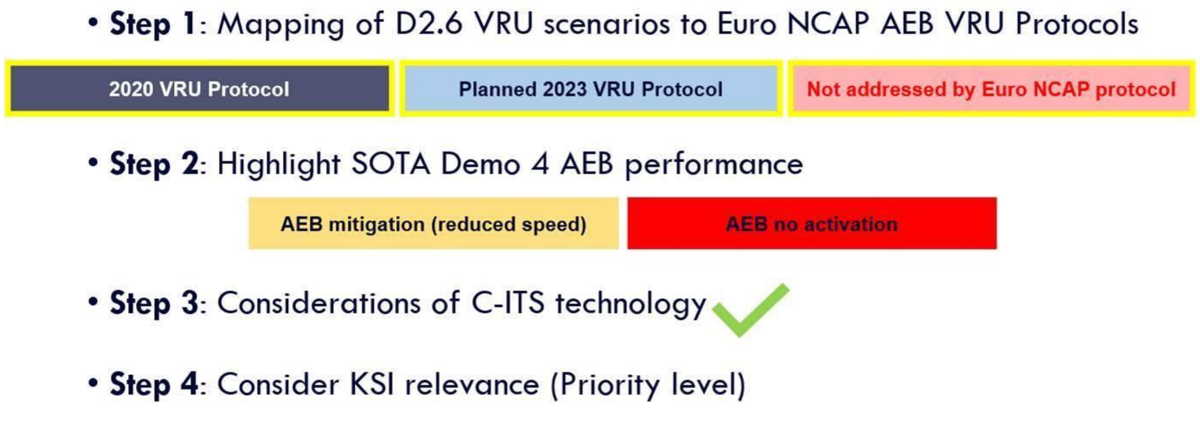

Figure 4: Method to define Demo 4 addressed scenarios.

The first step focuses on mapping the SAFE-UP D2.6 (Bálint, et al., 2021) findings, on both passenger car to pedestrian and passenger car to cyclist scenarios, to the Euro NCAP 2020 AEB VRU protocol (Euro NCAP, 2020). This allows to identify which are the scenarios that today's active safety systems are aiming to address. Additionally, since a future update of this protocol is expected to be implemented on January 2023 (Euro NCAP, 2021), the draft scenarios included in that protocol will also be mapped in this step. Finally, the scenarios which are not addressed by Euro NCAP to-date will be also highlighted.

The second step focuses on understanding which is the SOTA AEB VRU performance according to Euro NCAP 2020 protocol. For that, a spreadsheet from the Euro NCAP test results of a vehicle which achieved a 5 star rating and with a similar safety system as Demo

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4 vehicle is used. The scenarios, in which for at least one of the test conditions addressed in the Euro NCAP 2020 AEB VRU protocol, there was no AEB VRU activation, are highlighted with a red rectangle and the scenarios in which there was AEB VRU activation, but in at least one case, this was not sufficient to avoid the collision (AEB mitigation), are highlighted in an orange rectangle.

The third step takes into account the situations where C-ITS technology may demonstrate safety potential, such as non-designated crossings for pedestrians as well as intersections for cyclists, according to D2.6 recommendations. The scenarios with obstructions are also considered since those pose special challenges to the SOTA AEB VRU systems, as the VRUs may be hidden by such obstructions and therefore not detectable on time by those systems.

The final step performs the prioritisation of the scenarios based on the KSI figures and also the definition of concrete parameters such as speeds of the passenger car and the pedestrians and cyclists. For this step, D2.6 is considered as a basis, elaborated with further considerations related to Demo 4.

The following sections present in detail the above-mentioned steps for the Car to Pedestrian and Passenger car to cyclist scenarios identified as relevant to Demo 4.

4.2 Selected scenarios for Demo 4

This section analyses both passenger car to pedestrian and passenger car to cyclist scenarios, applying the above-mentioned methodology. A summary of the Demo 4 selected scenarios is presented in Section 4.2.3. Since Demo 4 is addressing VRUs in general, the justifications for the selected scenarios are similar for both pedestrian and cyclist scenarios.

4.2.1 Selected Car to Pedestrian scenarios

At first, it is necessary to reference to the results of the D2.6 (Bálint, et al., 2021) for these crash situations, which are shown in Figure 5.

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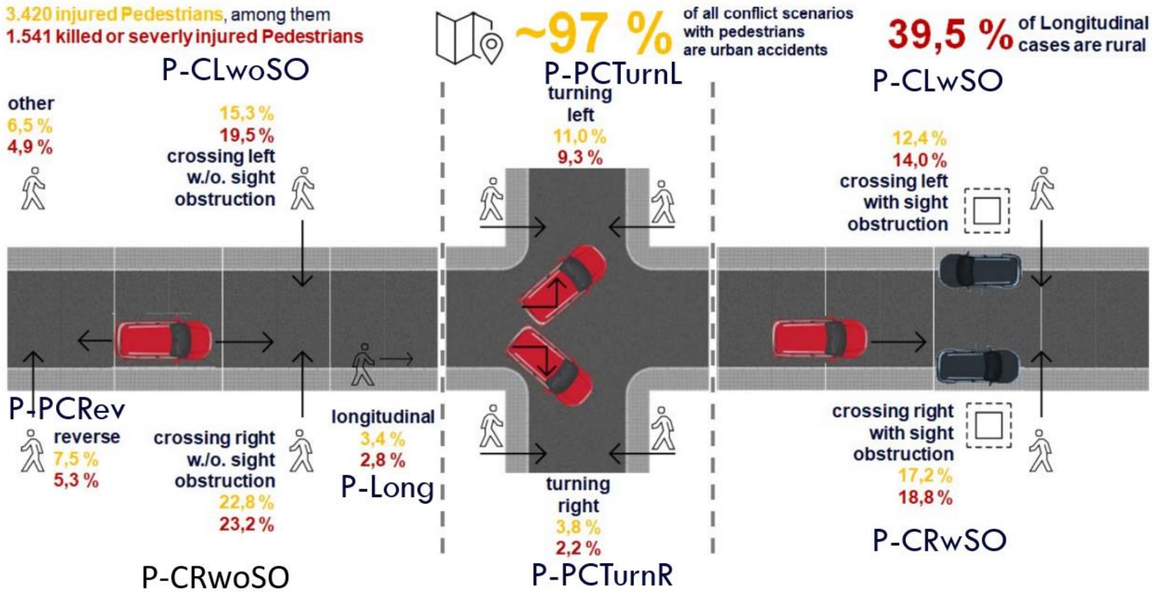

Figure 5: D2.6 Overview of passenger car vs. pedestrian crash scenarios.

As mentioned in the methodology of Section 4.1, **Step 1** maps the scenarios shown in Figure 5 to the Euro NCAP AEB VRU Protocol. This mapping is shown in Figure 6 below.

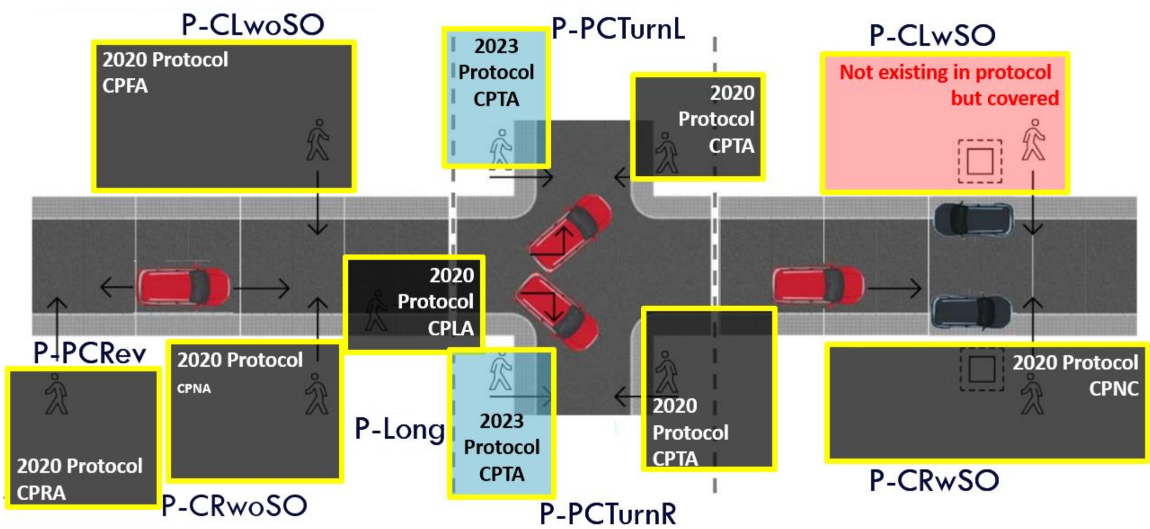

Figure 6: Step 1: Mapping of D2.6 car vs. pedestrian crash scenarios to Euro NCAP AEB VRU Protocol.

From Figure 6, it can be understood that most of the passenger car to pedestrian scenarios identified in D2.6 are or will be addressed by current and upcoming Euro NCAP AEB VRU Protocols. This relates only to the overall scenarios since due to the multiple test conditions related to speed combinations, trajectories and impact points, it could not be stated that all passenger car to pedestrian crash scenarios happening in real life are covered by Euro NCAP protocols.

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At next, **Step 2** focuses on highlighting what is the SOTA AEB VRU performance of a vehicle with a similar system as the one that will be used by the Demo 4. The results are presented in Figure 7.

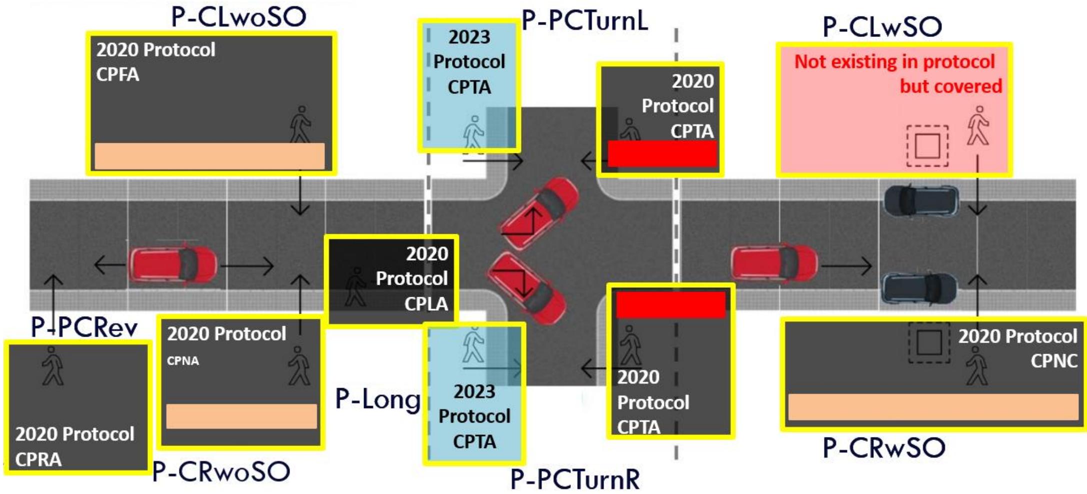

Figure 7: Step 2: Mapping of D2.6 car vs. pedestrian crash scenarios to SOTA AEB VRU performance based on Euro NCAP 2020 AEB VRU Protocol: red rectangle: no AEB VRU activation in at least one test condition; orange rectangle: AEB VRU activation but in at least one test condition not enough to avoid impact.

