D3.7 Demo 4 (system for on-time warning provisions to VRUs and drivers in critical conditions) update

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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 summarises the development, integration and pre-testing phase of Demo 4 "System for on-time warning provisions to VRUs and drivers in critical conditions". The main focus for the work performed and reported in this Deliverable is divided in four layers:

1) **SCENARIOS IN-DEPTH ANALYSIS:** The scenarios selected in the preliminary version of Demo 4 presented in D3.4 (Nikolaou, et al., 2021) are characterised and analysed to fulfil the requirements of the testing phase.
2) **FINAL DEVELOPMENT OF SUBSYSTEMS:** The final development for each Demo 4 subsystem (vehicle, RSU, pedestrian safety device and cyclist safety device) are summarised.
3) **INTEGRATION & PRE-TESTING:** The integration of the individual subsystems into the final integrated Demo 4 system, the problems faced and solutions selected and the pre-testing of the final systems is presented.
4) **FINAL DEMONSTRATOR:** The outcomes from the integration and pre-testing phase (simulations and physical tests) are analysed and technical limitations encountered are highlighted and upscaled to recommendations for future research and development.

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List of abbreviations

Abbreviation	Meaning
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AES	Autonomous Emergency Steering
AV	Autonomous Vehicle
B-CL	Bicyclist crossing from left (D2.6)
B-CR	Bicyclist crossing from right (D2.6)
BLE	Bluetooth Low Energy
B-PCTurnL	Bicyclist in conflict with Passenger Car turning left (D2.6)
CAM	Cooperative Awareness Message
CBNAO	Car-to-Bicyclist Nearside Adult Obstructed (Euro NCAP)
CBTA	Car to Bicycle Turning Adult (Euro NCAP)
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
CPNC	Car-to-Pedestrian Nearside Child (Euro NCAP)
DSRC	Dedicated Short Range Communication
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
H-point	Hip point
Hz	Hertz
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

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Abbreviation	Meaning
LCD	Liquid Crystal Display
LDM	Local Dynamic Map
LSS	Lane Support Systems
Mgmt	Management
mPCIe	Mini Peripheral Component Interconnect Express
OBU	On Board Unit
PCB	Printed Circuit Board
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)
RF	Radio Frequency
ROS	Robot Operating System
RQ	Research Question
RSU	Road-side Unit
RTK	Real-time kinematic positioning
SAE	Society of Automotive Engineers
SOTA	State of the Art
TTC	Time To Collision
UNECE	United Nations Economic Commission for Europe
V2X	Vehicle-to-Everything
VEH	Vehicle
VRU	Vulnerable Road User
VUT	Vehicle Under Test
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 in detail the final status of the Demonstrator 4 and in a nutshell includes:

- Final development of Vehicle, RSU and VRU devices (pedestrian and cyclist) components.

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- Characterisation (based on EuroNCAP testing protocol) of Demo 4 selected scenarios reported in D3.4 (Nikolaou, et al., 2021).
- Integration of the individual subsystems into the final Demo 4 integrated system.
- Pre-testing of the final system and final testing of cyclists' safety system with real human volunteers.
- Discussion on Demo 4 outcomes and limitations and recommendations for future research.

1.3 Report Organization

This Deliverable is organised as follows: **Section 2** provides an overview of Demo 4 scope and objectives. **Section 3** includes the final overall architecture of the Demo 4 system as reported in D3.9 (Nikolaou & Panou, 2022). In **Section 4**, the selected Demo 4 scenarios that were reported in D3.4 (Nikolaou, et al., 2021) are further analysed in order to provide understanding on obstruction type and characteristics for those scenarios related to an obstruction (Section 4.1), whereas all scenarios are characterised using the EuroNCAP VRU testing protocol (Section 4.2). This work facilitated the preparation of the testing procedure and the test runs to be held both for the simulations and the real tests at IDIADA premises. **Section 5** describes the final development status for each of the four main components of Demo 4. It should be noted here that an update on the VRU devices in relation to D3.4 is introduced in this report; two individual VRU devices one for pedestrians and one for cyclists were developed due to the fact that they are different road users with different characteristics and safety-related requirements. **Section 6** summarises the work performed during the integration phase and pre-testing preparation at IDIADA premises (Section 6.1), the setups of the simulations of the Demo 4 scenarios (Section 6.2) and the final testing of the cyclists' safety system with real human cyclists (Section 6.3). Finally, **Section 7** discusses the main outcomes and limitations of the performance of the Demo 4 system and proposes recommendations for future research, whereas **Section 8** summarises the main results of this report.

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2 Demo 4 Overview

2.1 Overall Demonstrator scope

The overall detailed description of Demo 4 scope is included in D3.4 (Nikolaou, et al., 2021), which was the preliminary version of the Demonstrator.

In brief, Demo 4 develops a VRU safety system based on V2X technology that provides enhanced communication between vehicles, road infrastructure (RSU installed nearby) and VRUs (pedestrians and cyclists). The actual target is to provide additional environmental perception to vehicles regarding the presence of VRUs in critical situations, especially in cases where the vehicle sensors reach their limits (i.e. obstructed areas). Connected VRUs are able to directly exchange V2X messages with the equipped V2X vehicles, whereas the non-connected VRUs are monitored by the RSU that exchanges messages with the V2X equipped vehicles.

The system deploys effective on-time warning messages on critical situations to both drivers and connected VRUs. For the VRUs the warnings are delivered via a custom-developed C-ITS smart device. The vehicle is equipped with an AEB system based on perception sensors that may be engaged in cases where an immediate emergency stop is required. This AEB system will potentially increase its efficiency in certain scenarios in combination with V2X technology. Perception sensors data and V2X information will feed the AEB system in order to be engaged on-time and to perform an earlier system reaction in situations with limited sensor perceptibility. With high V2X localization accuracy the system reaction could have the potential of an earlier AEB intervention.

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3 Architecture

Demo 4 consists of four main components:

- Vehicle equipped with V2X technology.
- Road-side unit: Infrastructure component equipped with sensors that detect VRUs, in addition to V2X technology.
- VRU safety system equipped with V2X technology for pedestrians.
- VRU safety system equipped with V2X technology for cyclists.

The main architecture of Demo 4 is the communication architecture which is presented in Figure 1 below. The diagram shows the relationship between all Demo 4 entities involved on high level. The final physical architectures for each of the main components are included in D3.9 (Nikolaou & Panou, 2022).

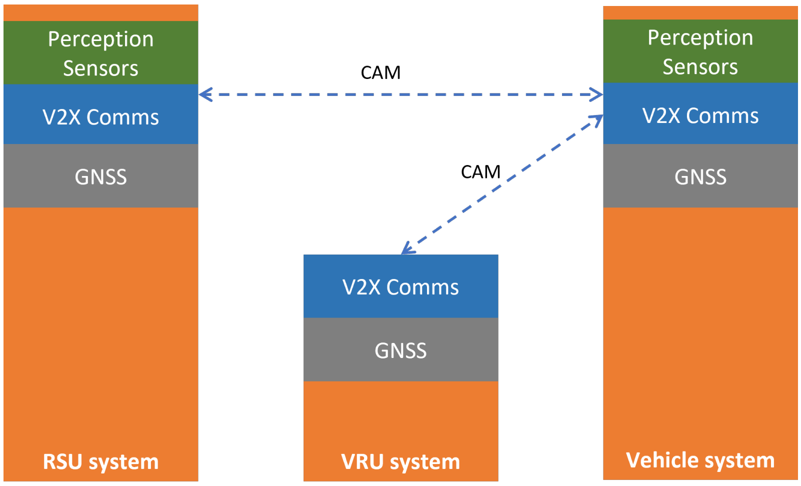

Figure 1: Demo 4 Communication architecture diagram.

The Demo 4 has two main operational modes:

- Direct communication: The VRU system (pedestrian or cyclist) and the vehicle share CAM messages, which include key information such as location, heading, speed, etc. via V2X. The VRU device uses the information coming from the vehicle to trigger a warning to the user. The vehicle uses the VRU information to feed the perception system, fusing it with its own perception sensor's data, and trigger a warning to the driver and the AEB system if necessary.
- Indirect communication: The RSU detects non-connected VRUs using perception sensors and informs the vehicle via CAM messages using V2X technology. The CAM messages include the information of the detected VRUs (location, speed, heading, etc.) and the vehicle uses them as for the same purpose as the direct communication mode.

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4 Demo 4 scenarios in-depth analysis

The Demo 4 selected scenarios were defined under deliverable D3.4 (Nikolaou, et al., 2021). In total, 4 scenarios were proposed for passenger car to pedestrian conflicts and 3 for passenger car to cyclist conflicts, as can be seen in the Figures below:

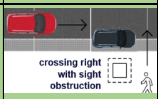
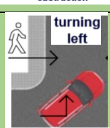
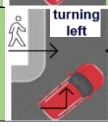
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)	
Demo_4_01	Pedestrian	C-ITS-P3 D2.6 P-CRwSO		18,7	17,1	26 - 45	25 - 45 (every 5 Kph)	-	8	5
Demo_4_02	Pedestrian	C-ITS-P3 D2.6 P-CRwSO		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 2: Selected passenger car to pedestrian scenarios for Demo 4 (Nikolaou, et al., 2021).

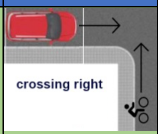
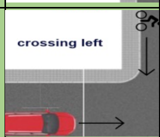
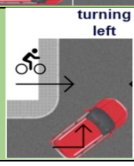
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)	
Demo_4_08	Cyclist	C-ITS-B1 D2.6 B-CR + Obstruction		37,8	35,2	5-30	15-30 (every 5 Kph)	N/A	15 - 20 (every 5 Kph)	8
Demo_4_09	Cyclist	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 3: Selected passenger car to cyclist scenarios for Demo 4 (Nikolaou, et al., 2021).

A further analysis was performed in order to characterise each scenario, by detailing the main parameters (vehicle position, user position, obstruction type, etc.) in order to setup the testing phase. This work is divided in two sections; Section 4.1 presents the GIDAS-based analysis that was performed in order to define the characteristics of the obstruction-related scenarios both for pedestrians and cyclists and Section 4.2 focuses on defining the scenarios using the EuroNCAP protocol (Euro NCAP, 2020) as a reference.

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4.1 GIDAS-based analysis for the characterisation of obstruction-related scenarios

The next step of this work was to retrieve more information about the type of obstructions that should be considered in 4 of the Demo 4 scenarios. Specifically, for two of the passenger car to pedestrian scenarios proposed (Demo_4_01 & Demo_4_02) and for two of the passenger car to cyclist scenarios (Demo_4_08 & Demo_4_09), an obstruction was considered. Figure 4 below, shows the overview of these scenarios.

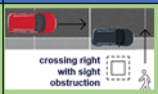
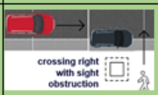
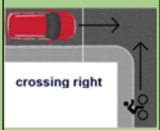
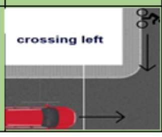
Scenario ID	VRU Type	D2.6 scenario label	Pictogram	Injury coverage		Speed (Km/h)				Total test cases
				% KSI	%All	VUT (KSI/All)	VUT (Proposal)	VRU (KSI/All)	VRU (Proposal)	
Demo_4_01	Pedestrian	CITS-P3 D2.6 P-CRwSO		18.7	17.1	26 - 45	25 - 45 (every 5 Kph)	-	8	5
Demo_4_02	Pedestrian	CITS-P3 D2.6 P-CRwSO		18.7	17.1	27 - 45	35 - 65 (every 5 Kph)	N/A	5	7
Demo_4_08	Cyclist	CITS-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	CITS-B2 D2.6 B-CL + Obstruction		25.5	22.4	5-30	15-30(every 5 Kph)	N/A	20	4

Figure 4: Demo 4 selected scenarios where obstruction is considered.

As mentioned in D3.4, the conflicts with the presence of obstructions are situations where C-ITS technology may have safety potential based on the lack of visibility of the VRU by the approaching vehicles. However, it is necessary to understand and characterise those obstructions so the physical tests performed in Demo 4 can reflect them.

In order to do that, an accident analysis has been performed by TME. The basis has been the same criteria as defined in D2.6 (Bálint, et al., 2021), using also German In-Depth Accident Study (GIDAS) (Seeck, et al., 2009) and GIDAS-Pre-Crash-Matrix (GIDAS-PCM) databases (Schubert, et al., 2016). GIDAS data has been used to extract additional information in order to understand the presence and characteristics of obstruction in crashes. GIDAS-PCM data has been used to perform a case-by-case analysis on some crashes to understand visually how the obstruction looked like.

4.1.1 Variables for the analysis of obstructions

To analyse the presence and type of obstructions on the crash situations, the GIDAS variables used are the presence of sight obstruction (SICHTBV) and the type of sight

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obstruction (SICHTV).), from the perspective of the passenger car. The presence of a sight obstruction is classified in the following categories:

- view obstacle present, no further details
- no present view obstacle
- view obstacle present but not permanent
- view obstacle present and permanent
- other type of view obstacle
- unknown

The type of view obstruction is classified as:

- existing, no further details
- no view obstruction
- view obstruction related to parking vehicles
- view obstruction related to structural circumstances (buildings…)
- view obstruction related to waiting/starting vehicles
- view obstruction related to driving vehicles
- view obstruction related to own vehicle (dirt, fogged window…)
- other type of view obstruction

4.1.2 GIDAS analysis

This section shows the GIDAS analysis performed for both passenger car to pedestrian and passenger car to cyclist crashes, according to the definition of the scenarios in D2.6 (Bálint, et al., 2021) which are related to Demo 4. The analysis does not consider the specific speed values proposed for each Demo 4 scenario, since that lowers the sample of the analysed data. Table 1 shows the mapping between Demo 4 scenarios and D2.6 scenarios.

Table 1: Relation between Demo 4 and D2.6 scenarios.

Demo 4 scenario	D2.6 scenario
Demo_4_01 & Demo_4_02	P-CRwSO
Demo_4_08 & Demo_4_09	B-CR & B-CL

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4.1.2.1 Passenger car to pedestrian

Figure 5 shows the presence of obstruction in crashes. In total, 544 crashes were analysed. For almost 80% of the crashes, the presence of obstruction is relevant. It shall be noted, that the original crashes related to this P-CRwSO scenario, where identified from the conflict situation which did not consider the presence of obstruction from the passenger car driver point of view.