From Figure 7 it can be derived that scenarios related to crossing, either from an intersection or from a non-designated area with or without obstruction seem to be challenging.

After this mapping of crash scenarios, **Step 3** is applied. The expected benefit of C-ITS solution is foreseen to be in scenarios which pose a challenge from a system point of view of SOTA AEB VRU technology. This means, that it is not the scope of the C-ITS solution to focus on scenarios where there could be enough visibility between the car and the pedestrian. Instead, the expectation is to focus on those cases where even an outperforming system would face difficulties to either warn the driver or avoid a collision. Based on this, Figure 8 shows the most relevant scenarios to Demo 4 C-ITS solution, highlighted with a green tick mark.

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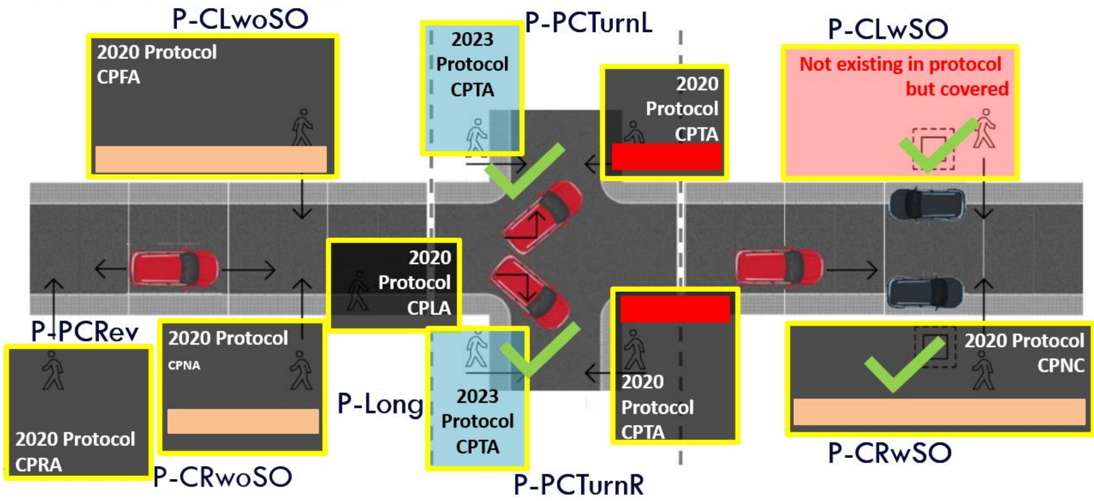

Figure 8: Step 3: Expected safety benefit of C-ITS solutions for car vs. pedestrian crashes to SOTA AEB VRU performance based on Euro NCAP 2020 AEB VRU Protocol C-ITS benefit is highlighted with a green tick mark.

It should be noted that from Figure 8, it shall not be concluded that other scenarios could not be addressed by C-ITS solution, but rather which ones would potentially pose greater challenges to SOTA AEB VRU systems due to field of view limitations. Those include non-designated crossings with obstructions, either from the right or left, as well as the turning cases at intersections (either right or left) with the pedestrian coming from the same direction with the car.

Step 4: The last step to finalise the selection of passenger car to pedestrian scenarios is to understand the KSI relevance, as well as the concrete parameters for each scenario. To facilitate this process, SAFE-UP D2.6 (Bálint, et al., 2021) is considered as a basis, elaborated with further considerations related to Demo 4. Among the latter, the consideration of relatively higher speeds than those identified in D2.6 for VRUs or passenger cars are considered for the crossing scenarios. The main reason is that in those scenarios, the SOTA AEB VRU already has certain performance and therefore the focus shall be on cases which might be more challenging to address by these systems. In Figure 9, the details for each of the scenarios identified after Step 3 are shown, with those highlighted in “green” colour being selected for Demo 4 implementation.

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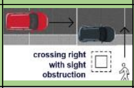
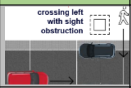
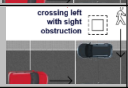
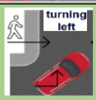
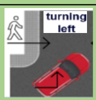
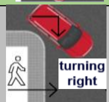
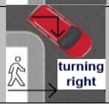
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases	Crossing type (based on D2.6)
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)		
Demo_4_01	**Pedestrian**	**C-ITS-P3 D2.6 P-CRwSO**		**18,7**	**17,1**	**26 - 45**	**25 - 45 (every 5 Kph)**	**-**	**8**	**5**	**76/9% non-designated crossing (68.9% not related to intersection)**
Demo_4_02	**Pedestrian**	**C-ITS-P3 D2.6 P-CRwSO**		**18,7**	**17,1**	**27 - 45**	**35 - 65 (every 5 Kph)**	**N/A**	**5**	**7**	**76/9% non-designated crossing (68.9% not related to intersection)**
Demo_4_03	Pedestrian	C-ITS-P4 D2.6 P-CLwSO		14,2	12,5	28 - 45	30 - 45 (every 5 Kph)	-	8	4	68.6% non-designated crossing (71% not related to intersection)
Demo_4_04	Pedestrian	C-ITS-P4 D2.6 P-CLwSO		14,2	12,5	28 - 45	35 - 65 (every 5 Kph)	-	5	3	68.6% non-designated crossing (71% not related to intersection)
Demo_4_05	**Pedestrian**	**D2.6 P-PCTurnL**		**9,2**	**11**	**10 - 28**	**10 - 30 (every 5 Kph)**	**-**	**5**	**5**	**36.4% non designated crossing (97.6% related to intersection)**
Demo_4_06	**Pedestrian**	**D2.6 P-PCTurnL**		**9,2**	**11**	**10 - 28**	**10 - 30 (every 5 Kph)**	**-**	**8**	**5**	**36.4% non designated crossing (97.6% related to intersection)**
Demo_4_07	Pedestrian	Not proposed for C-ITS in D2.6		2,2	3,8	11-25	10 - 25 (every 5 Kph)	-	5	4	23.8 % non designated crossing (100% related to intersection)
Demo_4_08	Pedestrian	Not proposed for C-ITS in D2.6		2,2	3,8	11-25	10 - 25 (every 5 Kph)	-	8	4	23.8 % non designated crossing (100% related to intersection)

Figure 9: Step 4: Overview of relevant scenarios for Demo 4 passenger car to pedestrian cases.

As shown in Figure 9, four main scenarios for passenger car to pedestrian implications have been selected for Demo 4. All four scenarios are part of D2.6 and they correspond to the following labels:

- Demo_4_01 & Demo_4_02 ⇨ D2.6 P-CRwSO (Pedestrian crossing from right with sight obstruction; passenger car moves forward)
- Demo_4_05 & Demo_4_06 ⇨ D2.6 P-PCTurnL (Passenger car turning left)

The justification for the selected and non-selected scenarios is provided hereunder:

4.2.1.1 Demo_4_01

This scenario has the highest KSI rate and is largely related to non-designated crossings (76.9% of the crashes take place at non-designated crossings. The selected speed values for the passenger car (which is referred to as VUT in Figure 9) are aligned with the findings in D2.6, although there has been a simplified adjustment for the lower value for the actual demonstrator, having a spread of cases every 5 kph. A relevant aspect here is the fact that the VRU speed considered will be of 8 kph, considering a running pedestrian. The reasons for considering the higher speed are: i) the intention to deal with new interactions between VRUs and drivers, ii) when looking at SOTA AEB VRU performance, it is expected that the

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baseline case already has certain performance and that an increased pedestrian speed matches well with the motivation of Demo 4 of addressing cases that would pose a challenge for SOTA AEB VRU technology and where C-ITS technology could show safety effect. In this case, a reason for the challenge is that for the same vehicle speed, if the pedestrian would have a higher speed, it would appear at a later time in the field of view of the vehicle, having less reaction time from both vehicle and pedestrian to avoid or mitigate the collision. The value of 8 kph for a running pedestrian has been also found as appropriate figure based on past research (Bartels & Erbsmehl, 2014). Considering the combination of the proposed speeds, a total amount of 5 test cases were identified for this scenario.

4.2.1.2 Demo_4_02

The same justifications as for Demo_4_01 scenario apply here, regarding the KSI rate as well as the relation to non-designated crossings. With respect to Demo_4_01, this scenario considers the same pedestrian speed values as in D2.6 (5 kph), whereas the change point is related to the vehicle speed. With the same motivation of trying to address which scenarios pose a greater challenge to SOTA AEB VRU systems and keeping into consideration that same number of KSI rate is kept, the speed ranges have been shifted to higher values (between 35-65 kph). This selection will not only allow Demo 4 to assess what is the expected safety benefit at higher speeds than the current Euro NCAP 2020 protocol which reaches up to passenger car speed of 60 kph, but also justify the overall safety benefit of C-ITS technology, by considering lower speeds that correlate with the KSI figures identified in D2.6. Considering the combination of the proposed speeds, a total amount of seven cases were identified for this scenario.

4.2.1.3 Demo_4_03 & Demo_4_04

Those scenarios have not been selected since they shall be covered by scenarios Demo_4_01 & Demo_4_02, as mentioned in Step 1.

4.2.1.4 Demo_4_05

This scenario has the highest KSI rate from the turning scenarios for pedestrians. Since this scenario is related to an intersection, the non-designated crossing rate is not as high, showing that 36.4% of these crashes happen at those conditions. An interesting aspect of this accident scenario is that it shows a new interaction between VRU and passenger car at urban area, since the VRU is not in the field of view of the passenger car, nor the passenger car is in the field of view of the VRU. This makes the scenario relevant for C-ITS technology since it could show a safety effect in those situations. Previous research already highlighted the challenge of this scenario for SOTA AEB VRU technology, and how the effectiveness of such systems could increase, if further spatial information would be available for the vehicle, via for example vehicle to cloud communication (Sander, 2017). The speed values selected for the passenger car have just been adjusted compared to the proposed ones in D2.6 to allow a step of 5 kph in between each proposed test case. The speed of the pedestrian has been kept equal to the

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values indicated in D2.6. Considering the combination of the proposed speeds, a total amount of five test cases were identified for this scenario.

4.2.1.5 Demo_4_06

This scenario is similar to Demo_4_05 but with an increased speed of the pedestrian to 8 kph, with a similar justification as the one provided in scenario Demo_4_01 with regard to the pedestrian speed. Considering the combination of the proposed speeds, a total amount of five test cases were identified for this scenario.

4.2.1.6 Demo_4_07 & Demo_4_08

Those scenarios have not been selected due to the low KSI rate when compared to the Turn left scenarios, considering that conceptually both of them are very similar.

4.2.2 Selected Passenger car to cyclist scenarios

Initially, it is required to highlight the results of D2.6 (Bálint, et al., 2021) that are relevant to passenger car-to-cyclist crash cases and are presented in Figure 10.

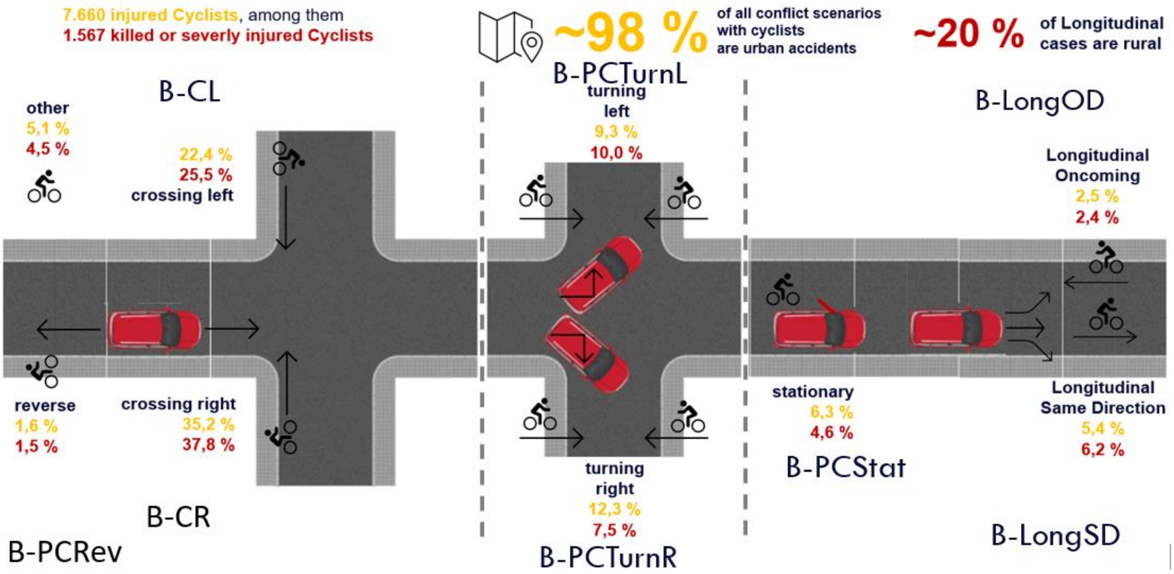

Figure 10: D2.6 Overview of passenger car vs. cyclist crash scenarios.

According to **Step 1** of the defined method, the above scenarios are mapped with the Euro NCAP AEB VRU Protocol. The results of this mapping are presented in Figure 11 below.

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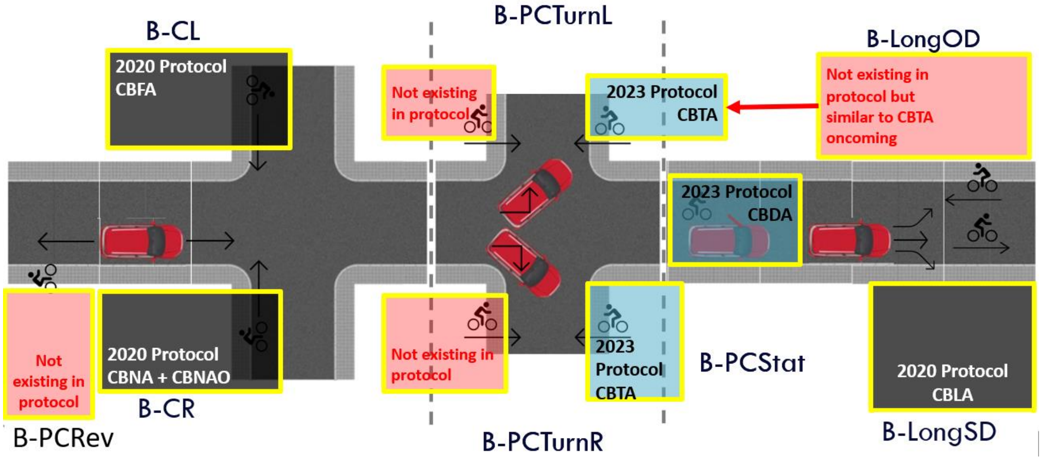

Figure 11: Step 1: Mapping of D2.6 passenger car vs. cyclist crash scenarios to Euro NCAP 2020 AEB VRU Protocol.

Analysing Figure 11, it can be deducted that unlike passenger car to pedestrian scenarios, not all the identified passenger car to cyclist scenarios are addressed by either current or upcoming Euro NCAP protocols. Regarding the longitudinal oncoming scenario, from the description in D2.6, it might be assumed that this scenario could be similar to the planned CBTA (Car to Bicycle Turning Adult) Euro NCAP scenario for 2023, although further evaluation would be needed to understand if that could be the case, due to different behaviours in the vehicle (e.g. turning vs. overtaking).

Following the method explained in Section 4.1, **Step 2** focuses on highlighting the SOTA AEB VRU performance of a vehicle compared to a similar system as the one that will be developed by the Demo 4. The results are presented in Figure 12.

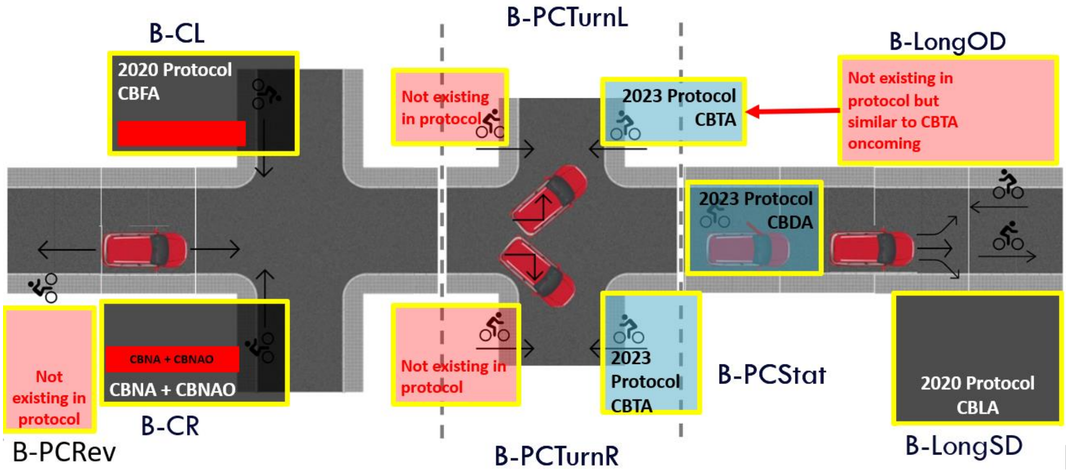

Figure 12: Step 2: Mapping of D2.6 passenger car vs. cyclist crash scenarios to SOTA AEB VRU performance based on Euro NCAP 2020 AEB VRU Protocol: red rectangle: no AEB VRU activation in at least one test condition; orange rectangle: AEB VRU activation but in at least one test condition not enough to avoid impact.

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From Figure 12, it can be resulted that those scenarios related to crossing, with or without obstruction, seem to be challenging for SOTA AEB VRU technology.

After the above mapping of crash scenarios, **Step 3** is applied. The expected benefit of C-ITS solution is foreseen for scenarios which pose a challenge from a system point of view of SOTA AEB VRU technology. This means, that it is not the scope of the C-ITS solution to focus on scenarios where there could be enough visibility between the car and the cyclist (exactly as stated for the pedestrian scenarios in Section 4.2.1). Instead, C-ITS solutions shall focus on those cases where even an outperforming system would have difficulties to either warn the driver or avoid a collision. Based on those statements, Figure 13 shows the scenarios that are identified as more relevant for C-ITS based solutions and are highlighted with a green tick mark.

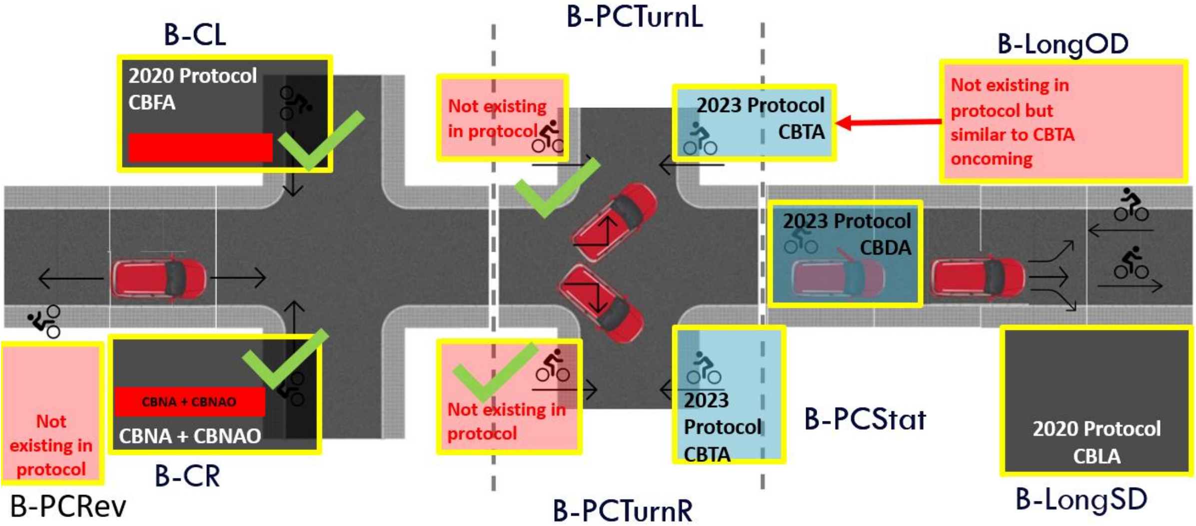

Figure 13: Step 3: Expected safety benefit of C-ITS solutions for car vs. cyclist crash scenarios to SOTA AEB VRU performance based on Euro NCAP 2020 AEB VRU Protocol; C-ITS benefit is highlighted with a green tick mark.

A similar justification as for passenger car to pedestrian cases is applied to Passenger car to cyclist ones, that is focusing on cases where C-ITS technology can demonstrate a greater potential compared to SOTA AEB VRU systems due to field of view limitations. Based on this, the crossing scenarios at intersection are more relevant and were selected. It has to be considered that since the focus will be in cases with field of view limitations the CBNAO (Car-to-Bicyclist Nearside Adult Obstructed) Euro NCAP case was selected instead of the CBNA (Car-to-Bicyclist Nearside Adult) for the crossing from right and the left. Similarly to the Car to pedestrian cases, the turning cases with the cyclist coming from the same direction as the vehicle show higher relevance.

Step 4: The last step is to understand the KSI relevance as well as the concrete parameters for each scenario. To achieve this, D2.6 is considered as reference, as well as further considerations related to Demo 4. Among these, will be the consideration of relatively higher speeds for VRUs, compared to the ones shown in D2.6. The main reason is that in those

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scenarios, the SOTA AEB VRU already has certain performance and therefore the focus shall be on cases which would be more difficult to address by these systems, but would still be representative of the accident data of D2.6 findings. In Figure 14, the details for each of the scenarios identified after Step 3 are presented, of which those highlighted in "green" colour being proposed for Demo 4.