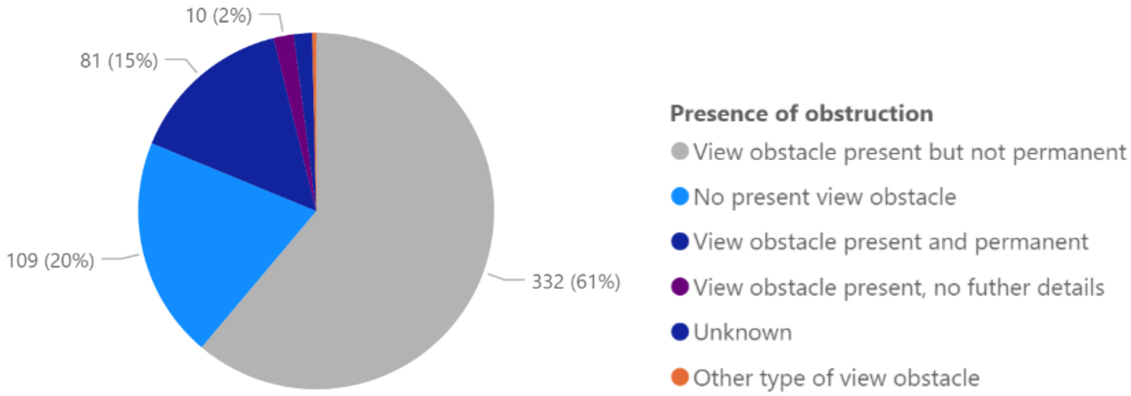

Figure 5: Presence of obstruction in passenger car to pedestrian crashes based on D2.6 P-CRwSO.

In 61% of the cases, a view obstacle is present although the obstruction is not permanent and for almost 15% of the cases, the view obstacle was present and permanent. To analyse further the type of obstruction, the crashes where the presence of obstruction existed were considered. This is done, using the variable “type of obstruction”, where all the “blank” cases have been excluded. This led a to a lower amount of relevant cases where the presence of obstruction existed (n=302).

Figure 6 below shows the distribution of type of obstruction for those crashes.

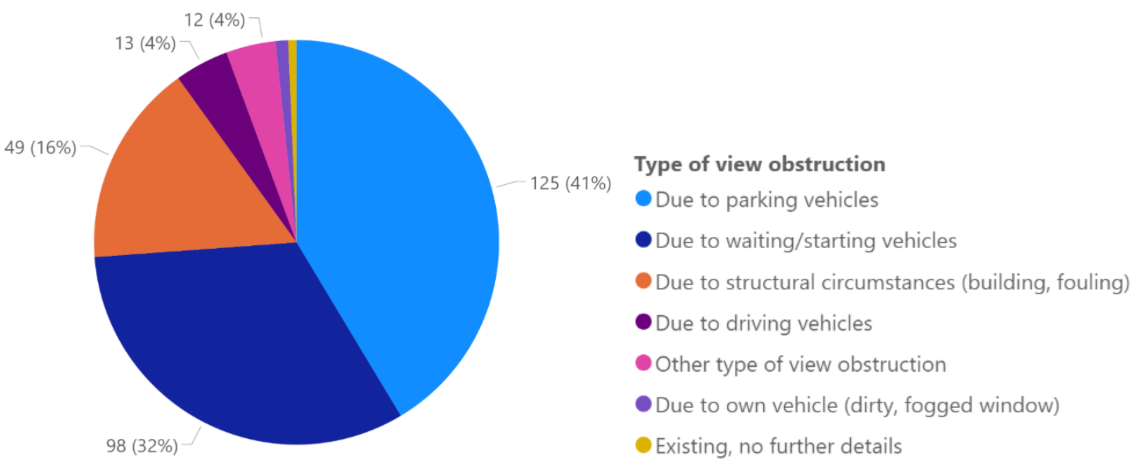

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Figure 6: Type of obstruction in passenger car to pedestrian crashes based on D2.6 P-CRwSO.

The analysis shows that 73% of the view obstructions are related to stationary vehicles, either parked (41%) or waiting/starting (32%). The next main type of view obstruction is related to structural circumstances such as buildings (16%). The other types of view obstruction related to others without further details or to the own vehicle.

4.1.2.2 Passenger car to cyclist

In D2.6 (Bálint, et al., 2021), the analysis of passenger car to cyclist crossing scenarios, named as B-CR and B-CL, did not differentiate between cases with obstruction present or cases without obstruction. Therefore, the analysis has been redone including this differentiation, using the GIDAS variables aforementioned.

Figure 7 below shows the presence of obstruction. In total, 1081 crashes were analysed. For 63% of the crashes, view obstacle is present and permanent and for 35% of the crashes, the view obstacle was present but not permanent.

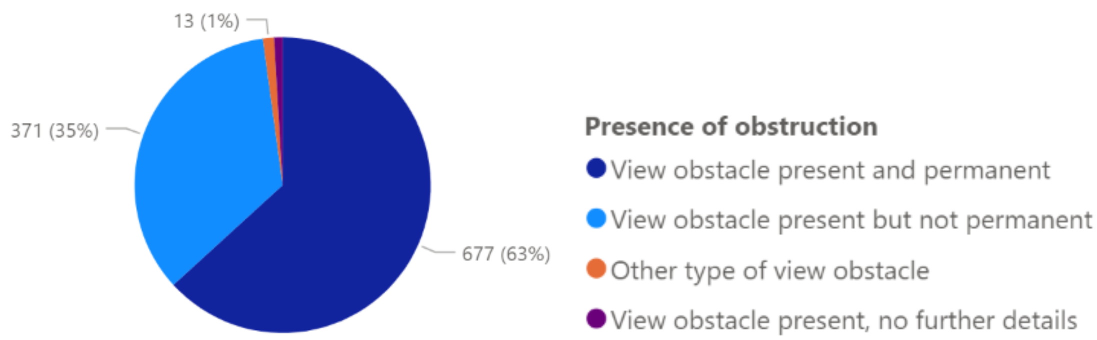

Figure 7: Presence of obstruction in passenger car to cyclist crashes based on D2.6 B-CR and B-CL.

Figure 8 below shows the distribution of type of obstruction for those crashes.

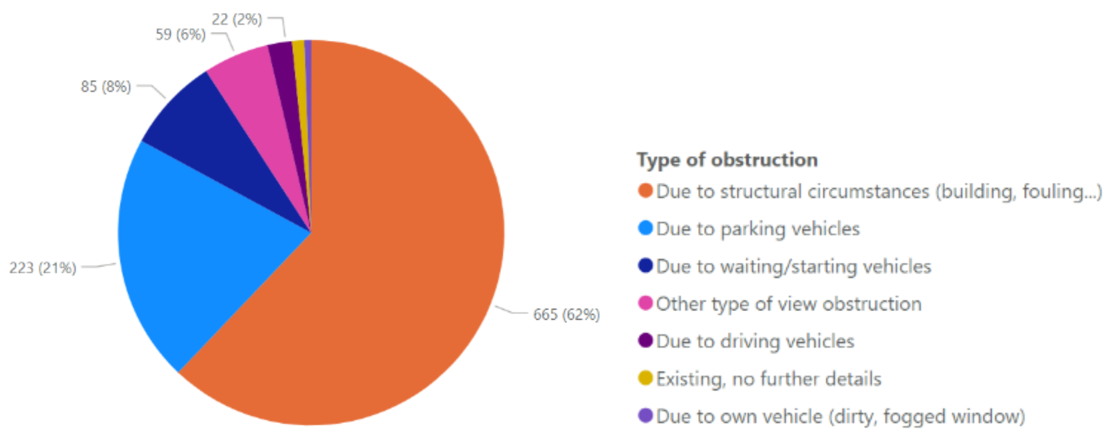

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Figure 8: Type of obstruction in passenger car to cyclist crashes based on D2.6 B-CR and B-CL.

In contrast with the passenger car to pedestrian results, the analysis shows that the main type of obstruction is related to structural circumstances (62%). Obstructions related to vehicles are next, with parking vehicles (21%), waiting/starting vehicles (8%), driving vehicles (2%). Finally, other type of obstructions accounts for 6% of the crashes.

4.1.3 GIDAS-PCM analysis

Based on the GIDAS analysis it is possible to already identify that the main type of obstruction related to passenger car to pedestrian scenarios is related to vehicles and the one for passenger car to cyclist scenarios are structural elements such as buildings.

However, with this analysis it is difficult to understand more details of such obstructions, such as size or location. Therefore, TME has performed a case-by-case analysis using a software "PCM-Viewer" that can visualize GIDAS-PCM reconstructed accidents. From the GIDAS analysis, the available numbers in GIDAS-PCM for TME were 203 for the passenger car to pedestrian cases and 656 for the passenger car to cyclist scenarios. Due to the big amount of cases, a case-by-case study has been done on random cases, checking the different type of obstruction elements.

One example for "Obstruction due to parking vehicles", "Obstruction due to waiting / starting vehicles" and "Obstruction due to structural circumstances (building, fouling)is presented in the figures below. The software provides both a 2D view (top-view) and a 3D view. The passenger car is represented with a red shape whereas the VRU is represented with a smaller green shape. The trajectories of each participant can also be seen, using the same colour code. The obstruction is represented by a grey shape. All these elements are shown overlaid with the accident sketch which includes lane markings and infrastructure like road edges and pavements.

a. Obstruction due to parking vehicles

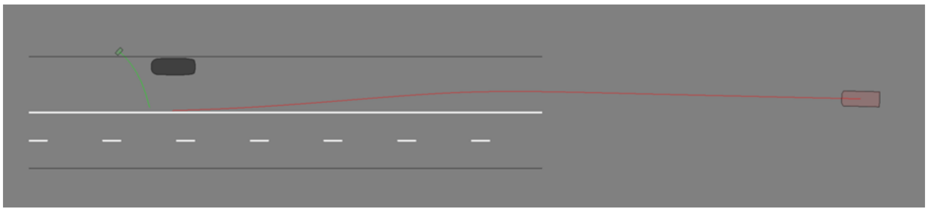

Figure 9: Top view of obstruction due to parking vehicles.

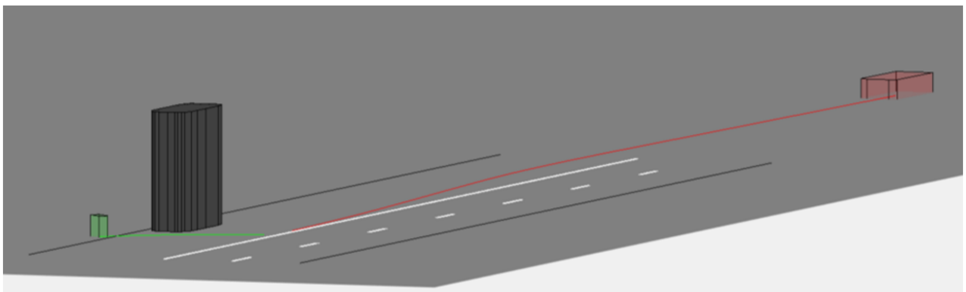

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Figure 10: 3D view of obstruction due to parking vehicles.

b. Obstruction due to waiting / starting vehicles

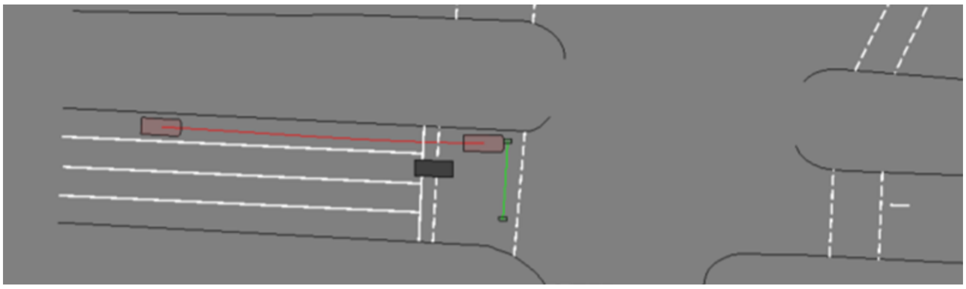

Figure 11: Top view of obstruction due to waiting / starting vehicles.

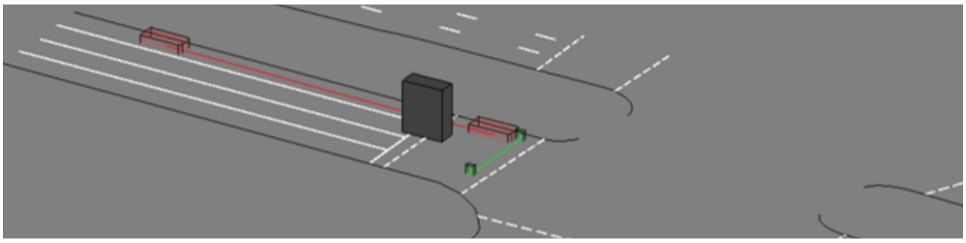

Figure 12: 3D view of obstruction due to waiting / starting vehicles.

c. Obstruction due to structural circumstances (building, fouling)

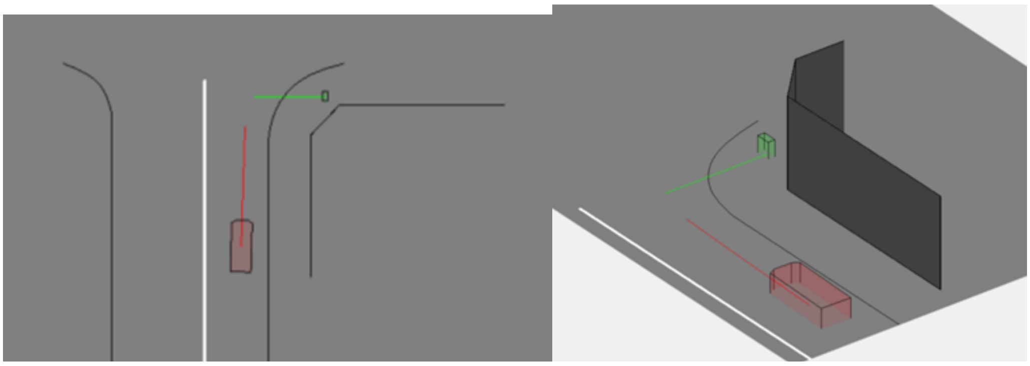

Figure 13: Top view (left) and 3D view (right) of obstruction due to structural circumstances.

4.1.4 Conclusion

Based on this analysis, it is possible to have a better understanding on what type of obstructions are related to Demo 4 proposed scenarios and how should they be implemented for the physical testing.

For passenger car to pedestrian, parking vehicles is the most common obstruction. Since there is already a state-of-the-art approach to realise those in physical testing, based on Euro NCAP 2020 VRU protocol (Euro NCAP, 2020), it is suggested to use the same definition as in this protocol.

For passenger car to cyclist scenarios, structural circumstances are the most common obstruction type. Looking at the state-of-the-art of physical testing to understand such an

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obstruction, current Euro NCAP 2020 VRU protocol (Euro NCAP, 2020), considers an obstruction element for passenger car to cyclist scenarios, although only for cases where the cyclist is crossing from the right of the vehicle. Such obstruction element is represented by a large vehicle, which according to the protocol shall be an off-road 4x4 vehicle, for which minimum and maximum dimensions are defined. H2020 PROSPECT project, which aimed at tackling proactive safety systems for pedestrians and cyclists, also analysed the representation of obstructions which shall represent a wall or a building, proposing a structure and dimensions which in height are larger than the Euro NCAP protocol (Seiniger, et al., 2016). Commercial solutions in this direction are also available today in the market (4activesystems, n.d.). Based on this, it has been decided that the obstruction element for passenger car to cyclist shall not be a passenger car but a larger object. After discussing the available options at the testing facility of IDIADA, it was decided to use a large van which would be representative of the solution proposed in H2020 PROSPECT project and in accordance to the Euro NCAP 2020 VRU protocol, which addresses passenger car to bicyclist coming from right with an obstruction. The same obstruction layout is proposed for the bicyclist coming from left, since that scenario is not existing today in the Euro NCAP 2020 VRU protocol, with an obstruction element.

The obstruction elements defined in this section are implemented by IDIADA in the physical testing of Demo 4.

4.2 Scenarios characterisation

In D3.4 (Nikolaou, et al., 2021), the scenarios identified for the Demo 4 have been designed and characterized accordingly to be represented in the simulations and on the test tracks. Such characterization has consisted in defining all measurements and variables of the relevant actors (dynamic and static). In general, the distance measurements have been concluded following EuroNCAP's parameters from TEST PROTOCOL – AEB/LSS VRU systems v4.0.0 (Euro NCAP, 2021), since it ensures replicability and allows the results to be comparable with past and current EuroNCAP's test results.

The speed of the different actors has already been identified in D3.4 in order to maximize the impact of the selected scenarios when an active system (e.g. AEB) would have troubles trying to avoid the accident and, therefore, a V2X technology would improve the result.

The complete list of the identified parameters set from the characterization of the Demo 4 scenarios is presented in Table 2 below.

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Table 2: List of identified parameters set for the Demo 4 scenarios characterisation.

Parameter	Description
D_L	Distance in x-direction between vehicle under test and obstruction (units: meter)
D_X	Distance in y-direction between the obstruction and the VRU hip point (H-point) (units: meter)
D_{init}	Distance in x-direction between the VRU initial position and the impact point (units: meter)
D_R	Distance in x-direction between the RSU fixed position and the impact point
I_{WP}	Target impact location on the vehicle front-bumper. It represents a point of the front-bumper starting from the right side (0%) to the left side (100%).50% represents the centre of the vehicle units:
T_{Typ}	Type of VRU (pedestrian or cyclist)
V_S	Vehicle speed (units: kph)
V_T	VRU speed (units: kph)
C_S	Vehicle connectivity (states: active/inactive)
C_T	VRU connectivity (states: active/inactive)
C_R	RSU connectivity (states: active/inactive)

The definition of such parameters is generic, but it may vary depending on the scenarios. For each, if a parameter is defined differently than the previous table, the new parameter description will be provided.

The main target for the connectivity is representing the following cases:

- No connectivity (baseline)
- Vehicle (C_S) and VRU (C_T) connectivity active. RSU (C_R) connectivity inactive.
- Vehicle (C_S) and RSU (C_R) connectivity active. VRU (C_T) connectivity inactive.

Therefore, the RSU connectivity (C_R) and the VRU connectivity (C_T) are inversed since each scenario will be tested with connected VRUs (no RSU involved) and with non-connected VRUs (RSU active). The details for each run can be found in Section 6.

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4.2.1 Demo_4_01 & Demo_4_02: Approaching a pedestrian crossing from nearside

Both Demo_4_01 and Demo_4_02 scenarios share the same physical space (represented in Figure 14).

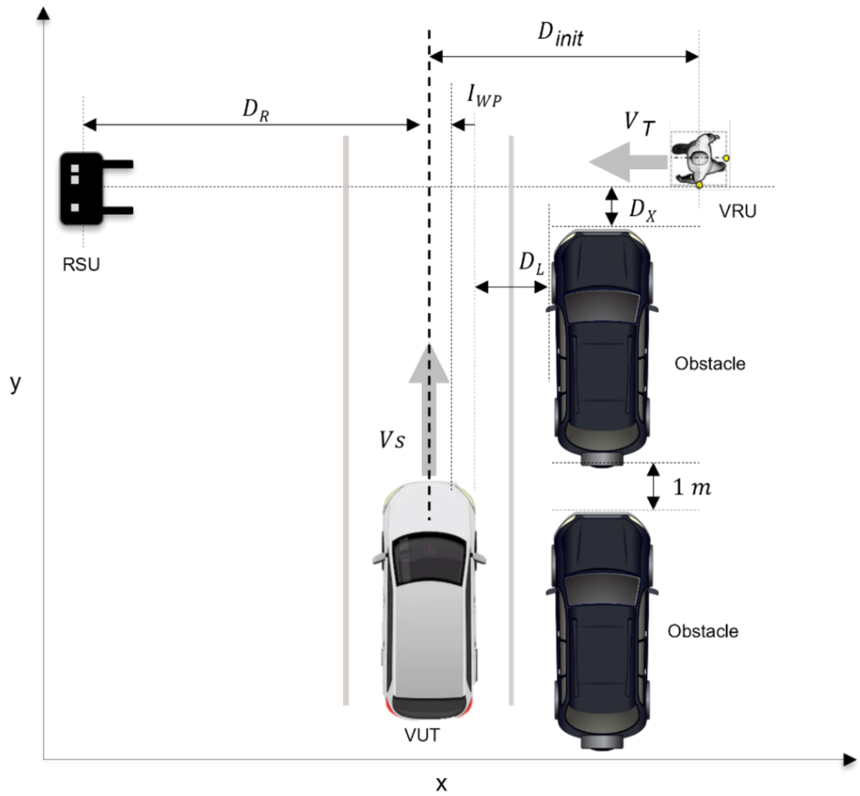

Figure 14: Demo_4_01 and Demo_4_02 testing scenarios.

The characterization in terms of distance measurements are shown in Table 3.

Table 3: Fixed parameters for Demo_4_01 and Demo_4_02 scenarios.

Parameter	Demo_4_01	Demo_4_02
D_L	1	1
D_X	1	1
D_{init}	4	4
D_R	6	6
I_{WP}	50	50
T_{Typ}	Adult	Adult

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The only difference between them are both the vehicle under test (VUT) and the VRU speeds (see differences between **Error! Not a valid bookmark self-reference.** and Table 5). The basis of this scenario is the EuroNCAP CPNC test case.

Table 4: Variable parameters for Demo_4_01 scenario.

Parameter	Min	Max	Step
V_S	25	45	5
Parameter	**Value**		
V_T	8		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

Table 5: Variable parameters for Demo_4_02 scenario.

Parameter	Min	Max	Step
V_S	35	65	5
Parameter	**Value**		
V_T	5		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

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4.2.2 Demo_4_05 & Demo_4_06: Approaching a crossing pedestrian walking from farside while turning to the farside

Like the 01 and 02 scenarios, Demo_4_05 and Demo_4_06 also share the same physical distribution of the elements and actors involved (see Figure 15). The basis of both scenarios is the EuroNCAP CPTA 2023.

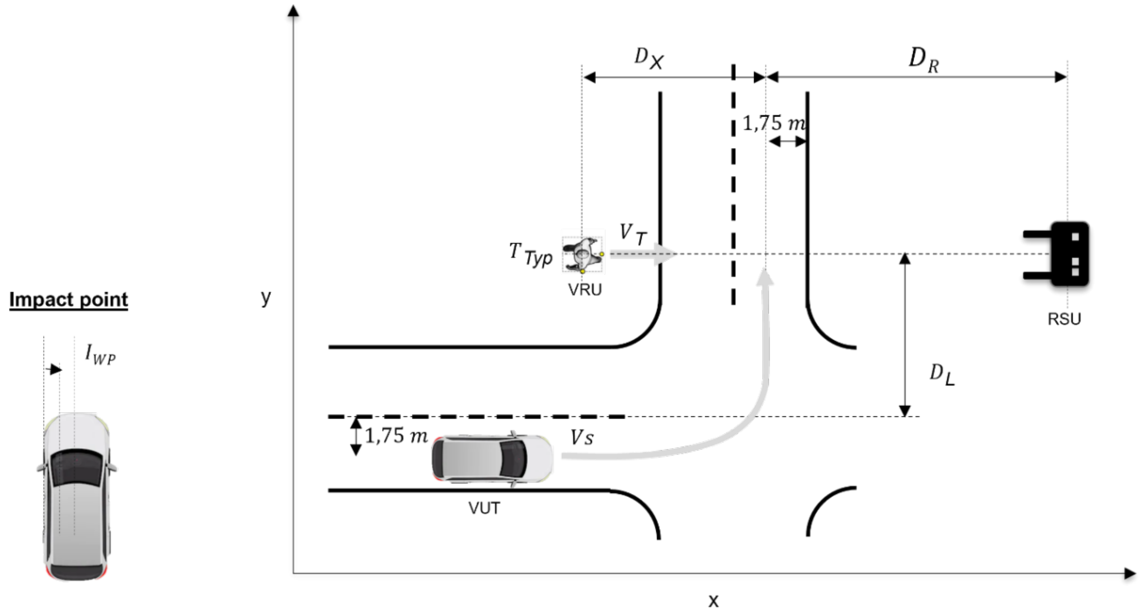

Figure 15: Demo_4_15 and Demo_4_06 testing scenarios.

For these turning scenarios, the D_L and D_X parameters' definition is different from the ones defined in the introduction section (Table 2), since they were related to an obstruction which is not present in this kind of turning scenarios. For Demo_4_05 and Demo_4_06, D_L and D_X are defined as shown in Table 6:

Table 6: Description of D_L and D_X parameters for Demo_4_05 and Demo 4_06 scenarios.

Parameter	Description
D_L	Distance in y-direction between the centre of the dashed lane marking of the vehicle and VRU trajectory (units: meter)
D_X	Distance in x-direction between the VRU initial position and the impact position (units: meter)

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The fixed parameters of both test scenarios are available in Table 7, while variable parameters for Demo_4_05 can be found in Table 8 and for Demo_4_06 in Table 9.

Table 7: Fixed parameters for Demo_4_05 and Demo_4_06 scenarios.

Parameter	Demo_4_05	Demo_4_06
D_L	9.5	1
D_X	6	1
D_R	6	6
I_{WP}	50	50
T_{Typ}	Adult	Adult

Table 8: Variable parameters for Demo_4_05 scenario.

Parameter	Min	Max	Step
V_S	10	30	5
Parameter	**Value**		
V_T	5		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

Table 9: Variable parameters for Demo_4_06 scenario.

Parameter	Min	Max	Step
V_S	10	30	5
Parameter	**Value**		
V_T	8		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

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4.2.3 Demo_4_08: Approaching a bicyclist crossing from nearside obstructed

This characterization of this scenario, based on the EuroNCAP CBNAO test case, is represented in the following Figure 16:

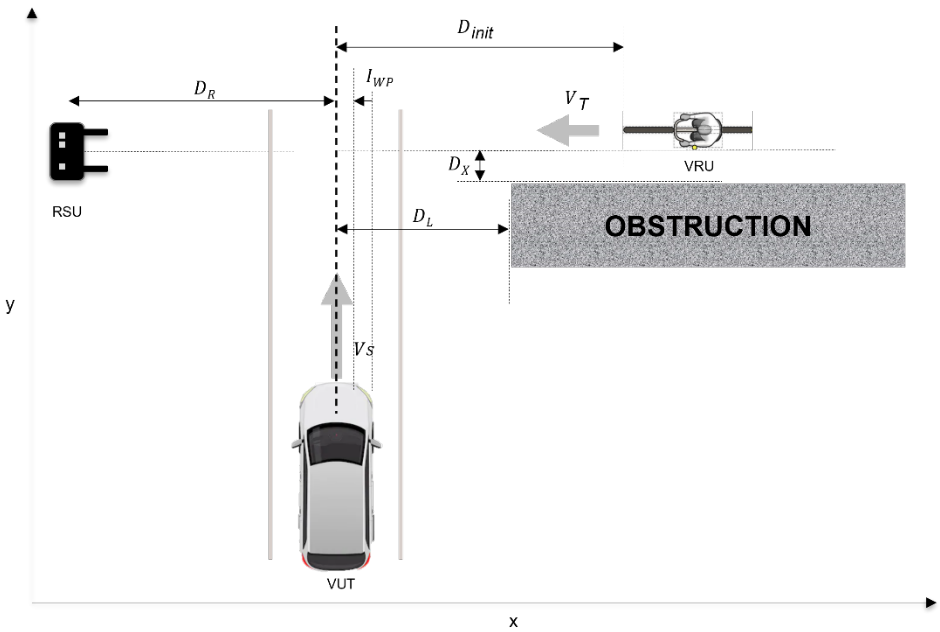

Figure 16: Demo_4_08 testing scenario.

It was decided that the cyclist scenarios will have obstruction dimensions that in height are larger than in the Euro NCAP protocol. The reason behind this, is that the cyclists' testing phase engages real humans (cyclists), therefore there is a need for a realistic obstruction of the human sight, in contrary to the EuroNCAP protocol that focuses on obstruction of the vehicle sensing. For the final testing, such obstruction is expected to be a van, instead of passenger cars, in order to satisfy the height specification.

The fixed parameters for Demo_4_08 scenario are presented in Table 10 while the variables parameters can be found in Table 11.

Table 10: Fixed parameters for Demo_4_08 scenario.

Parameter	Demo_4_08
D_L	3.55
D_X	4.8
D_{init}	13
D_R	6

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Parameter	Demo_4_08
I_{WP}	50
T_{Typ}	Adult

Table 11: Variable parameters for Demo_4_08 scenario.

Parameter	Min	Max	Step
V_S	10	30	5
V_T	15	20	5
Parameter	**Value**		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

4.2.4 Demo_4_09: Approaching an obstructed bicyclist crossing from farside

This scenario is not entirely represented by EuroNCAP. The Demo_4_09 is based on the EuroNCAP CBFA test case, with the addition of an obstruction to reduce the visibility of the VRU.