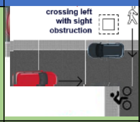
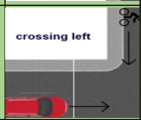
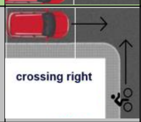
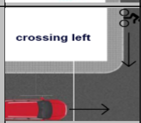
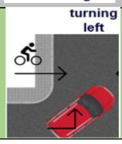
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases	Crossing type (based on D2.6)
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)		
Demo_4_08	**Cyclist**	**C-ITS-B1 D2.6 B-CR + Obstruction**		**37,8**	**35,2**	**5-30**	**15-30 (every 5 Kph)**	**N/A**	**15 - 20 (every 5 Kph)**	**8**	**11.6% related to intersection 28% using bicycle path**
Demo_4_09	**Cyclist**	**C-ITS-B2 D2.6 B-CL + Obstruction**		**25,5**	**22,4**	**5-30**	**15-30(every 5 Kph)**	**N/A**	**20**	**4**	**92.4% related to intersection 1.6% using bicycle path**
Demo_4_10	Cyclist	C-ITS-B1 D2.6 B-CR		37,8	35,2	5 - 30	10 - 25 (every 5 Kph)	10 - 18	15 - 20 (every 5 Kph)	8	**11.6%** related to intersection 28% using bicycle path
Demo_4_11	Cyclist	C-ITS-B2 D2.6 B-CL		25,5	22,4	7 - 32	10 - 30 (every 5 Kph)	12 - 20	20	5	92.4% related to intersection 1.6% using bicycle path
Demo_4_12	Cyclist	D2.6 B-PCTurnR		7,5	12,3	10 - 30	10 - 30 (every 5 Kph)	14 - 20	15 - 20	10	99.3% related to intersection
Demo_4_13	**Cyclist**	**D2.6 B-PCTurnL**		**10**	**17,1**	**11 - 29**	**10 - 30 (every 5 Kph)**	**12 - 21**	**15 - 20**	**10**	**99.4% related to intersection**

Figure 14: Step 4: Overview of relevant scenarios for Demo 4 passenger car to cyclist cases.

From Figure 14, three main scenarios are derived for Demo 4. All scenarios are part of D2.6 and they correspond to the following labels:

- Demo_4_08 & Demo_4_09 ⇨ D2.6 B-CR (Bicyclist crossing from right) & B-CL (Bicyclist crossing from left)
- Demo_4_13 ⇨ D2.6 B-PCTurnL (Bicyclist in conflict with PC turning left)

Below an explanation is given for the selection of each of them as well as the justification of the selected parameters. The same is done for the cases which are not selected.

4.2.2.1 Demo_4_08

This scenario has the highest KSI rate out of the proposed Demo 4 scenarios. It should be noted that the original scenario does not refer to an obstruction blocking the view of the VRU to the vehicle and vice versa, however considering an obstruction, is probably more relevant

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for a C-ITS solution to demonstrate its safety benefit. For the actual shape and position of the obstruction further studies will be performed and reported in the final Demo 4 deliverable.

The speeds of both the passenger car and the cyclist are aligned with the findings of D2.6, although it is evident that the amount of test cases with all possible speed combinations would lead to a quite high number of test cases. Since, the proposed scenarios will be carried out in a physical demonstrator, there is a dire need to limit the number of tests, by focusing on upper range of speed values for both the passenger car and the cyclist. For the cyclist, the upper values of the speed have been rounded up to consider 5 kph interval in between the two proposed speeds. Considering the combination of the proposed speeds, a total amount of eight test cases were selected for this scenario.

4.2.2.2 Demo_4_09

The same justifications as for Demo_4_08 scenario apply to this scenario as well, with regard to the KSI rate and the consideration of obstructions. A similar logic as for the Demo_4_08 scenario follows regarding the amount of test cases and proposed speed values. For this scenario, since it is considered that the crossing from the left side would allow SOTA AEB VRU systems for a less challenging scenario compared to the crossing from the right, only the higher speed value for the cyclist is selected. Considering the combination of the proposed speeds, a total amount of four test cases were selected for this scenario.

4.2.2.3 Demo_4_10 & Demo_4_11

These scenarios were not selected since they represent cases without a sight obstruction and even if these scenarios would pose a challenge to the SOTA AEB VRU systems, Demo 4 focus, as previously mentioned, is not to propose an improved AEB VRU system, but rather to focus on the scenarios related to a lack of field of view from the vehicle perspective.

4.2.2.4 Demo_4_12

This scenario has not been selected due to the lower KSI rate when compared to the Turn left scenarios, considering that conceptually both of them are very similar.

4.2.2.5 Demo_4_13

This scenario has the highest KSI rate out of the turning scenarios for cyclists. Similarly for the Car to pedestrian Demo_4_05 & 06 scenario, an interesting aspect of this scenario is that it shows a new interaction between the VRU and the passenger car at urban areas, since the VRU is not in the field of view of the passenger car, nor the passenger car is in the field of view of the VRU. This identifies the scenario as highly relevant for C-ITS technology in terms of safety enhancement. The speed values selected for both the passenger car and the cyclist have been adjusted compared to the proposed ones in D2.6 to allow a step of 5 kph in between each proposed test case. Considering the combination of the proposed speeds, a total amount of ten test cases were selected for this scenario.

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4.2.3 Summary of Demo 4 scenarios

This section summarises the selected scenarios for Demo 4, deriving from Sections 4.2.1 and 4.2.2, both for Car to Pedestrian and Passenger car to cyclist conflicts.

4.2.3.1 Car to Pedestrian scenarios

The selected passenger car to pedestrian scenarios for Demo 4 are shown in Figure 15.

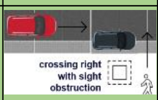
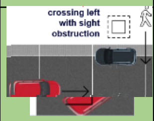
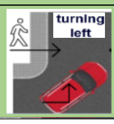
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)	
Demo_4_01	Pedestrian	C-ITS-P3 D2.6 P-CRwSO		18,7	17,1	26 - 45	25 - 45 (every 5 Kph)	-	8	5
Demo_4_02	Pedestrian	C-ITS-P3 D2.6 P-CRwSO		18,7	17,1	27 - 45	35 - 65 (every 5 Kph)	N/A	5	7
Demo_4_05	Pedestrian	D2.6 P-PCTurnL		9,2	11	10 - 28	10 - 30 (every 5 Kph)	-	5	5
Demo_4_06	Pedestrian	D2.6 P-PCTurnL		9,2	11	10 - 28	10 - 30 (every 5 Kph)	-	8	5

Figure 15: Selected passenger car to pedestrian scenarios for Demo 4.

4.2.3.2 Passenger car to cyclist scenarios

The selected passenger car to cyclist scenarios for Demo 4 are shown in Figure 16.

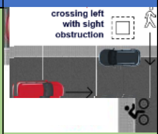
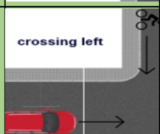
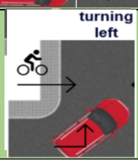
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)	
Demo_4_08	Cyclist	C-ITS-B1 D2.6 B-CR + Obstruction		37,8	35,2	5-30	15-30 (every 5 Kph)	N/A	15 - 20 (every 5 Kph)	8
Demo_4_09	Cyclist	C-ITS-B2 D2.6 B-CL + Obstruction		25,5	22,4	5-30	15-30(every 5 Kph)	N/A	20	4
Demo_4_13	Cyclist	D2.6 B-PCTurnL		10	17,1	11 - 29	10 - 30 (every 5 Kph)	12 - 21	15 - 20	10

Figure 16: Selected passenger car to cyclist scenarios for Demo 4.

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4.3 Applicability in future scenarios

The method and process for selecting the scenarios for Demo 4, show the intention to focus on scenarios where SOTA VRU detection systems could have some limitations mainly due to the lack of visibility of the VRU, for which it is assumed that a C-ITS solution could demonstrate a safety benefit.

Besides that, it is also the intention to consider new interactions between VRUs and drivers such as the running pedestrian or the VRU coming from the same direction as the passenger car for both Car to pedestrian and Passenger car to cyclist cases.

Regarding the applicability of the scenarios, it should be noted that Demo 4 is not aiming at developing a near to production safety solution based on C-ITS, but to rather show the potential safety benefit of C-ITS technology. Additionally, there are some challenges that Demo 4 will not be able to address and that should be part of further work such as: a) the accuracy of the positioning of both VRUs and vehicles, since Demo 4 will focus on the timely issuance of such warnings; b) Demo 4 will integrate the necessary signals for the prototype communication units to be able to trigger warnings or actions on the vehicle, but such integration of signals requires further work, especially on following standard communication procedures, and, c) Demo 4 will perform the demonstration in a controlled environment within a test track, so aspects related to multiple users, false activations or warning perception and acceptance, will not be able to be assessed, but should be certainly investigated before considering the deployment of such technology.

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5 Demo 4 development status

The Demo 4 is based on 3 main subsystems (Vehicle, RSU and VRU), which are to date at different development stages. All three are currently under development, although there are certain functionalities already available to be tested. The main objective for these intermediate tests is to validate the current implementation to set the basis for the next testing phase. None of the scenarios can be performed involving all subsystems, as the current implementation phase does not allow for interactions between them, but only individual subsystem tests. However, selected laboratory interoperability tests have been performed to make sure that current developments go in line with the requirements for Demo 4. Such tests are:

1. Demo_4_02 (Pedestrian crossing from right with sight obstruction; passenger car moves forward) was tested at IDIADA test tracks

   This scenario has been selected for the intermediate demonstrator from a practical point of view. As slightly differs from the standardised CPNC (Car-to-Pedestrian Nearside Child) Euro NCAP scenario, it represents a proper baseline to evaluate the implementation of the AEB system for Demo 4. The results can be easily compared with the performance that commercial vehicles have achieved in this Euro NCAP test, therefore it will allow us to identify situations where the AEB performance can be improved in order to reach the desired baseline point and provide good feedback for further development.

2. Interoperability validation of the V2X devices

   The vehicle and the RSU will be equipped with the same V2X unit, while the VRU device will incorporate a different unit. Their interoperability is key for the success of the Demo 4 and, therefore, a set of tests were selected to be performed in advance, before the actual integration takes place in the vehicle, RSU and VRU devices, towards the implementation of the final Demo 4 solution. This is a first step to ensure intercommunication between the two devices, so as to eventually evaluate the performance of this solution on collision mitigation.

   The compatibility and performance of the V2X will be evaluated in Demo 4 to assess the potential of this technology not only on supporting the perception of active safety systems, but also of drivers and VRUs in common critical situations via on-time warnings. The use of V2X will allow to extract conclusions on what timings are required for useful warnings to drivers and VRU on critical situations. Such conclusions can derive on new requirements to take into account when designing future safety systems based on V2X.

5.1 Demonstrator subsystems

This section describes the current status of the different subsystems and their modules (Vehicle, RSU and VRU), following the updated architecture presented in Section 3.

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5.1.1 Vehicle modules

Table 1: Status of vehicle modules.