Figure 17 show represents this Demo_4_09 scenario.

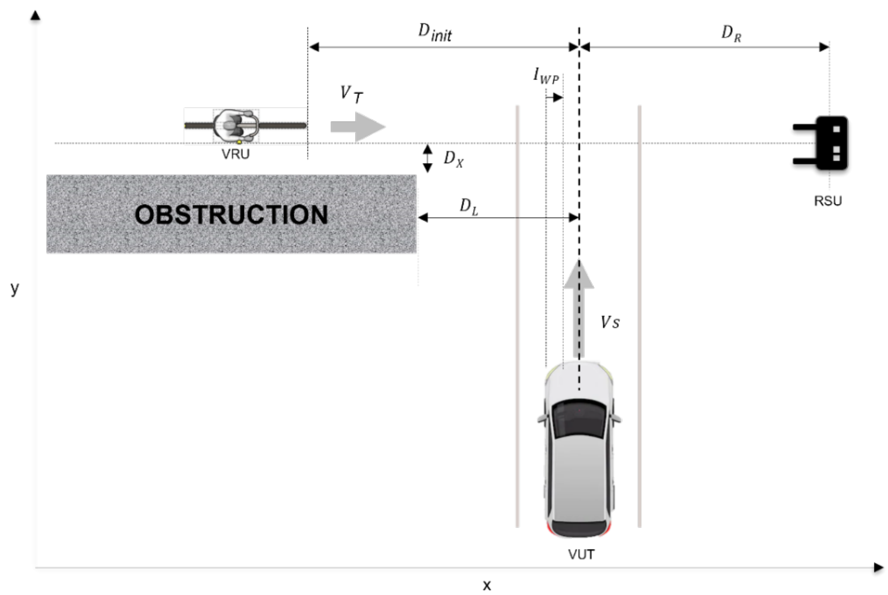

Figure 17: Demo_4_09 testing scenario.

The fixed parameters for this scenario can be found in Table 12.

Table 12: Fixed parameters for Demo_4_09 scenario.

Parameter	Demo_4_08
D_L	7.55
D_X	4.8
D_{init}	17
D_R	6
I_{WP}	50
T_{Typ}	Adult

The variable parameters are in Table 13.

Table 13: Variable parameters for Demo_4_09 scenario.

Parameter	Min	Max	Step
V_S	10	30	5
Parameter	**Value**		
V_T	20		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

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4.2.5 Demo_4_13: Approaching a crossing bicyclist moving from farside while turning to the farside

Based on the EuroNCAP CBTA 2023 test case, the characterization of this scenario is presented in Figure 18.

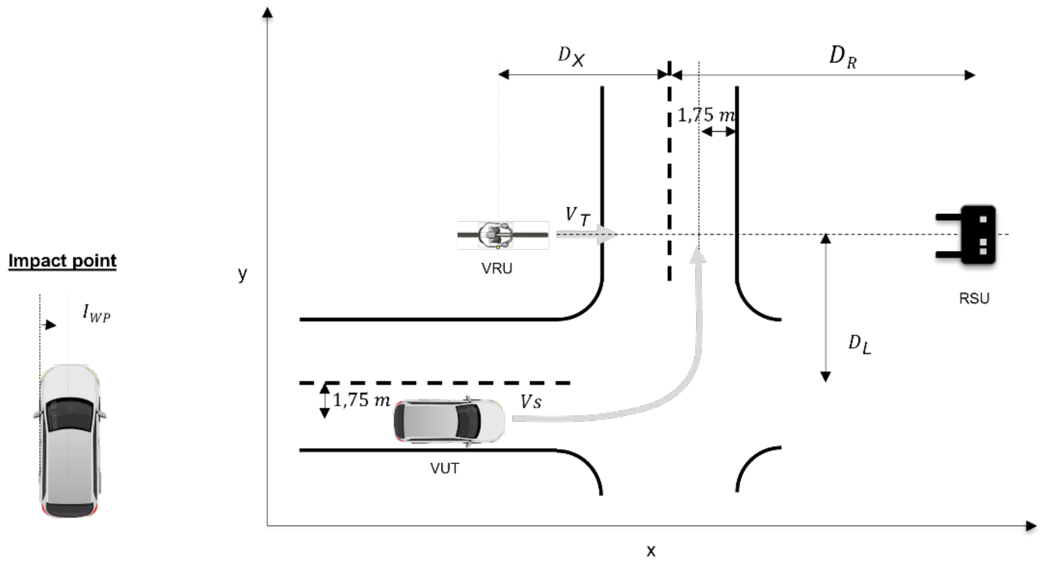

Figure 18: Demo_4_13 testing scenario.

Like Demo_4_05 and Demo_4, 06, D_L and D_X are defined differently for this Demo_4_13 turning scenario than for the simple intersection scenarios (definition available in Table 2). The D_L and D_X parameters for this scenario are defined as shown in Table 14:

Table 14: Description of D_L and D_X parameters for Demo_4_05 and Demo 4_06 scenarios.

Parameter	Description
D_L	Distance in y-direction between the centre of the dashed lane marking of the vehicle and VRU trajectory (units: meter)
D_X	Distance in x-direction between the VRU initial position and the impact position (units: meter)

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The fixed parameters for Demo_4_13 are present in Table 15.

Table 15: Fixed parameters for Demo_4_13 scenario.

Parameter	Demo_4_08
D_L	4.5
D_X	17
D_R	6
I_{WP}	50
T_{Typ}	Adult

The variable parameters are inTable 16.

Table 16: Variable parameters for Demo_4_13 scenario.

Parameter	Min	Max	Step
V_S	10	30	5
V_T	15	20	5
Parameter	**Value**		
C_S	Active; Inactive		
C_T	Active; Inactive		
C_R	Inverse to C_T		

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5 Demo 4 development status

5.1 Demonstrator subsystems

This section presents the final development of the four main subsystems and their modules (Vehicle, RSU, VRU-pedestrian, VRU-cyclist), based on the architecture presented in Section 3.

5.1.1 Vehicle modules

Table 17: Status of vehicle modules.

Module	Status
Physical vehicle	Ready
Vehicle-mounted sensors (Cameras, RADAR)	Ready
V2X unit	Ready
Perception Unit	Ready
Driving Function Unit	Ready
GNSS	Ready

5.1.1.1 Demo 4 vehicle and Sensors

Prior the final Demo 4 vehicle preparation, IDIADA used its own AV vehicle, named CAVRide (Codina, 2021), to test the different vehicle functions required for Demo 4 aiming to validate them before being integrated into the final Demo 4 vehicle (Toyota RAV4 provided by TME).

The RAV4 2021 is a commercial hybrid vehicle from Toyota used in SAFE-UP's Demo 4 as the main vehicle, which has been equipped with perception sensors, a V2X unit, a new perception system able to fuse V2X with sensors' data and a Driving Function Unit that implements the AEB function.

The sensors installed in the vehicle have been selected in order to provide the system a combination of perception sources as closer to the set of sensors available in current passenger vehicles as possible. The system will be tested without V2X (baseline, only with perception sensors) and with V2X, which will provide the impact of this technology in the selected scenarios.

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5.1.1.2 V2X Unit

The V2X unit, used in both the vehicle and in the RSU, is a prototype device called IDAPT (IDIADA ADAS Platform Tool) implementing ITS-G5 technology. It has been successfully tested in real world and testing environments, being capable of sending and receiving V2X information to/from other ITS-G5 stations fully complying with the ETSI standards. it is capable of sending and receiving a set of common standard ITS messages. For the vehicle case, it is expected to send CAM messages letting other nearby stations, in this case the VRUs, know the real-time positioning, dynamics and other key information of the vehicle.

At the same time, the vehicle V2X unit is able to receive the CAM messages from the other stations involved in the Demo 4 scenarios. In this case, external senders are the RSU and the VRUs. All messages coming from those stations in the different scenario combinations are read, validated, decoded by the V2X unit and provided to the vehicle's data fusion system (Perception Unit) for further processing.

5.1.1.3 Perception Unit

As for the final perception device, a high-performance automotive processing unit is used in both the vehicle and the RSU.

This device is the manager of a ROS network that internally connects the different components that serve as input and/or output destination of the fused data. All data sources, including the camera and the radar and the V2X (when available), publish raw data to the network that is captured by the Perception Unit. Such data is fused to build a model representation of the environment every 40 milliseconds (24Hz).

In obstructed scenarios, the only expected source of perception data is the V2X (from the RSU or the VRU) when the target object (VRU) is behind the obstacles. When the VRU gets visible, the other sources' data is fused with the V2X to improve the calculation of the target's size, type, speed, direction, distance, etc.

The detected targets are constantly reported to the Driving Function Unit (via the ROS network) to analyse whether a reaction is required.

5.1.1.4 Driving Function Unit

The device that implements the ADAS function (AEB) and the driver warning algorithm is a MicroAutoBox™ II from dSPACE (dSPACE, n.d.). This device is an ECU-like unit for fast function prototyping used to run real-time algorithms.

For SAFE-UP Demo 4, it implements an AEB function and a driver warning following the UN Regulation No. 152 2020 from UNECE (UNECE, 2020).

The objects detected coming from the data fusion (Perception Unit) serve as inputs for the algorithms. The system is able to trigger a braking order to the vehicle in case the situation exceeds a threshold risk point, in order to avoid or mitigate the collision. Before reaching this point, the algorithm calculates if a warning can be given to the driver so he/she can perform an emergency braking before the AEB activates.

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It is expected that thanks to the V2X information coming from the VRU in an obstructed situation, the AEB and the warning are going to be triggered earlier than without such technology.

5.1.1.5 GNSS

The final architecture for the vehicle includes a GNSS RTK (Real Time Kinematic) receiver offering reception of differential corrections via radio and Wi-Fi. This way, the positioning of the vehicle is highly accurate (at centimetre level), as well as its heading, providing quality location data to the internal vehicle systems (e.g. the V2X Unit) and, therefore, to the nearby stations via the CAM message RSU modules.

5.1.2 RSU modules

Table 18: Status of RSU modules.

Module	Status
Sensors (Camera and LiDAR)	Ready
V2X unit	Ready
Perception Unit	Ready
GNSS	Ready

5.1.2.1 Demo 4 RSU and Sensors

The RSU module development has been finished. According to the scenario testing parameters (Section 4.2), the RSU will need to be placed in different locations in order to optimize the perception of the VRUs for each scenario. Therefore, it has been decided to mount the RSU equipment into a vehicle for the final tests. Since the RSU will be placed in a non-obstructed location and it needs to detect the non-connected VRUs in the scenarios, its equipment consists of a camera and a LiDAR. Such combination of sensors is better in terms of accuracy and performance than the vehicle's, since the LiDAR provides higher accuracy on the positioning and type of the detected objects. As main drawback, they are more susceptible to distortions from adverse weather conditions.

5.1.2.2 Perception Unit

The Perception Unit for the RSU is the same as for the vehicle (Section 5.1.1.3). However, the data flow is a bit different since the main target of the RSU is not capturing and integrating external V2X information to the perception, but to convert the perception into V2X signals in order to inform the vehicle.

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The RSU Perception Unit is configured to fuse both camera and LiDAR sensors data in order to detect the non-connected VRUs in the scenario. Such information is published to the ROS network to be captured by the V2X Unit.

All perception systems work in a relative environment, which means that all detected objects are located using coordinates relative from the detector/sensor's position. Such relative information is converted into absolute parameters before being handled to the V2X unit.

5.1.2.3 V2X Unit

The hardware of the RSU V2X Unit is the same as the vehicle one. In this case, it only receives orders to send V2X data from the detections generated by the data fusion in the Perception Unit.

Each VRU detection is converted into a standard CAM message formatted like a VRU CAM. Upon the reception of this CAM message, the vehicle will handle CAM messages coming from the RSU or the VRU indistinctly.

5.1.2.4 GNSS

In order to convert VRU detection information, which is generated using relative coordinates, into absolute coordinates, the RSU needs to know its own exact absolute position in every scenario. For that, the same high-accuracy GNSS device as the vehicle is used for the RSU.

5.1.3 VRU device modules

During the development phase of the VRU device and based on the Demo 4 initiative to test both pedestrians and cyclists as VRUs, using different testing protocols, it became apparent that two VRU devices had to be developed, one for each VRU type, that are architecturally similar, but differ in some key aspects. The main operational difference is that in the cyclist's case, the VRU device is practically an OBU (it is attached to the bicycle and not to the rider) and can take advantage of additional sensing information (speed, cadence, brake) that do not exist in the pedestrians VRU case. Both VRU devices incorporate all the necessary hardware and software modules to facilitate DSRC ITS-G5 V2X communications with the transmission and reception of ETSI standardized CAM messages. A Local Dynamic Map (LDM) of all connected objects (vehicles and other transmitting ITS stations) in range, is maintained during operation. This LDM together with the self-localization and motion dynamics module are the key input to the control action strategy module that is responsible for triggering the necessary user warnings in case of imminent collision detections. The summary of the VRU devices' modules and their current status are presented in Table 19 and Table 20.

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5.1.3.1 Pedestrian VRU device

The pedestrian VRU device is a prototype portable device developed by CERTH specifically for SAFE-UP project purposes. During the final stage of development, efforts were concentrated in the control action strategy software module that is responsible for the main output of the VRU device, which is the warning of a collision with a vehicle. The device becomes aware of the connected ITS stations (vehicles equipped with appropriate OBU) with the reception and decoding of CAM messages that carry information, among other things, about their position and motion characteristics. Also, the VRU device encodes and transmits constantly with 10 Hz message rate, its own CAMs that are populated with information coming out of the localization and motion dynamics module. Received awareness messages of connected vehicles together with the spatial and dynamic motion self-perception, enable the control action strategy module to continuously calculate TTC (Time to Collision) with all targets in range and identify dangerous situations related to the VRU, when near future trajectory overlap is detected.

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

The VRU pedestrian device is portable so that a human can be able to carry it without effort like any common handheld device. All the hardware components (main PCB with all installed materials, display, communication and GNSS receiver antennas) had to be enclosed in a case that would facilitate this. A container was designed especially tailored to the VRU device hardware components and manufactured with the use of 3d printing technology.

The selected testing protocol at IDIADA premises for Demo 4 regarding the pedestrian device is for it to be attached in a testing dummy upon a moving platform for obvious safety reasons related to the testing scenarios that could result in collisions between a vehicle and a human. For this reason, CERTH concentrated the HMI development efforts on the VRU bicycle device, where a different testing protocol was selected (real human rider with virtual vehicle), since in the pedestrian's case there is no real human interacting with the device. Of course, every potentially produced warning by the device is being logged with millisecond resolution timestamp information, for evaluation of VRU device's performance.

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Table 19: Status of pedestrian VRU device's 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	Ready
Local Dynamic Map and objects/events fusion	Ready
Control action strategy	Ready
HMI (visual, audio, input)	Not applicable (device is mounted on a dummy platform)

5.1.3.2 Bicycle VRU device

The core operation of the bicycle VRU device is the same as the pedestrian one, but there are three fundamental differences that can be exploited in order to increase performance. These are:

- GNSS receiver and V2X communication antennas can be more like the ones that are normally installed on a vehicle without the restrictions that arise from the handheld nature of the pedestrian VRU device.
- Sensors installed on the bicycle itself, measuring bicycle speed, cadence and brake status, can feed the device and significantly increase the self-perception potential.
- Since the device is permanently mounted on the bicycle’s body, in a predefined orientation that remains steady in relation to the bicycle during operation, a higher performance IMU module is used, that can sense and follow more accurately dynamic motion changes.

Therefore, the bicycle VRU device offers better sensing abilities regarding geo-localization and motion characteristics, better V2X RF communications and a real-time knowledge of the rider input during cycling, with the installed cadence and brake sensors. All these improvements ultimately feed the control action strategy module with enhanced information, giving the ability for more accurate predictions about imminent collisions and therefore also rider warnings.

The device is equipped with a touch LCD display, where the rider is informed about sensor outputs (positioning, speed, heading, battery status). Using this HMI, the user can also interact with the device, by starting and stopping on-demand its operation, for better control over the experiments. There are also visuals on the screen that present collision warnings and are accompanied with acoustic buzzer sound, in case of collision detection, so that the

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cyclist becomes aware of potentially dangerous situations as fast as possible after the detection from the system, without having to keep his gaze constantly on the screen, in order to take avoiding action.

The bicycle used in Demo 4 is a Kona Dew-E electric commercial bike. It is equipped with a common bike computer which accumulates real time information about bike's status, regarding the current speed (via a Hall sensor installed on the back wheel), the current cadence (via the electric motor's controller), battery status etc. This bike computer is connected with the VRU bicycle device via BLE (Bluetooth Low Energy) and therefore this information becomes available to it. For the brake status of the bicycle CERTH installed Hall sensors in both front and back brake levers. These brake sensors are directly connected (wired connection) with the VRU device, so the brake status is also available. Besides the enhanced awareness, brake status can be used as a trigger for measuring rider reaction after an emitted warning.

Figure 20: Bicycle with the VRU device mounted.

The main difference from the pedestrian VRU device in hardware installed modules, is the use of a higher performance GNSS receiver and IMU. Bicycle device is not a handheld device, instead it is permanently installed on the bicycle. Restrictions regarding physical dimensions of modules and antennas are far more relaxed. A high-performance positioning engine with multi-band GNSS receiver (Ublox model ZED-F9P) is used, in combination with an IMU that besides its own accelerometer, gyroscope and magnetometer sensors, can also use the GNSS receiver signals and provide enhanced positioning results via its fusion engine (Xsens model MTi-7).

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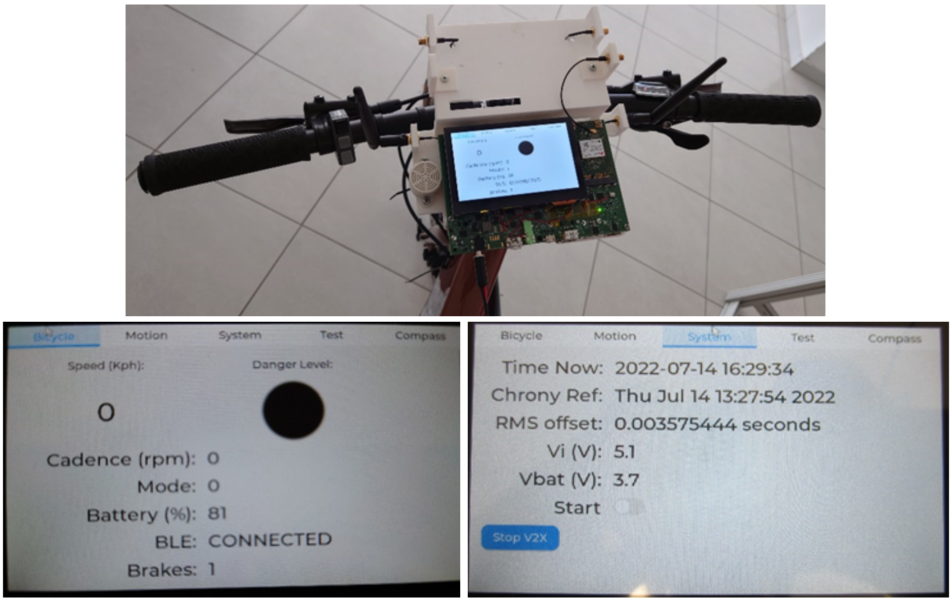

Figure 21: HMI example screens of VRU bicycle device.

Table 20: Status of VRU bicycle device's 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	Ready
Local Dynamic Map and objects/events fusion	Ready
Control action strategy	Ready
HMI (visual, audio, input)	Ready (visual information via on-board display, sound warnings via buzzer, user input via touch)

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6 Integration Phase and Pre-Testing

6.1 Integration and testing preparation

The three demonstrator subsystems are developed to answer to the three research questions (RQs) of Demo 4, which were presented in D3.4 (Nikolaou, et al., 2021) and are summarised below:

- **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?

Demo 4 subsystems are not individual systems targeting a single RQ each, but jointly contribute to all RQs. These RQs are going to be assessed in the impact assessment that will be performed in WP5. However, the development of Demo 4 system was targeted towards the direction of the RQs to facilitate the impact assessment.

On this ground, in order to be able to feed the first research question (RQ1) related to a safety benefit from a VRU C-ITS warning system on connected VRUs, two VRU devices have been developed able to trigger on-time warnings to the users when a risky situation with a vehicle is detected. At the same time, they are key in feeding the RQ2 and RQ3 because they are the source of V2X information required to give a proper warning to a driver approaching a critical situation with the VRU (RQ2), and also to improve an AEB system to be able to avoid or mitigate the impact with such VRU using an automatic emergency braking (RQ3). Another source of V2X information for RQ2 and RQ3 is the RSU subsystem, used as an alternative implementation to show that the system can perform with connected and non-connected VRUs.

As described in D3.4 (Nikolaou, et al., 2021), one of the first steps to ensure that the subsystems were compatible was to perform a V2X interoperability test. At that stage, they were prototype modules and individual units still not integrated into their final architecture and

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place. During the next phase, the development of those modules was finalized and the integration and testing preparation was launched.

6.1.1 Vehicle

The main challenge after developing the different modules for the vehicle (Section 5.1.1) was the integration phase. Despite that a preliminary version of the systems were tested using IDIADA CAVRide's vehicle for a pre-validation, the simulations for the final validation (details can be found in Section 6.2), the integration to another different vehicle (Toyota RAV4), and the deeper testing performed in test tracks (Section 6.4) brought up some issues that needed to be resolved in almost all the technical areas.

Focusing on the physical integration with the Toyota vehicle, the main challenge was to comply with the requirement of having all devices (including the sensors and the equipment), cables and structures installed with easy disassembly, being able to leave the vehicle in the original condition as when it was delivered to IDIADA. Figure 22 below shows the final status of the perception sensors, including the Demo 4 sensors (front camera and radar in green colour) and other additional sensors (LiDAR and two side cameras in blue colour) only for validation purposes. The LiDAR and the side cameras will not be part of the perception system in the final testing.

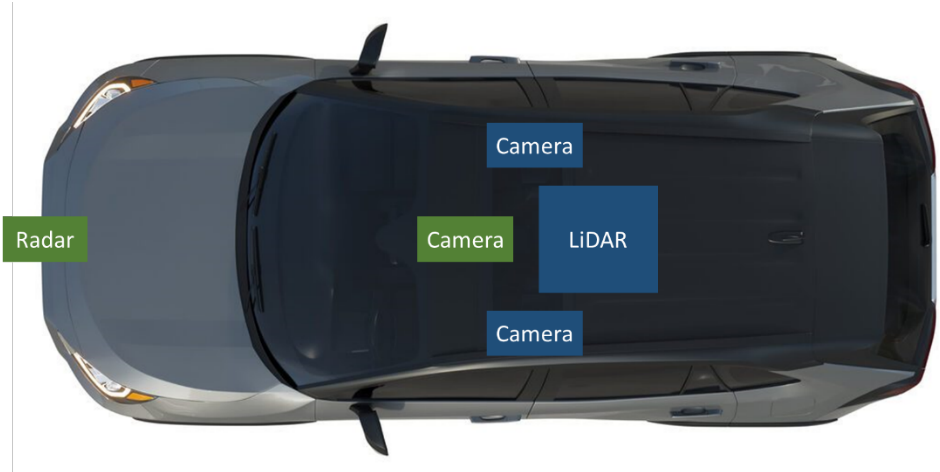

Figure 22: Final status of vehicle perception sensors (front camera and radar in green colour) and other additional sensors (LiDAR and two side cameras in blue colour.

The following figures show the final status of the vehicle, including the subsystems installation. Figure 23 shows the front view of the vehicle. Figure 24 shows a closer look on the perception sensors from the roof of the vehicle. Figure 25 show a general view of the trunk's rack and Figure 26 brings a closer look to the systems installed in such rack.

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Figure 23: Demo 4 vehicle front view


Figure 24: Demo 4 vehicle sensors


Figure 25: Demo 4 vehicle rack installation

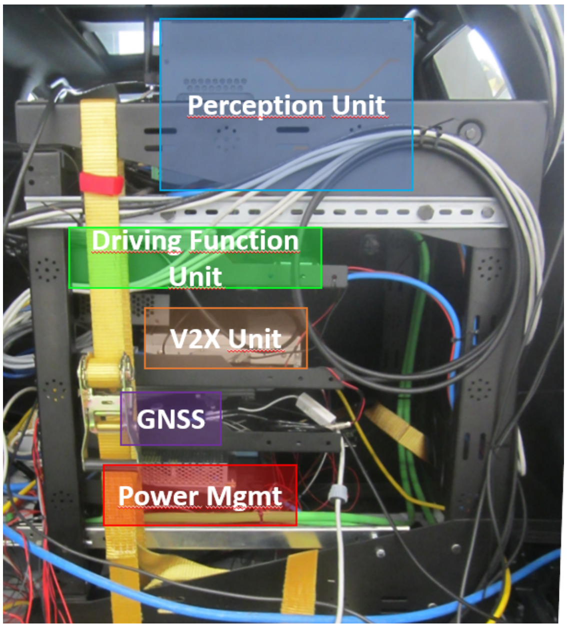

Figure 26: Demo 4 vehicle rack equipment

6.1.1.1 Driving Function Unit integration and issues

The Driving Function Unit implements the AEB and the driver warning system of the vehicle. During the integration phase, a close collaboration between IDIADA and TME (Toyota Motor Europe) was established towards the successful operation of the systems.

The Driving Function Unit is connected to the Toyota RAV4's CAN system to trigger braking orders to the vehicle's ECU. Since the vehicle is already implementing an AEB system, IDIADA, with the support from TME, has developed a bypass system which captures the signals from the vehicle and overrides, discards or forwards them depending on the needs, especially to avoid the vehicle AEB to interfere with the SAFE-UP AEB system.

A set of track tests to extract CAN recordings were conducted, with the standalone vehicle to capture and validate the messages involved in different braking situations. The CAN bus was

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analysed and some signals from the AEB launch flag, deceleration and torque release were validated with TME's information.

Those captured signals had to be filtered, so the SAFE-UP AEB would be the only system acting over the brakes. To do so, the Driving Function Unit had to synchronize the kickout message flag from those messages so the vehicle would not notice about the absence of those messages.

After solving these integration issues with the vehicle and its CAN system, a set of tests were performed at IDIADA's test tracks representing the SAFE-UP Demo 4 scenarios to validate the integration and performance. In collaboration with TME and after some deep testing, the AEB braking characterization was performed. The parameters required to have a proper performance of the braking, considering the vehicle dimensions, braking capacity, weight, centre of gravity, etc, were the brake delay (from the command to the action), the brake prefill time, the deceleration jerk and the maximum deceleration value inside the dynamic limits of the vehicle.

6.1.1.2 Perception Unit integration

After installing all sensors to the vehicle, the perception system had to be configured and calibrated.

First, the perception system software, which was already pre-validated with the CAVRide vehicle, had to be calibrated for the Toyota vehicle. Different vehicle height, width and length, sensors mounting structure position, etc. have effect in how the perception understands and computes the sensors' data in the Data Fusion system.

Figure 27 and Figure 28 below show how the Data Fusion works in the Toyota RAV4. The blue box corresponds to the VRU (pedestrian) detection according to the front camera. The camera is able to classify the target (VRU) as a Pedestrian (94.80% of certainty), and the way it models such target is by the means of a box with a certain height and width (therefore it provides the target dimensions). The yellow mark is the detection of the VRU by the radar. The detections from the camera have a higher frontal error than lateral error due to the depth ambiguity of the sensor, this error is higher as the distance to the object increases and the velocity is not provided. The radar provides a better frontal location accuracy of the target (at 23.03m from the vehicle) and its relative speed with the vehicle (16.62m/s). This can be seen in the following figure, where a point cloud generated by a lidar is also shown as reference, but is not used in our calculations.

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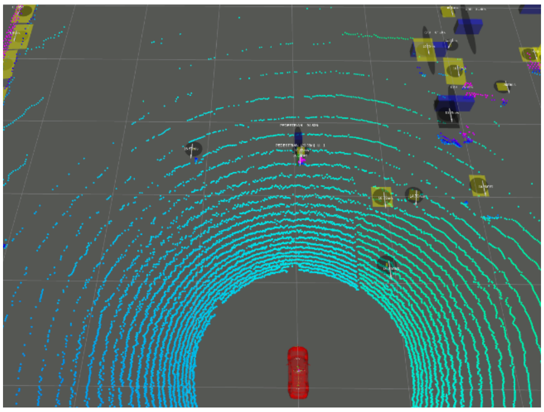

Figure 27: Example of the top view of the Data Fusion output.