Module	Status
Physical vehicle	Ready (available)
In-vehicle sensors (Cameras, RADAR, LiDAR)	Ready (installed and working)
V2X unit	Ready (available)
Perception Unit	Under development
Driving Function Unit	Partially ready (collision probability algorithm for AEB developed)
HMI	Under development

5.1.1.1 Intermediate Demo 4 vehicle and Sensors

The CAVRide (Codina, 2021), a vehicle with Connected and Automated functions developed by Applus+ IDIADA, is used as the platform to demonstrate the Demo 4 at this stage of the project. This vehicle is able to drive autonomously within IDIADA's facilities thanks to a multimodal sensor set (cameras, LiDAR and RADAR). For the SAFE-UP project, connectivity capabilities are being added, which allows the vehicle to engage the AEB function relying on fused data from the sensors and V2X. All this development will be integrated into the TME vehicle for the final demonstrator expected in 2022.

Figure 17: CAVRide vehicle (IDIADA).

5.1.1.2 Vehicle V2X Unit

The V2X unit, used in both the vehicle and the RSU, is a prototype implementing ITS-G5 technology. It has been successfully tested in real world and testing environments, being

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capable of sending and receiving V2X information from other ITS-G5 stations and fully complying with the ETSI standards. The compliance of this device is presented in Section 6. As a summary, it is capable of sending and receiving a set of common standard ITS messages using ITS-G5 technology. For the vehicle case, it is expected to send (and receive) CAM messages letting other nearby stations (e.g. VRUs) know the real-time positioning, dynamics and other key information of the vehicle. However, since the complete implementation and interfaces with the vehicle systems are not yet ready, this V2X module is not used in this intermediate demonstration for Demo 4.

Figure 18: Vehicle V2X and processing unit.

5.1.1.3 Vehicle Perception Unit & Driving Function Unit

IDIADA's portfolio contains a platform unit for ADAS prototyping known as IDAPT, which has V2X capabilities as well. This device will be the core of the vehicle and the RSU for the Demo 4, since it will enable sensor data acquisition, fusion functionalities (Perception Unit) and risk algorithm execution (Driving Function Unit). The current status of this unit comprises the implementation of fusion capabilities for the vehicle-mounted sensors (without V2X information) and the implementation of the collision probability algorithm for the AEB.

Moreover, in order to perform a first iteration of Demo 4, a bypass has been developed to make use of the AEB function only with V2X-like information, ignoring vehicle sensors information. This bypass helps to evaluate the V2X information flows inside the vehicle and understand whether V2X data has the required quality to be used for the fusion and the AEB's collision probability algorithm. This evaluation will provide conclusions to improve and guide the next development iterations for the final Demo 4 in 2022.

5.1.2 RSU modules

All subsystems from the Road-side Unit (RSU) are under development, since the vehicle is the priority unit at this stage of the project. However, some developments for the vehicle will be also used for the RSU implementation. For example, the V2X unit, the Sensors and the Perception Unit will be based on the vehicle implementation with minor adaptations due to the RSU's larger field of view and positioning.

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Table 2: Status of RSU modules.

Module	Status
RSU mounting structure	Under development
Sensors (Camera and LiDAR)	Under development
V2X unit	Ready (available)
Perception Unit	Under development
Control Logic	Under development

5.1.3 VRU device modules

The VRU device is a prototype that was uniquely designed and developed for SAFE-UP project purposes. At the current stage of development, all hardware components have been installed and tested for basic operation. This means that every embedded hardware system like the V2X and LTE transceivers, the GNSS positioning, RTK and IMU together with the display and audio outputs have been installed and their basic operational behaviour has been verified. However, the full integration of every sub-system at application layer is a work in progress and currently still at an early phase for most of them.

The main effort during this initial stage of Demo 4, after the design and hardware development of the VRU device, focused on the implementation of V2X communications. For Demo 4, V2X connectivity is the key enabler technology and any delays on this part may also hinder the effort of partners that are responsible for the connectivity of vehicles (OBU) and infrastructure (RSU). It is crucial that the main V2X devices are able to interconnect and communicate equally comprehensive messages to each other. The V2X software stack from access to facilities layer has been incorporated in the VRU device and it is fully capable of transmitting and receiving the necessary C-ITS messages for Demo's purposes. At this stage of development, however, the positioning and motion dynamics information in the device's awareness messages (CAM) is updated solely by the GNSS solution without RTK and IMU enhancements for precision and accuracy being utilized yet.

A basic difference of the VRU device, compared to other conventional V2X devices, is its portable nature especially for the pedestrian case. While the necessary antennas of vehicle OBUs and infrastructure RSUs can be installed at fixed outside locations for optimum performance, in the VRU case they must be attached to the main body of the device and of course be of relevant small size. Draft preliminary tests upon that matter, have indicated that a range of 100 meters is reachable in line of sight. Since the VRUs are low speed traffic participants, the achieved range seems promising regarding system's efficiency.

The heart of the VRU device's system is the control action strategy software running on VRU core's host processor. Any radio frequency (RF) telecommunication message exchange starts from here or end up in this module. It is responsible for the constant monitoring of all

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neighbour objects and events obtained via V2X messages, in relation with the self-localization and motion dynamics achieved with the fusion of all active localization sources (GNSS, IMU and RTK). Based on this information, a risk evaluation algorithm will continuously estimate current and near future risks for the VRU, by calculating time to collision and will initiate user warnings in case of danger situation prediction. This crucial software module is at an early stage of development. After all the self-localization feature is currently only achieved with the GNSS sensor information while the fusion of different sources will be introduced at a later stage.

It has to be noted that although the HMI elements (display and audio) of the device have been tested for hardware compatibility and correct operation, they are not yet integrated into the device. The user interfaces for application control and warning delivery for both pedestrians and cyclists will be developed at the second and final phase of the Demo 4 implementation.

Figure 19: VRU device used for the preliminary tests at IDIADA premises.

Table 3: Status of VRU modules.

Module	Status
V2X transceiver	Ready (radio module is installed and the firmware driver has been ported and tested)
V2X software stack	Ready (implemented and tested)
Localization and motion dynamics	Under development
Local Dynamic Map and objects/events fusion	Not started
Control action strategy	Under development
HMI (visual, audio, input)	Not started

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6 Preliminary test results for demo 4

6.1 V2X device interoperability validation

In order to assess the interoperability between VEH/RSU and VRU V2X units, a set of tests have been performed in both devices individually and also by exchanging information between them. Prior to these tests, a theoretical interoperability check was performed to ensure that both V2X units are interoperable on paper, by analysing all protocol stack layers. The results are the following:

Table 4: Interoperability test results between Vehicle RSU unit and VRU device V2X unit.

ITS-G5 protocol layer	Standard	VRU	VEH / RSU	Status	Comments
Physical Layer	IEEE 802.11-2016	OK	OK		
Access Layer	ETSI EN 302 571 V2.1.1 (2017-02)	OK	OK		
	ETSI EN 302 663 V1.2.1 (2013-05)	OK	OK		
	ETSI TS 102 724 V1.1.1 (2012-10)	OK	OK		
	ETSI TS 102 724 V1.1.1 (2012-10)	OK	OK		
	ETSI TS 102 687 V1.2.1 (2018-04)	OK	OK		
	ETSI TS 102 636-4-2 V1.1.1 (2013-10), (Geonetworking)	OK	OK		
Network Layer	ETSI EN 302 636-4-1 V1.4.1 (2019-11), (Geonetworking)	OK	OK		
	ETSI EN 302 636-5-1 V2.2.1 (2019-05), (BTP)	OK	OK		

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ITS-G5 protocol layer	Standard	VRU	VEH / RSU	Status	Comments
	ETSI EN 302 931 V1.1.1 (2011-07), (Geographical Area Definition)	OK	OK*		
	ETSI TS 102 636-6-1 V1.2.1 (2014-05), (Geonetworking internet integration)	Basic impl.	Basic impl.		Does not affect Demo 4
	ETSI TS 103 097 V1.3.1 (2017-10), (Security)	OK	OK		
	ETSI TS 102 941 V1.3.1 (2019-02), (Security PKI)	OK	NOK		Unable to use PKI security for Demo 4 (at least as of Nov '21)
Facilities Layer	ETSI EN 302 637-2 V1.4.1 (2019-01), (Basic set of applications CA basic service)	OK	OK		
	ETSI EN 302 637-3 V1.3.1 (2018-08), (Basic set of applications DEN basic service)	OK	OK		
	ETSI TS 102 894-1 V1.1.1 (2013-08), (Users and applications requirements facility layer structure …)	OK	OK		
	ETSI TS 102 894-2 V1.3.1 (2018-08), (Users and applications requirements app and FL CDD)	OK	OK		
	ETSI TS 103 301 V1.3.1 (2020-02), (FL protocols and communication	OK	OK		

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ITS-G5 protocol layer	Standard	VRU	VEH / RSU	Status	Comments
	requirements for infrastructure services)				
	Supported protocols are SPATEM, MAPEM, SREM, SSEM, IVIM (CEN ISO/TS 19321)	OK	OK		
	Supported protocols are RTCMEM (CEN ISO/TS 19091)	OK	NOK		No GNSS/RTK corrections can be sent via V2X
	ETSI EN 302 890-1 V1.2.1 (2019-04), (SA specification)	OK	OK		
	ETSI TR 103 562 V2.1.1, (Collective Perception Message)	Partial impl.	NOK		CPM message potentially implemented in further iterations in the VEH/RSU unit
	ETSI TS 103 300-3 V2.1.1 (2020-11), (VRU Awareness Message)	NOK	NOK		VAM message potentially implemented in VRU and VEH unit

This initial exploration has confirmed that the communication between the VRU and the VEH can be realised using CAM messages, while the communication between the RSU and the VEH is possible using DENM messages, which are designed to notify hazardous situations. Therefore, VRUs and VEH will exchange CAM messages to create awareness of their location and status, while the RSU can use DENM message to inform the VEH about the presence of VRUs in the vicinity.

The use of CPM messages, created to signal the identified presence of a VRU in the vicinity from the vehicles and the infrastructure, will be explored to be integrated into the VEH and RSU systems for the final demo.

The use of the VAM (VRU Awareness Message) messages, which is a quite recent standardised message from ETSI for the awareness of VRUs, is to create and maintain awareness of vulnerable road users, replacing the CAM messages. This option will be explored in further iterations.

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Once the theoretical check has confirmed that Demo 4 is feasible in terms of V2X interoperability among its three main components, laboratory tests were performed to prove this in practice as well. The tests were focused on the CAM message types, since both VRU and VEH/RSU units need to communicate using this type of message. Therefore, the following tests were performed for both V2X units:

Table 5: CAM message testing framework.

Root	Test code	Test name	Check
CAM	MSG	Message generation	The CAM is generated, at least, at 10Hz rate (10 messages per second)
	IPC	ITS profile checking	The CAM contains the key elements from an agreed profile (latitude, longitude, altitude, positionConfidenceEllipse, heading and speed)
	INF	Information adaptation	The CAM contains certain elements set to a value according to the use case (e.g. Pedestrian as *stationType*)
	POS	Position checking	The CAM contains real and updated localization information from the device GNSS/positioning system
	MSE	Message exchange	The CAM is sent and received correctly by the other station

The results of the interoperability tests are available in the following tables:

Table 6: Vehicle RSU V2X unit CAM message results.