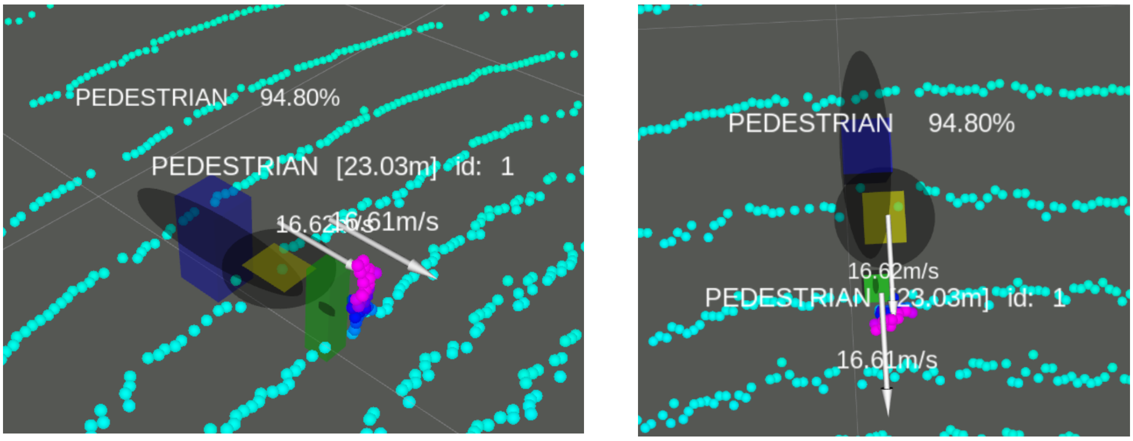

Figure 28: Example of the detection of a pedestrian by the Data Fusion.

The data fusion combines this information by means of Kalman Filter with a constant velocity model to extract the statistics that are presented in the above figures. There is a probability of 94.08% of being a pedestrian at 23.03 meters and with a speed (relative compared to the vehicle) of 16.61 m/s. As shown, the final position of the target (green box) doesn’t correspond to the position of either of the data sources (camera or radar). The Data Fusion corrects the location of the target based on the signal delay from detection to the fusion calculation and the current vehicle speed and predicted trajectory. This way, the accuracy of the prediction is higher.

For the Demo 4, a new sensor for the perception is present. The V2X information coming from the VRU or the RSU is an external source of information which needs to be modelled and characterized so that the Data Fusion handles it at the same level as the other data sources. Since the VRU device contains a standard GNSS system, the location accuracy of the V2X messages sent to the vehicle could vary depending on different factors (number of satellites, signal level, etc.). For this reason, IDIADA is still performing pre-testing to understand the impact of inaccurate information to the data fusion system. However, a clear advantage of using V2X messages for the data fusion system is that the input detections generated from V2X messages will not depend on the sensors field of view, and therefore will be present even in cases of occlusion.

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6.1.2 VRU

Real testing involving VRUs and vehicles in scenarios that can potentially lead to collisions, encompass crucial safety issues. Human VRUs can never be subjected to such threats during testing. Normal relative testing procedures in test tracks, involve dummies upon a moving platform instead of real humans. As already explained in VRU device modules description, the two VRU devices have common operational principles, with the bicycle device in reality being an enhanced version, with more advanced and better sensing equipment. In order to fully exploit these enhancements and evaluate the actual performance of the developed system, realistic riding behaviour from a real cyclist upon a bicycle, that could react to warnings was necessary. For this reason, Demo 4 adopted the testing procedure with the virtual vehicle in this case.

In track testing, where no human VRUs are involved, the pedestrian VRU device is used to assess both pedestrian and bicycle scenarios. The dynamic movement of the dummy used as VRU is similar in both pedestrian and cyclist cases, since the dummy test platform follows a rectilinear path at certain speed from the beginning to the end of the planned trajectory. Therefore, there is no expectancy of any VRU action when a collision warning is triggered. In any case, track testing execution parameters reflect the selected pedestrian and bicycle scenarios respectively.

6.1.2.1 Cyclists' system testing preparation and issues

The testing for the cyclist case aimed to evaluate the performance of the cyclist system when providing an on-time warning in critical situations with vehicles, answering to RQ1. It included Demo_4_08, Demo_4_09 and Demo_4_13 scenarios (see Sections 4.2.3, 4.2.4 and 0 respectively), which are the scenarios where a cyclist VRU is involved for Demo 4. , Despite the scenarios' speeds have been identified and justified in D3.4, they only apply for the track testing with dummies. For the tests with real VRUs (cyclists), a dedicated analysis of accidentology data has been performed by TME in order to identify the most relevant speeds where cyclists suffer more injuries. (Figure 29). This means that for these tests, high speeds (>25kph for the vehicle and >20kph for the cyclists) were not included since they are usually not involved in common accidents in urban scenarios.

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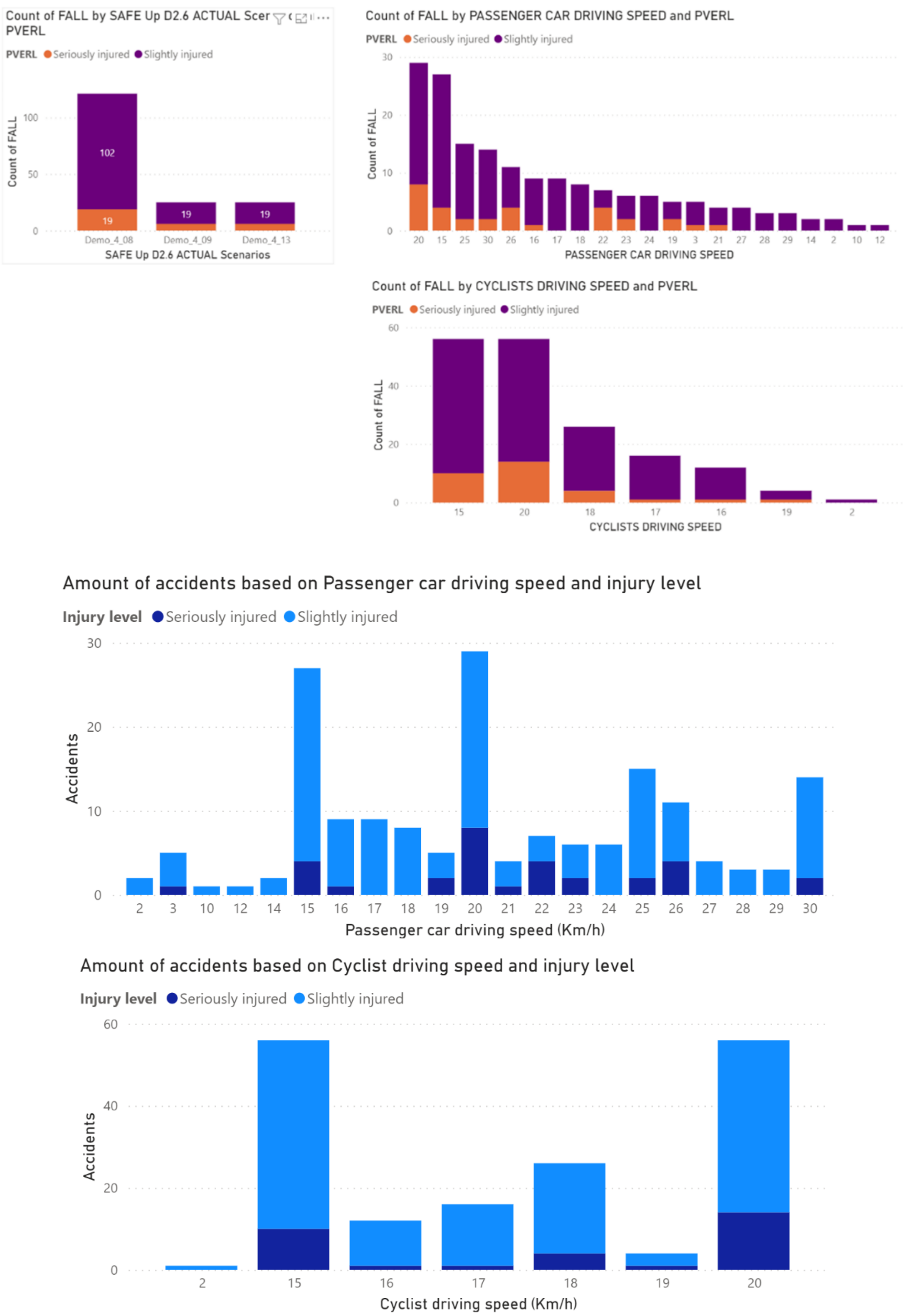

Figure 29: Analysis of passenger car to cyclists' accidents by TME.

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Following serious injury criteria, the most relevant combination of speeds per scenario involving cyclists are:

- **Demo_4_08:**
  - Top 1: Car: 20Kph / Bicyclist: 20Kph
  - Below cases have same share
    - Car: 15Kph / Bicyclist: 18Kph
    - Car: 20Kph / Bicyclist: 15Kph
    - Car: 15Kph / Bicyclist: 15Kph
    - Car: 22Kph / Bicyclist: 15Kph
- **Demo_4_09:**
  - Top 1: Car: 20Kph / Bicyclist: 20Kph
  - No more relevant cases
- **Demo_4_13:**
  - Most common speed found between 23 and 26Kph for passenger car. Final selected testing speed: 25Kph.

These conclusions directly became the test matrix for the cyclist testing. Therefore, a set of 7 runs were expected to be performed in order to assess the benefit of the cyclist's device warning system.

The selected strategy for these tests involves a real cyclist cycling on predefined paths corresponding to the chosen scenarios, in a closed area concurrently with a virtual vehicle for obvious safety reasons. The testing preparation included the area selection and setup, the recruitment of volunteers, the virtual vehicle programming and the VRU device preparation for testing. CERTH collaborated closely with IDIADA, since the used bicycle is owned by CERTH, the cyclist's VRU device has been developed also by CERTH, and the virtual vehicle and the testing premises are owned by IDIADA.

6.1.2.1.1 Testing area selection and preparation

Due to safety reasons, a closed testing location inside IDIADA facilities was selected in order to protect the real user (cyclist) from other tests happening at the same time at IDIADA. The selected spot had 35m height and 25m width, which was big enough for the planned scenarios.

6.1.2.1.2 Users recruitment

IDIADA started an inclusive recruitment process within its employees to attract volunteers willing to play the role of the cyclist in the scenarios. The target was having at least 10 people able to ride the bicycle at different speeds and let them react to the VRU device warnings. At the end, a total of 12 volunteers applied to participate. Each volunteer had to book a 30min slot within the 2 full days of testing.

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6.1.2.1.3 Virtual vehicle programming

CERTH and IDIADA agreed to use a virtual vehicle instead of a real vehicle for this real cyclist test. The term “virtual vehicle” essentially means a real OBU in RF range of the testing area that timely transmits CAM messages representing the vehicle’s route path according to the tested scenario. The main reason was the safety of VRU, since the probability of having a real collision was high, when involving a real vehicle and a real person in crossing scenarios.

Figure 30 and Figure 31 represent the difference in the scenario Demo_4_08 between the tests planned for the test tracks (with a VRU dummy) and this test with a real cyclist VRU and a virtual vehicle.

Having a virtual vehicle means that the VRU device (cyclist’s system) will think that there is a real vehicle approaching the intersection, as is going to happen in the real track test. A static V2X unit was planned to be placed nearby the scenario sending the V2X message that the vehicle would send. This way, the VRU device would trigger a warning to the rider when the situation reaches a critical level between itself and the virtual vehicle.

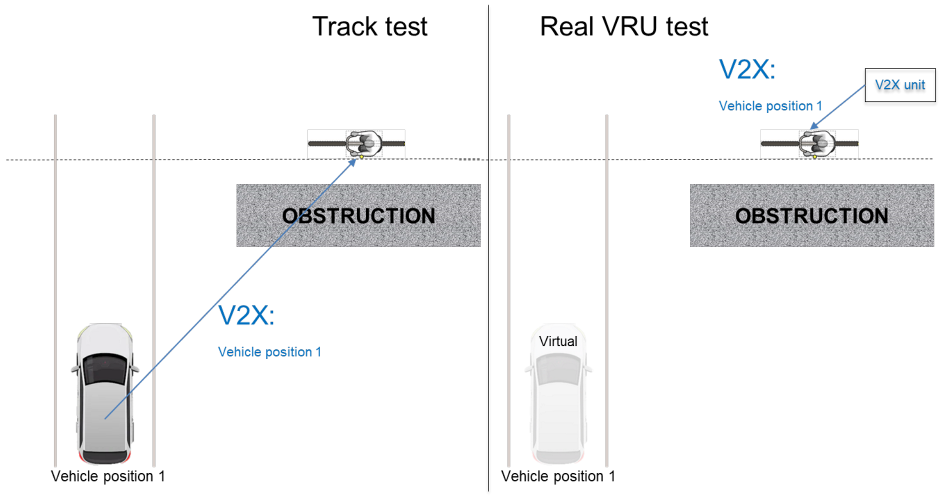

Figure 30: Representation of Demo_4_08 for track test and real VRU test (t=0).

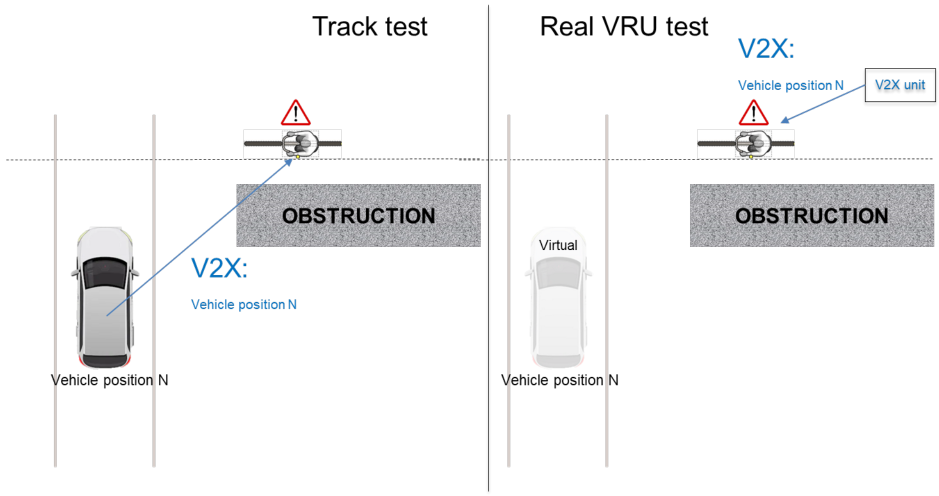

Figure 31: Representation of Demo_4_08 for track test and real VRU test (t=N).

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IDIADA used a simulation tool to recreate the vehicle paths and speeds for every scenario and test run. The same tool was used to simulate the scenarios to validate the systems and extract some interesting findings for the real track testing (section 6.2).