Root	Test code	Test name	Result	Comments
CAM	MSG	Message generation	Pass	Device sending at 10Hz
	IPC	ITS profile checking	Pass	The CAM contains latitude, longitude, altitude, positionConfidenceEllipse, heading and speed.
	INF	Information adaptation	Pass	StationType set to “5” (passengerCar)
	POS	Position checking	Pass	Real updated localization available in the CAM message
	MSE	Message exchange	Pass	VRU device receives the message from the VEH/RSU device correctly (see Annex logs)

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Table 7: VRU device V2X unit CAM message results

Root	Test code	Test name	Result	Comments
CAM	MSG	Message generation	Pass	Device sending at 1Hz and could be increased up to 10Hz
	IPC	ITS profile checking	Pass	The CAM contains latitude, longitude, altitude, positionConfidenceEllipse, heading and speed.
	INF	Information adaptation	Pass	StationType set to “1” (pedestrian)
	POS	Position checking	Pass	Real updated localization available in the CAM message
	MSE	Message exchange	Pass	The VEH/RSU device receives the message from the VRU device correctly (see Annex logs)

The results show full interoperability between both devices at CAM level, which is the only message required at this stage between the VRU and the VEH systems. Both V2X devices work properly and comply with the ETSI ITS-G5 standards. Further tests and developments will happen to implement the VEH-RSU communication, which uses the same V2X unit on both sides. To check examples and logs generated from the tests, check the Appendix section.

6.2 Demo 4 preliminary demo

The current implementation status of the three Demo 4 components does not allow to perform a complete demonstration with the participation of the VRU and the VEH units. However, one of the selected scenarios for Demo 4 identified in Section 4.2.3.1, was used to validate the vehicle component with the following main objectives:

- Validate fusion implementation with on-board sensors (camera, LiDAR and RADAR) before V2X is introduced.
- Validate the AEB implementation

The Demo_4_02 scenario, which is comparable with the CPNC50 from Euro NCAP, was chosen for this intermediate demonstrator. This scenario allows to validate, among other objectives, the AEB system in order to reach the state-of-the-art performance, which is the Demo 4 baseline for the evaluation of the in-vehicle safety system performance once V2X is included into the equation. Despite that Demo_4_02 scenario reaches up to 65 kph, this intermediate demonstrator scenario follows the Euro NCAP CPNC50 top speed, which is up

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to 60 kph and using a child pedestrian. Figure 20 and Figure 21 show a couple of pictures from the preliminary tests performed while developing and validating the data fusion and AEB algorithms.

Figure 20: IDIADA CAVRide in a preliminary AEB VRU scenario

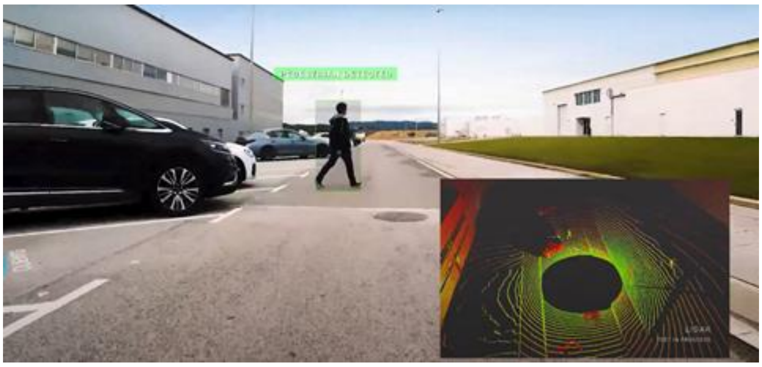

Figure 21: Preliminary test of the data fusion with on-board sensors

The test specifications are described in the Table 8 below.

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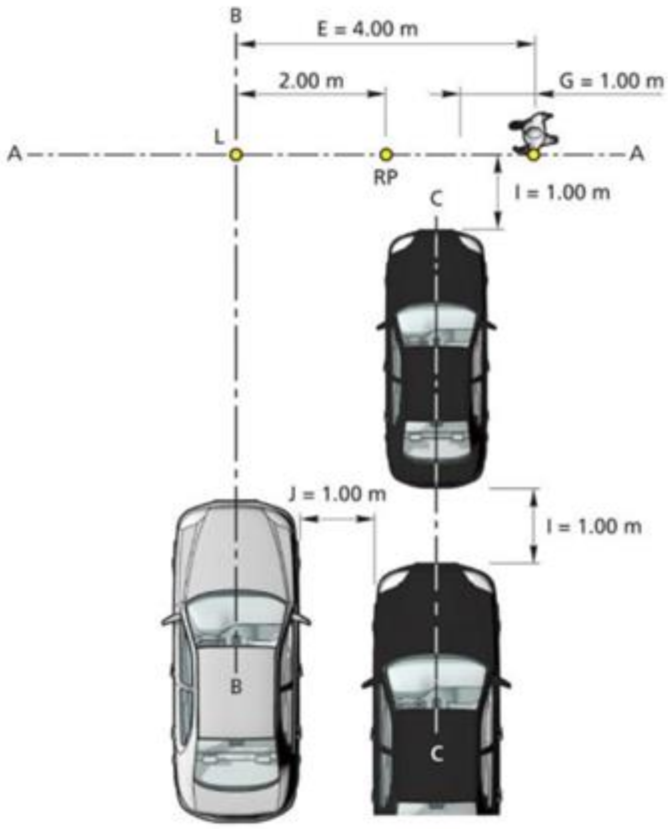
Table 8: Demo_4_02 scenario test specifications.

Scenario representation	
Source	Euro NCAP, SAFE-UP
Initial Conditions	– Drive gear is selected. – AEB is active – Subject vehicle speed is **Ve** – VRU speed is **Vt** – Impact point offset is **Of** – Good light conditions
Testing Steps	– Step 1: o Maintain vehicle speed to **Ve** o VRU speed is maintained to **Vt** – Step 2: o Wait until AEB actuation

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Trigger	Automated Emergency Braking is activated when pedestrian is detected and a certain collision probability threshold is reached
Acceptance criteria	Ego vehicle avoids the collision OR the ego vehicle mitigates the collision (reduced hit speed)
Parameters	(see table below)
Test strategy	Each step was performed 3 times, in order to discard issues in single test runs.

Layer	Parameters	Range	Step
VRU	Velocity (Vt)	5 km/h	-
	Type	Child	-
Ego Vehicle	Velocity (Ve)	[35 - 60] km/h	5 km/h
	Impact point offset (Of)	50 %	-
Environmental conditions	Light conditions (Lc)	Daylight	-

The results of the tests are represented by a speed versus time graph, with a summary table of the test results. The graphs show the VEH speed in blue and the VRU speed in red. The vertical red lines indicate the moment when the AEB was triggered, therefore the moment the algorithm calculated a high collision probability with the VRU at the current speed and distance. The results table show important parameters at the very specific moment when the AEB is triggered, as well as when the VRU is hit by the car (if it happens). Such parameters are:

- Time: Time elapsed in seconds since the beginning of the test until the AEB is triggered and the VRU is hit
- Time-To-Collision (TTC): When the AEB is activated, how many seconds it would take to hit the VRU if it had not braked.
- Distance VEH-VRU: Distance between the vehicle and the VRU when the AEB is triggered
- VEH speed: Speed in kph of the vehicle when the AEB is triggered and when the collision happens

Demo_4_02 at 35 kph

At 35 kph, the vehicle is able to avoid the collision and full stop at 1.88 m from the VRU. It starts braking when VRU is at 9.06 m of distance, resulting in a TTC of 0.92 seconds.

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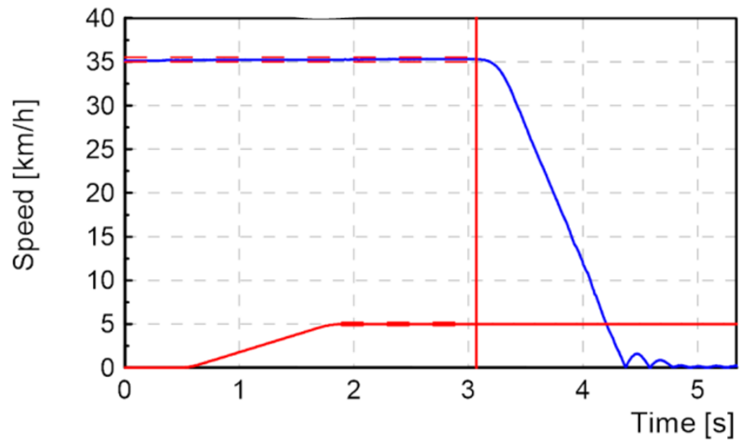

Figure 22: VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 35 kph

Table 9: Results of the Demo_4_02 scenario at 35 kph:

	AEB	Impact
Time [s]	3.07	N
TTC [s]	0.92	N
Distance VEH-VRU [m]	9.06	N
VEH speed [kph]	35.3	N

Demo_4_02 at 40 kph

At 40 kph, the vehicle is able to avoid the collision and full stop at 1.23 m from the VRU. It starts braking when the VRU is 10.49 m away.

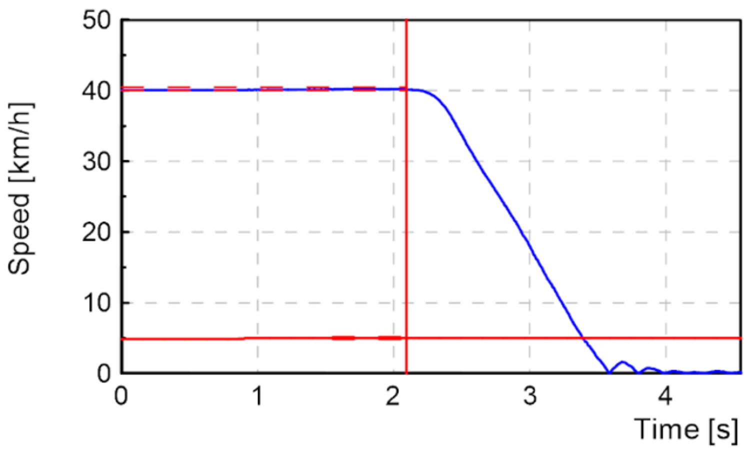

Figure 23: VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 40 kph.

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Table 10: Results of the Demo_4_02 scenario at 40 kph

	AEB	Impact
Time [s]	2.09	N
TTC [s]	0.94	N
Distance VEH-VRU [m]	10.49	N
VEH speed [kph]	40.15	N

Demo_4_02 at 45 kph

At 45 kph, the vehicle is able to avoid the collision and full stop at 0.91 m from the VRU. It starts braking at a distance of 13.36 m from the VRU.

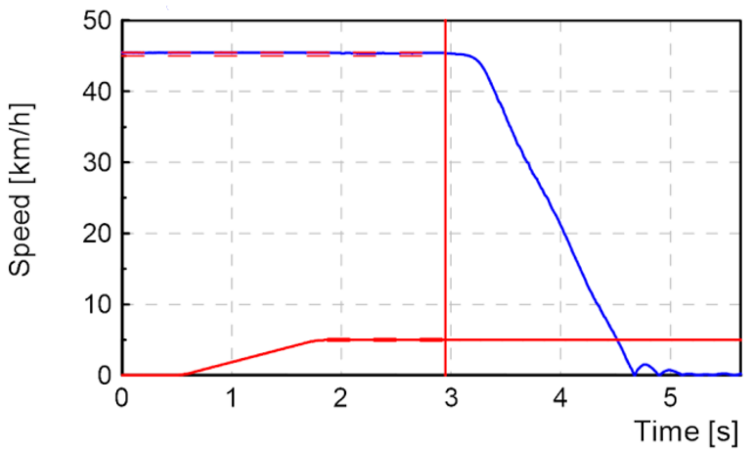

Figure 24: VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 45 kph.

Table 11: Results of the Demo_4_02 scenario at 45 kph.

	AEB	Impact
Time [s]	2.95	N
TTC [s]	1.06	N
Distance VEH-VRU [m]	13.36	N
VEH speed [kph]	45.38	N

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Demo_4_02 at 50 kph

At 50 kph, the vehicle is able to avoid the collision and full stop at 0.99 m from the VRU. Is starts braking at a distance of 13.79 m from the VRU.

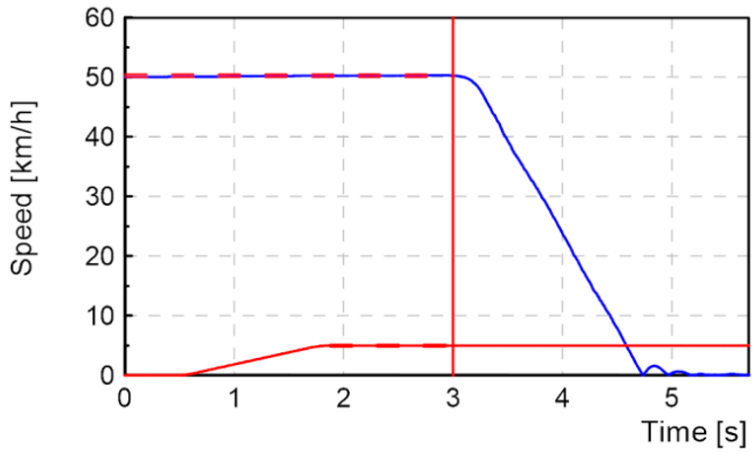

Figure 25: VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 50 kph.

Table 12: Results of the Demo_4_02 scenario at 50 kph.

	AEB	Impact
Time [s]	3	N
TTC [s]	0.99	N
Distance VEH-VRU [m]	13.79	N
VEH speed [kph]	50.26	N

Demo_4_02 at 55 kph

At 55 kph, the vehicle is not able to avoid the collision, which happens at 24.36 kph. The collision moment is represented by the green line in the graph below. In this case the vehicle detects the child pedestrian very late compared to the previous tests which makes the vehicle to react later and hit the VRU at relatively high speed.

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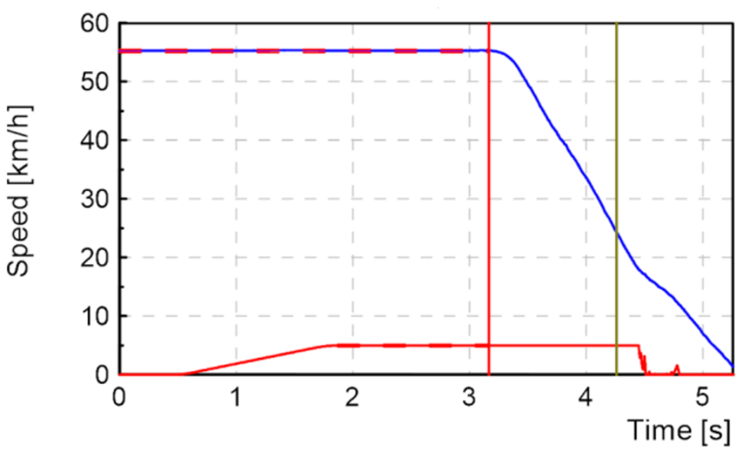

Figure 26: VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 55 kph.

Table 13: Results of the Demo_4_02 scenario at 55 kph.

	AEB	Impact
Time [s]	3.16	4.26
TTC [s]	0.83	0
Distance VEH-VRU [m]	12.79	0
VEH speed [kph]	55.3	24.36

Demo_4_02 at 60 kph

At 60 kph, the vehicle is not able to avoid the collision, which happens at 36.79 kph. In this case the vehicle detects the pedestrian later than at 55kph due to the higher driving speed.

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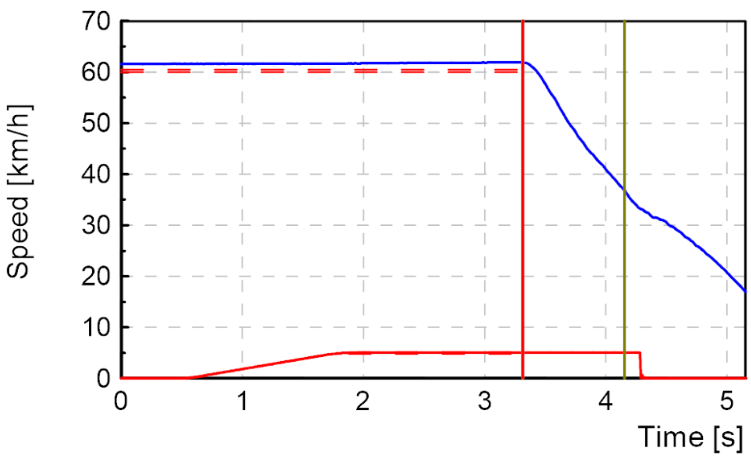

Figure 27 VEH speed (blue) and VRU speed (red) vs time graph for Demo_4_02 scenario at 60 kph.

Table 14: Results of the Demo_4_02 scenario at 60 kph.

	AEB	Impact
Time [s]	3.32	4.16
TTC [s]	0.67	0
Distance VEH-VRU [m]	11.53	0
VEH speed [kph]	61.88	36.79

The results of the runs for this scenario (Demo_4_02) show that the current status of the AEB system (including sensors, data fusion, collision algorithm and AEB ECU activation) performs well from 35 to 50 kph, avoiding the collision with the VRU, while it hits the pedestrian at 55 and 60 kph. This performance can become a good baseline for Demo 4. With V2X, these results are expected to improve especially in those runs where the vehicle almost or directly hits the child pedestrian (at 50, 55 and 60 kph).

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7 Discussion and Next Steps

7.1 Vehicle

The current status allows to demonstrate the developments regarding vehicle-mounted sensors, fusion of sensor data and the AEB algorithm in test tracks. The next step consist of adding V2X capabilities to the vehicle, and integrate it to the rest of the systems. Once the AEB algorithm is completely ready, the V2X information and the vehicle sensors data will be passed through the fusion system that will extract a complete picture of vicinity (the nearby VRUs, vehicles and obstacles) that will feed the collision risk algorithms (for driver warning and AEB activation) for a proper response, which is expected to perform better taking into account that V2X information will provide environmental data regardless the (limited) vision of the vehicle sensors.

Next, the driver warning algorithm and the corresponding HMI/warning systems will be implemented. When all the Vehicle systems are properly tested, they will be integrated into the TME vehicle. Some adaptations are expected to happen to fully integrate both systems, since the AEB ECUs are different between both vehicles. The signals that currently activate the AEB in the IDIADA CAVRide vehicle are different from the ones used by the TME car. However, such adaptation is expected to be quick since the TME signals are already identified.

After the integration, some calibration tests will be conducted, since the systems will be configured with respect to the IDIADA car's dimensions (height, installation position, etc.).

The VEH/RSU V2X unit has been developed in parallel to the vehicle functions, and its interoperability with the VRU V2X unit has been proven. Both devices are portable and can be used in a demonstrator if required. The next steps for the VEH/RSU V2X unit consist of implementing and testing the other ITS messages required for the Demo 4, which are still open since there are new draft ETSI message that could potentially fit our VRU use cases.

7.2 RSU

Some of the implementation for the vehicle will be taken and adapted as part of the RSU architecture. The sensors and data fusion (without V2X) systems from the vehicle will be reusable for the RSU, which will only need some calibration taking into account that this device is expected to be placed at higher altitude and its sensors pointing down the road. Also, a mobile platform supporting the RSU, its sensors and the power supply is currently being designed and it will provide freedom on the RSU placement for the demo. Some software implementation will be required to transform perception data to V2X messages that will inform the vehicle about the presence of the VRUs in the area.

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7.3 VRU

The next steps for the VRU device involve the optimisation of self-localization and motion dynamics by fusing information from on-board GNSS, RTK and IMU, in order for the device to provide the best possible results. High accuracy positioning of the VRU is considered as a critical aspect for the efficiency of Demo 4. In parallel, the control action strategy software and the related risk evaluation algorithm will continue being developed, particularly when the LDM software module and objects/events fusion reach a proper level of maturity. Finally, the device's user interface for application control and visual and acoustical HMI warnings for the VRU will have to be developed and implemented for the final VRU device.

There are many safety issues regarding the involvement of real humans in the final demonstration. If such an approach is finally selected and a real human cyclist riding a bicycle is involved, then the bicycle VRU device, which actually is an OBU in this case, will have on-board mounted sensors for speed, brake and steering wheel angle detection, connected to it, in order to increase the awareness information. This updated information will help both the risk evaluation on the device and every connected traffic actor also via the CAM message transmission.

7.4 Scenarios characterization

After the implementations and software tests for every individual system, the three main Demo 4 actors (VEH, RSU and VRU) will be tested deeply to fine-tune them based on the scenarios characteristics. Such characterization will happen right after this deliverable in order to accurately define the scenarios steps, actors' best positioning and movement pattern, number of runs, messages exchange rate, triggers, etc. This information is key to understand not only how the vehicle, the RSU and the VRU shall behave physically, but also taking into account V2X information exchange at every moment.

7.5 Final demonstrator

A set of test runs will be executed for every scenario, as defined in this deliverable. All of them will be demonstrated at IDIADA Test Tracks with the TME vehicle, the RSU and Pedestrian and Cyclist dummies. The evaluation results of these tests will answer the RQ2 and RQ3, since they will provide outputs on the driver warning and AEB performance improvement via V2X technology. To address RQ1, the aim is to involve volunteers in the testing scenarios. However, this is in a discussion phase currently as safety measures must be assessed and will be discussed in Task 5.4.1. The scenarios for the VRU on-time warning may be modified if it is accepted to test with volunteers. Demo 4 members will evaluate the need to execute simulations of certain scenarios as a replacement of proving ground tests in case safety issues or other reasons require it.

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8 Conclusions

This report presents the current intermediate version of Demo 4 that is expected to be finalised and tested during the second half of 2022.

In order to properly introduce Demo 4's scope, a detailed analysis of the technology and policy background, as well as the exact targets and expectations of this demo were presented in Section 2. In addition, the research questions relevant to this demo, reported in D5.1 that was published before the issuing of this report, were updated, to fit better the scope and targets of the solution under development.

Referencing also to other documentation published before this report, the Demo 4 overall as well as vehicle and VRU architectures reported in D3.1 were updated and included in Section 3, whereas the reference accident data and recommendations for the scenario selection of Section 4 process were retrieved from D2.6.