6.1.2.1.4 VRU device preparation

Prior to testing with real users, for the system integration phase, CERTH's team travelled to IDIADA's testing premises, in order to evaluate correct operation and interoperability between the systems.

Some minor problems regarding ITS G5 radio power and versioning of the used protocols were quickly identified and rectified by the two teams. These tests took place in July 2022 in Spain and the prevailing weather conditions at that time revealed a hardware malfunction of the bicycle VRU device, that could not be identified during the development phase of the device. Due to excessive heat conditions under the summer Spanish sun, the mPCIe connector that attaches the installed V2X module with the main board of the device, was subject to failure after some rather random time of operation. As a mitigation, CERTH installed on the cyclist device a small in dimensions V2X module, connected via the USB port with the main VRU device, as a backup solution in case of such failure. Of course, the two V2X modules could not operate concurrently. An OS system's parameter modification and a reboot of the device was needed after every new V2X module selection for operation.

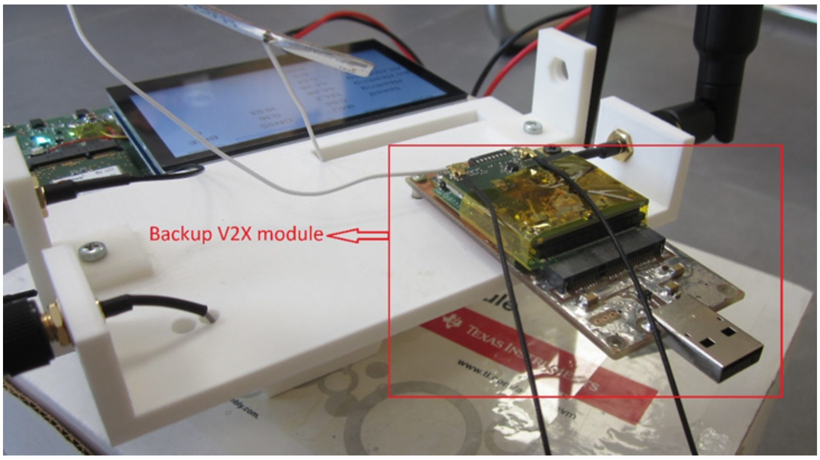

Figure 32: Backup solution for mitigating the malfunctioning of the V2X module connection.

After initial power-up of the bicycle VRU device (cold start), few tenths of seconds of operation, with the bicycle moving randomly in an open area, are needed for the localization and motion dynamics module of the device to reach its full performance potential. This start-up procedure (from power down state) is crucial for the GNSS and IMU fusion engine training. In this preparation phase the values of the TTC that lead to user warnings were also selected. A time period of less than four (4) seconds was adapted as a TTC that triggers a "lighter" rider warning corresponding to orange indication on the display and a time period of less than two (2) seconds for a "stronger" warning corresponding to red indication on the screen. Note however that in both warning cases the buzzer sound is also triggered.

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Figure 33: Views of the VRU device integrated in the bicycle for the testing phase at IDIADA premises.

6.1.2.2 Pedestrians' system testing preparation

In order to assess the safety benefit of an active safety system (RQ3) and an on-time driver warning (RQ2) with V2X technology, the pedestrians' system is used as a source of V2X.

Unlike the cyclist's system testing, the tests planned for the pedestrian system included all Demo 4 scenarios (for pedestrians and cyclist) with a real vehicle involved. The reason behind including all scenarios is because they are going to be executed at IDIADA test tracks with dummies as VRUs. The dummies' dynamic movement is exactly the same for pedestrian and cyclist platforms (rectilinear trajectory), which makes them compatible with the pedestrian device's way of working.

The pedestrian device is based only on the GPS and the received V2X information, while the cyclist system is fed from additional parameters extracted from the bike's sensors (IMU) that are not available in the cyclist dummies, although they are not required for their simple and predictable movement and the fact that no reaction is expected from them.

This way, the same tests will be used to evaluate the on-time warning for the pedestrian and cyclists and, therefore, give answer to RQ1 as well.

During the preparation for these tests, the test matrix for each scenario was created. The detailed parameters and the status of the devices/connectivity for every run is available in Appendix A. The main objective was having a baseline (no V2X), a direct VRU connectivity and an indirect connectivity (via RSU) for each of the runs from Demo 4 scenarios.

6.1.2.2.1 VRU dummy protection

For the pedestrian system tests, the dummies take the role of the VRUs in the scenarios. As a result, the VRU device must be attached to the dummies' platforms during the execution of the scenario, in order to be able to transmit the CAM messages as long as the dummy is moving with the correct location information.

However, during the preparation phase, IDIADA's testing team highlighted the chances of having hits in certain scenarios, especially at high speeds. It was therefore highlighted that this could jeopardise the integrity and safety of the VRU device, since when the dummies are hit, they are thrown several meters away.

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The main reason why the VRU device should be installed on the dummy platform is due to the need to capture the exact location at every moment. Therefore, IDIADA and CERTH worked in a solution in which only the GNSS antenna of the VRU device is attached to the dummy, while the rest of the device is placed in a safe location without any damage risk.

The following diagram shows the approach developed to solve this safety issue. It consists of a 11m flexible cable which connects the VRU device with the GNSS antenna attached to the dummies.

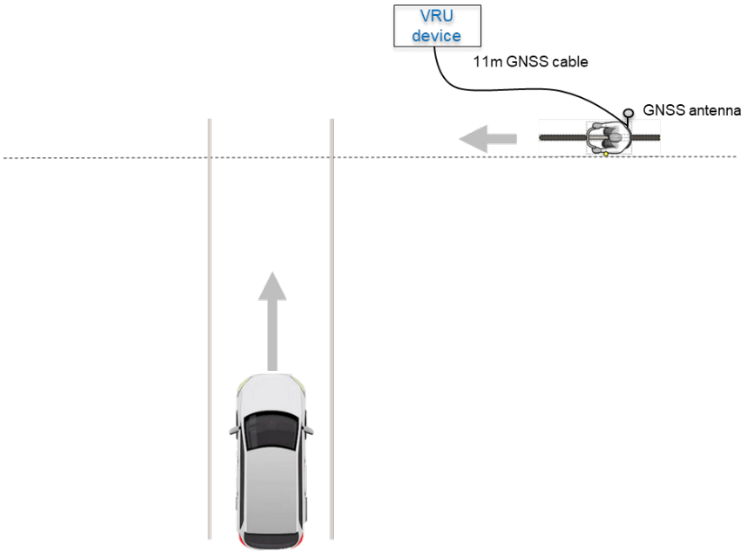

Figure 34: Solution to protect the VRU device installed on the dummy platform during testing.

This way, the GNSS antenna and the cable will follow along the path of the dummy. Therefore, the VRU device will work exactly the same way as if it was attached to the dummy without the risk of damage. This approach will be applied to all scenarios for the pedestrian system testing.

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6.2 Simulations

IDIADA has conducted simulations for all Demo 4 scenarios, including V2X and no V2X (baseline) configurations.

The purpose of these simulations was twofold.

- Validate the vehicle system prior entering to the test tracks, focusing more on the complex AEB system.
- Provide preliminary results of the impact of the V2X in the Demo 4 scenarios.

Performing simulations of an ADAS system before testing it in the real world is mandatory. The time resources and the number of testing variations when testing on the track tracks are limited. However, conducting hundreds of simulation tests with different scenarios, parameters and conditions is more cost-efficient. Moreover, the simulations provide insights and direct results of the issues that would have appeared in the real world, where the debugging and the information analysis may take longer.

The following aspects are key concerning the representativeness of the simulations with regards to test tracks testing with the real vehicle.

- Vehicle correlation: Ideally for obtaining more representative simulation results a fully correlated vehicle model could have been used. As this model was not available, in order to achieve an acceptable level of representativity of the vehicle behavior during the critical stage of the considered scenarios (where the VRU and the Ego trajectories cross), a basic longitudinal vehicle correlation for braking has been conducted.
- Sensors correlation: Similarly, to the previous point, the models from the sensors used in the vehicle were not available and neither was the data fusion. As a solution, ideal 3D sensors configured with the field of view provided by the real sensors have been used in simulations.
- Active system under test: IDIADA's AEB feature model has been integrated into the simulation platform (dSPACE ASM Traffic). This is the same AEB feature model used in the vehicle.

The results of the simulations from the safety impact perspective, will be reported in the impact assessment deliverable of WP5 (D5.6). Figure 35 represents a frame of a simulation of Demo_4_13 scenario using IDIADA's simulator ASM Traffic from dSPACE (dSPACE, n.d.). The results of the simulations include numeric results required from WP5 for the impact assessment as well as videos used for dissemination purposes.

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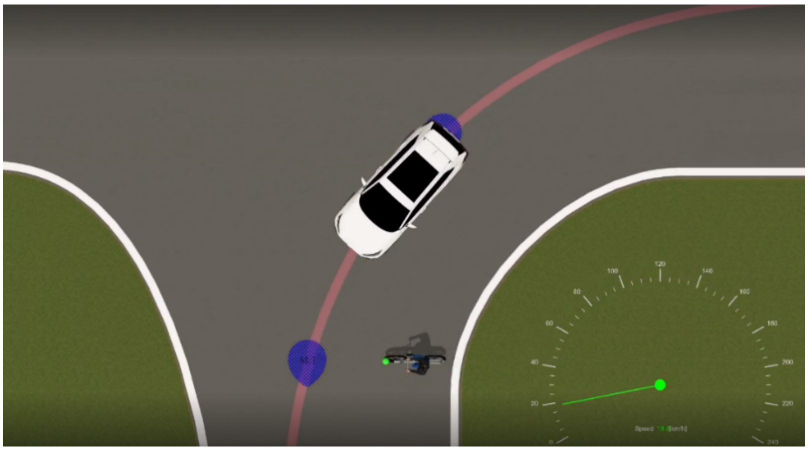

Figure 35: Example of Demo_4_13 simulation.

6.2.1 Trajectories definition for turning scenarios for the simulations

One challenge faced during the simulations design was, the trajectories required for the turning scenario (Demo_4_13), since they are defined as clothoid-arc-clothoid shapes from EuroNCAP's CPTA and CBTA 2023 (Euro NCAP, 2021). These are not directly configurable in the simulation platform used, which only allows spline and straight shape compositions for the definition of trajectories inside junctions. However, the tool allows importing trajectories defined externally, which enables creating them in a more convenient way through the usage of external tools (i.e.: *Python* scripts, *Matlab* scripts, …).

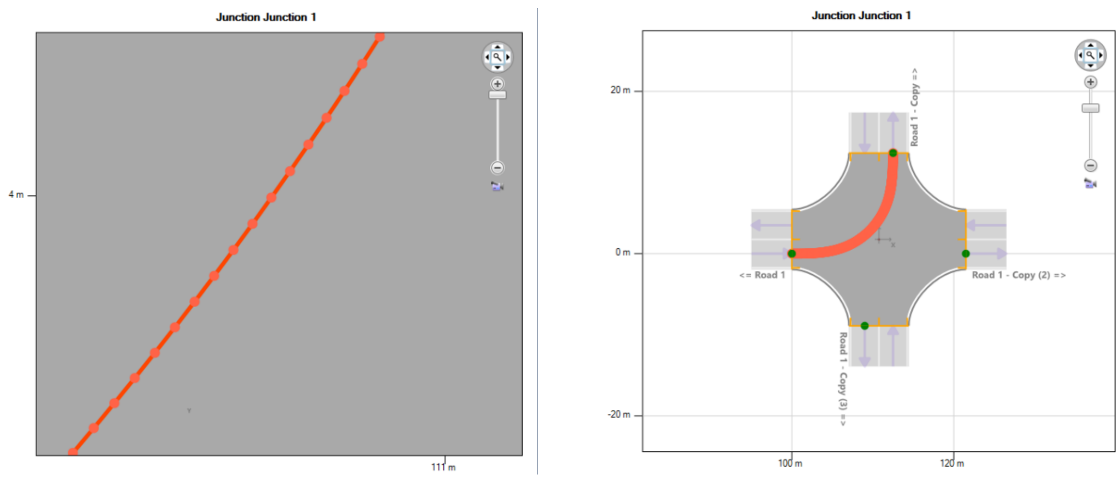

Figure 36: Curved trajectories required for Demo_4_13 scenario.

To be able to implement the above-mentioned trajectories, it was required to create a *Python* script which interpolates the ideal trajectory obtained from the clothoid and circular arc equations into small portions, as can be seen in the pictures below:

Once all the different trajectories were generated (10, 15 and 20 km/h) it was necessary to assign them to junction road elements. It was not possible to assign the three trajectories to a single junction element due to their different lengths (the greater the velocity the longer the trajectory). For this reason, three different junctions were created with the purpose of not only

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being able to accommodate each of the trajectories but also to keep the top-left corner of the junction the same as in the smallest junction (the one corresponding to the 10km/h trajectory, which is completely symmetric). The junctions with their corresponding trajectories are shown in the pictures below:

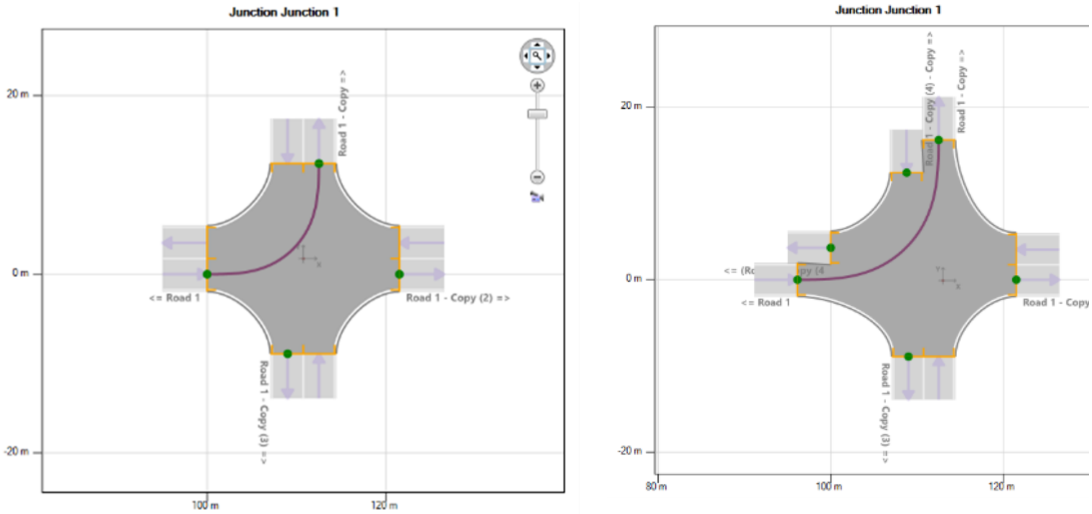

Figure 37: Different curved trajectories depending on the speed (10 and 15 km/h from left to right) (X and Y axis are distance in meters).