The main focus for the work performed and reported in this deliverable is divided in three layers:

4) **SCENARIOS:** Selecting and defining the scenarios and test runs for both pedestrian and cyclist conflicts, based on the developed knowledge of T2.1 (D2.6).
5) **DEVELOPMENT:** Developing the first prototypes of the Vehicle and VRU components of the Demo.
6) **VALIDATION:** Assessing the performance of the current developed subsystems on a) interoperability level, and b) on proving ground using a selected test scenario.

For the first layer a set of four scenarios for car to pedestrian conflicts and three scenarios for passenger car to cyclist conflicts were selected in Section 4, introducing additional characteristics to the findings of D2.6 that are relevant to C-ITS technology safety benefit expectations. Considering different speed combinations between the passenger car and the VRU, a number of test runs were also identified for each selected scenario.

For the second layer, a detailed description of the development status for each of the three main components was presented in Section 5. In this intermediate demonstration, the work focused on two out of the three main components; the vehicle and the VRU component, whereas the RSU development will be launched soon and reported in the final version of this report.

With regard to the third layer, a set of interoperability tests were performed on theoretical level initially to assess the communication potential between the vehicle/ RSU V2X unit and the VRU device V2X unit, reported in Section 6.1. After the theoretical confirmation, a set of real interoperability tests were performed, and the results prove the ability of the two devices to communicate properly with each other. Furthermore, a real test using one of the car to pedestrian selected scenario (D_4_02) was performed to validate the development status of the vehicle subsystem in terms of fusion and performance of the AEB system. The result of

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this test show that the implemented systems have a good performance and avoid colliding with the child pedestrian at vehicle speeds from 35 to 50 kph, while at faster speeds the system performance decreases as expected. These results are close to the common AEB performance of commercial vehicles based on Euro NCAP's CPNC50 scenario results, however there is some margin for improvement that will be explored to match such Euro NCAP results perfectly. This set of results will used as a baseline for the next tests with the introduction of V2X technology.

The final version of the Demo 4 system\ is due for Month 28 and will be reported in Deliverable 3.7.

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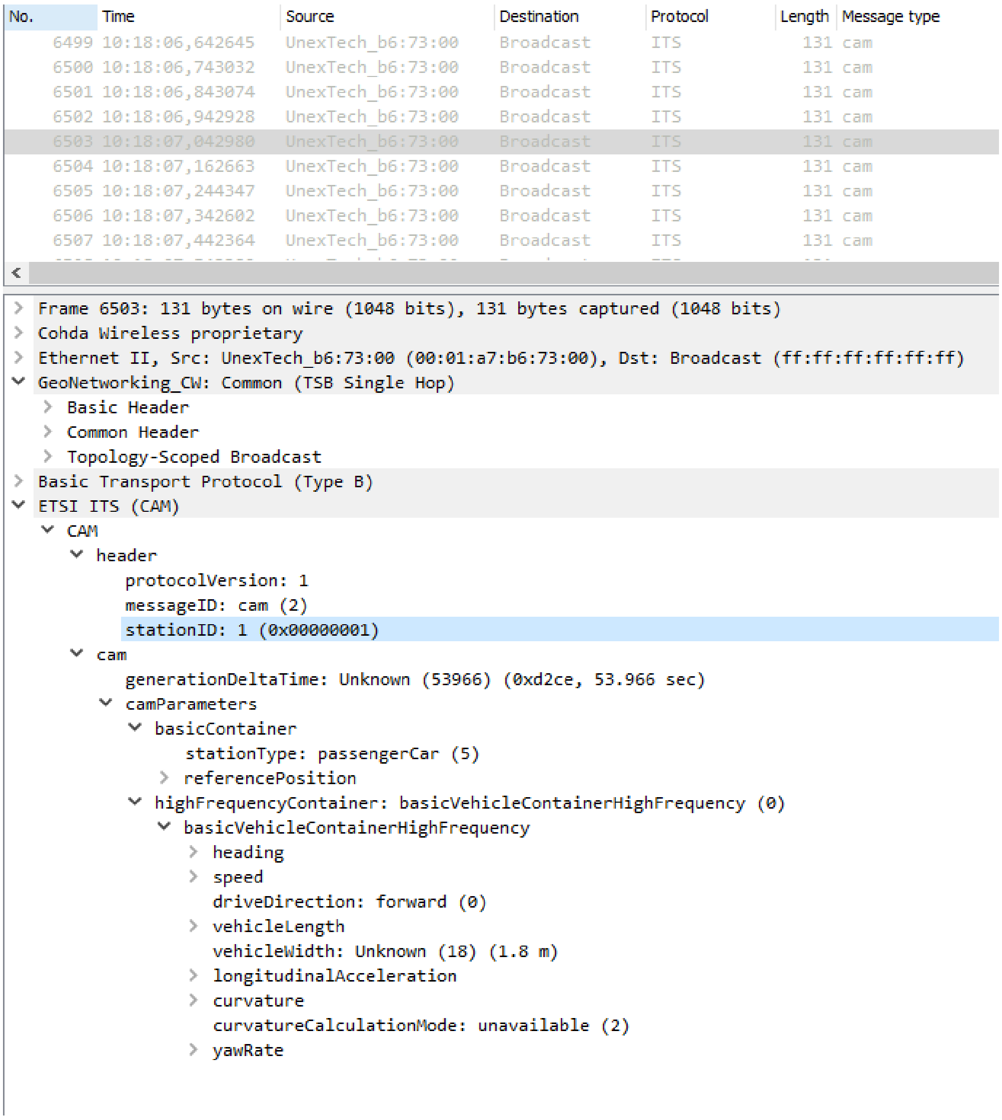
Appendix: Interoperability tests log files

This a trace provided by the VRU V2X devices where all received V2X messages are shown. The information received consists of CAM messages sent by the VEH/RSU V2X device, identified by the stationID “1” (0x00000001). Such CAM messages contain the minimum required information to perform the Demo 4, according the current testing requirements.



No.	Time	Source	Destination	Protocol	Length	Message type
6499	10:18:06,642645	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6500	10:18:06,743032	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6501	10:18:06,843074	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6502	10:18:06,942928	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6503	10:18:07,042980	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6504	10:18:07,162663	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6505	10:18:07,244347	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6506	10:18:07,342602	UnexTech_b6:73:00	Broadcast	ITS	131	cam
6507	10:18:07,442364	UnexTech_b6:73:00	Broadcast	ITS	131	cam

```
> Frame 6503: 131 bytes on wire (1048 bits), 131 bytes captured (1048 bits)
> Cohda Wireless proprietary
> Ethernet II, Src: UnexTech_b6:73:00 (00:01:a7:b6:73:00), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
v GeoNetworking_CW: Common (TSB Single Hop)
  > Basic Header
  > Common Header
  > Topology-Scoped Broadcast
> Basic Transport Protocol (Type B)
v ETSI ITS (CAM)
  v CAM
    v header
        protocolVersion: 1
        messageID: cam (2)
        stationID: 1 (0x00000001)
    v cam
        generationDeltaTime: Unknown (53966) (0xd2ce, 53.966 sec)
      v camParameters
        v basicContainer
            stationType: passengerCar (5)
          > referencePosition
        v highFrequencyContainer: basicVehicleContainerHighFrequency (0)
          v basicVehicleContainerHighFrequency
            > heading
            > speed
              driveDirection: forward (0)
            > vehicleLength
              vehicleWidth: Unknown (18) (1.8 m)
            > longitudinalAcceleration
            > curvature
              curvatureCalculationMode: unavailable (2)
            > yawRate
```

Figure 28: Packet trace from the VRU V2X device.

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The next figure represents the received messages from the VEH/RSU V2X device point of view. The CAM messages received are from the VRU V2X device with stationID 256 (0x00000100). Such CAM messages contain the minimum required information to perform the Demo 4, according the current testing requirements.

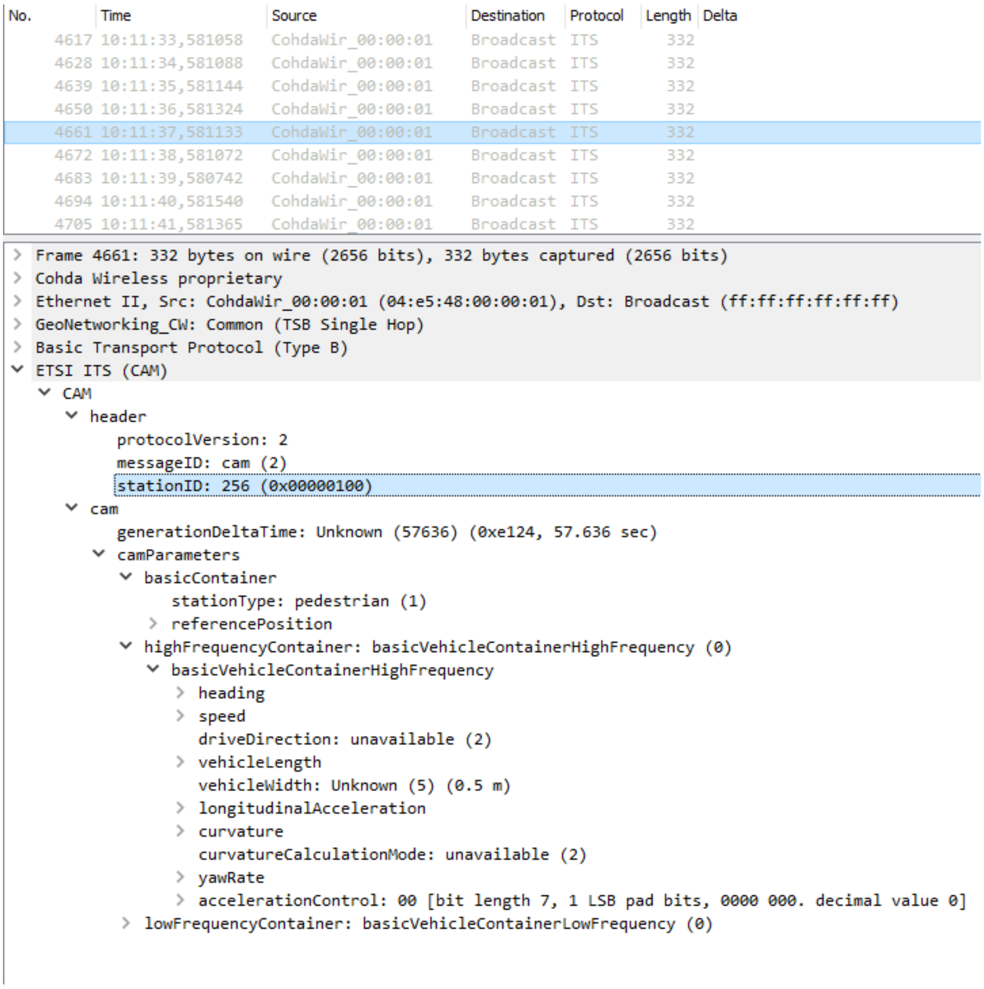

Figure 29: Packet trace from the VEH/RSU V2X device.

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