6.2.2 V2X simulation approach

As described, the main goal of the simulations was not providing relevant results for evaluating the performance of functionalities using V2X communication. For this reason, the current simulations include V2X as a see-through-obstacles 360º object sensor (see Figure 38).

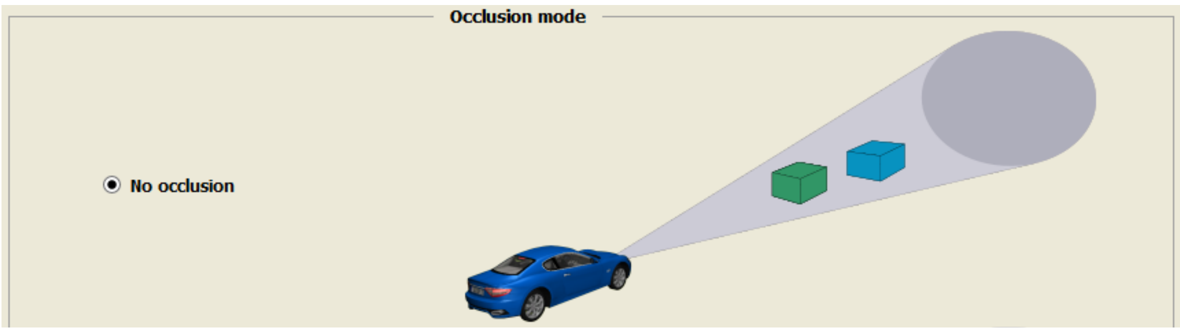

Figure 38: Representation of a see-through sensor used to simulate the V2X behaviour.

This approach is valid to infer the potential improvement of using V2X in ideal conditions. However, it should not be used to quantify this improvement. Instead, it would be required to use more realistic V2X models or to include V2X in the loop.

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6.3 Testing of system for cyclists' safety

6.3.1 Testing phase

The tests with the cyclist's system, as explained in section 6.1.2.1, were performed in 2 full days where the volunteers (12 in total) had 30min each to execute all planned scenarios and runs.

The agenda for every rider was:

- **Warmup (5min)**

  The volunteers were introduced to the purpose of the tests, the agenda, how the bike and the system work and they had the time to perform some mock runs to familiarize with the bike. This period of time was also necessary to calibrate the bike device system.

  In addition, the volunteers were asked to react with a braking manoeuvre upon the sound warning from the VRU device in every run.

- **Randomly selected test runs (20min)**

  The test organizer indicated the rider the target speed for every run. The selection of the run was random, in order to get better results and prevent the rider from predicting the scenario and the reaction to perform. The selected speeds for each scenario are presented in Table 21 below.

Table 21: Selected speeds per scenario for the cyclists' safety system testing.

Scenario	V_S	V_T
Demo_4_08	15	15
	20	15
	15	18
	20	20
	22	15
Demo_4_09	20	20
Demo_4_13	25	20

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Figure 39: Picture from a run of the Cyclist Scenario Demo_4_08.

- **Survey (5min)**

  The volunteers had to dedicate 5min to answer the survey. The results and conclusions are available in section 6.3.2 below.

During the testing phase, some of the volunteers reported that the warnings were triggered quite in advance, allowing them to brake on time and potentially avoid the crash. However, on a realistic urban scenario, the TTC used in these tests to calculate the potential collision would possibly trigger false positives due to the high number of possible trajectories from the bikes and the vehicles perspective. For this case, more tests with more scenarios and vehicles involved would be required to fine-tune the system and find the balance between later but still on-time warning and false positives. The simulations conducted by CEA in this project and will be reported in D3.8 (May, 2023), will provide good insights for such situations.

6.3.2 Participants (cyclists) survey results

A short survey was created by CERTH in order to collect feedback from the volunteers (cyclists) that participated in the cyclists' safety testing phase that took place at IDIADA premises in July and August 2022. In total, 12 surveys were collected by an equal number of responders, whereas the volunteers, as also stated in Section 6.1.2.1.2, were IDIADA personnel not involved in the SAFE-UP project.

The survey, the template of which is available in Appendix B, is structured in two sections:

A) **Briefing section** filled-in by the volunteers before the complete test – where general questions regarding users' familiarity with the Demo 4 technology are introduced and the Demo 4 cyclists' scenarios are presented in detail adjusted to the real testing environment.

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B) **Debriefing section** filled-in by the volunteers after the complete test – where questions related to the system performance, perceived safety, time and type of warning, etc. are evaluated.

The analysis of the Briefing and Debriefing section is provided in the following paragraphs.

6.3.2.1 Briefing Section

The Briefing section included general questions related to:

- Age & Gender of the respondent
- User familiarity with V2X technology
- Safety potential of V2X technology

As stated above, the survey was complete by the 12 volunteers that participated in the tests of the cyclists' safety system. Out of the 12 volunteers, 10 were male and 2 were female, whereas 3 were between 18-24 years old, 8 were at the age group of 25-39 years old and 1 volunteer was between 40-59 years of age.

Figure 40 presents the assessment of the users' familiarity with the V2X technology deployed in Demo 4. Most volunteers are familiar with V2X technology and we may therefore assume that they could easier understand the functions of the system.

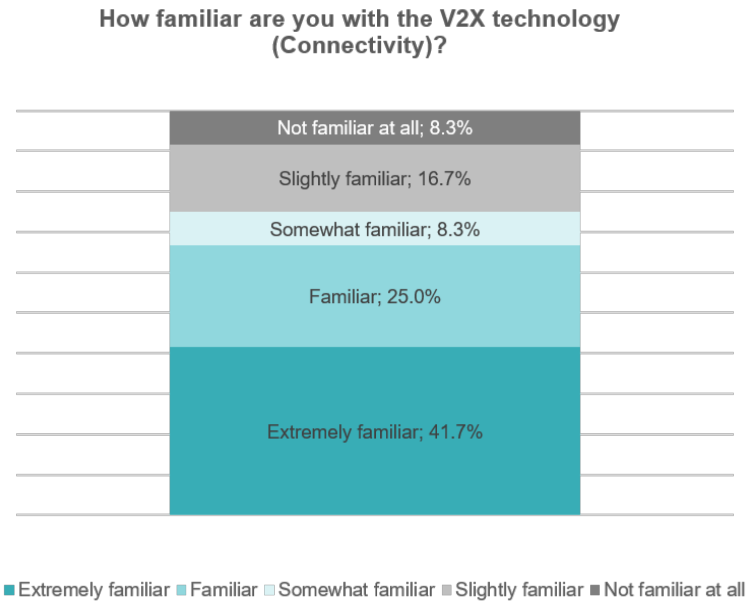

Figure 40: Volunteers' familiarity with V2X technology.

Those users that stated they were familiar with the V2X technology, were then asked their opinion on the potential safety benefit of this technology on road safety improvement. The results are presented in Figure 41 below. All users agree that V2X technology may contribute to the improvement of road safety.

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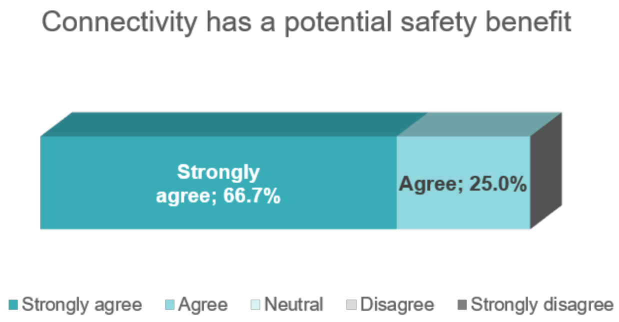

Figure 41: Volunteers' opinion on the safety benefit of V2X technology.

After the general questions, the survey presents to the volunteer the testing context for each tested scenario (Demo_4_08, Demo_4_09, Demo_4_13). This includes a schema of each scenario, a brief presentation of its context and guidelines that should be followed during the test (see Appendix B).

6.3.2.2 Debriefing Section

The Debriefing section of the survey includes questions related to the experience and perceived safety of the volunteer after the test.

The volunteers were initially asked to assess the relevance of the type of information that the system can provide to the cyclist while he/she is cycling in an urban area. The results are presented in Figure 42 below.

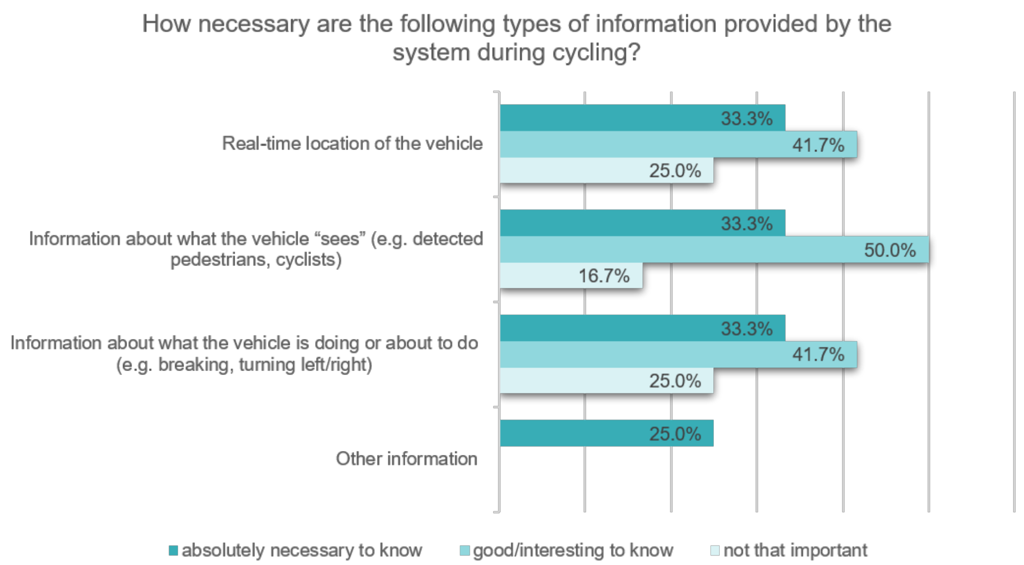

Figure 42: Relevance of the type of information the system can provide to the cyclist while cycling.

Most volunteers responded that it is either necessary or good to know real-time information on vehicle location, what is detecting and what is doing or about to do. A small only percentage of the respondents think that such information is not that important. Three volunteers specified other type of information that believe are vital for the cyclist, such as

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information related to crash avoidance and information provision via acoustic messages instead of visual.

The next question refers to the system usage evaluation in a real-world environment in terms of easiness of use, safety, usefulness, excitement and overall user experience. From the results presented in Figure 43 below, we can conclude that most volunteers agreed that the if the system was functioning in a real world it would be easy to use, safe, useful, pleasant and a positive experience for the cyclist. Two respondents believe however that the system usage would be too complicated in a realistic urban context.

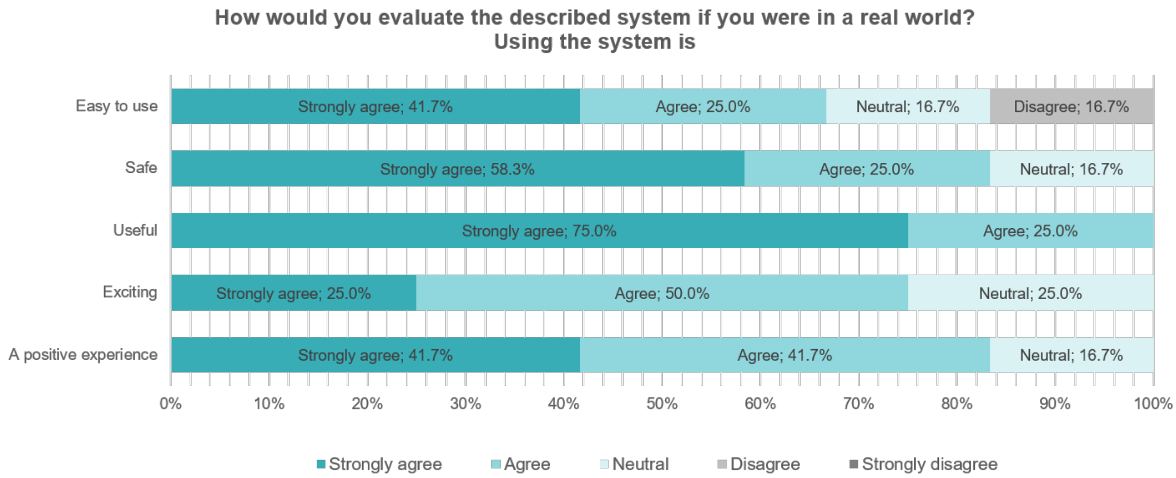

Figure 43: System usage evaluation in a real-world environment.

The volunteers were then asked to evaluate the time that the warning was provided by the system. From the results presented in Figure 44, we can easily notice that the warning during the testing phase was provided relatively early, an observation that is also further analysedin the discussion of Section 7.2.

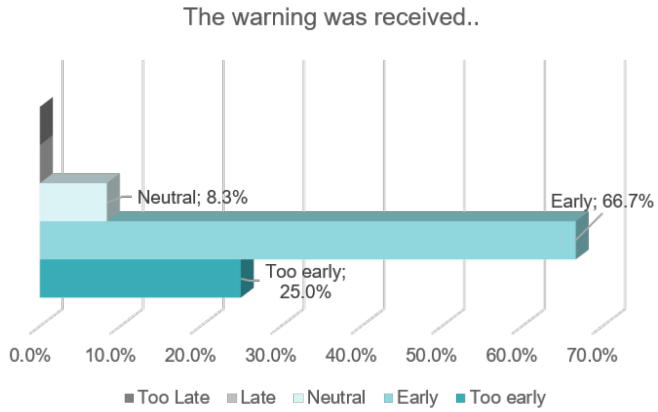

Figure 44: Evaluation of the system warning time.

The survey continues with the assessment of the necessity of the system in each of the three scenarios (Scenario A: Demo_4_08, Scenario B: Demo_4_09 and Scenario C: Demo_4_13) by the volunteers. Figure 45 summarises the feedback of the volunteers; the vast majority

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find the system as fully relevant for these scenarios, whereas none believes the opposite (not important).

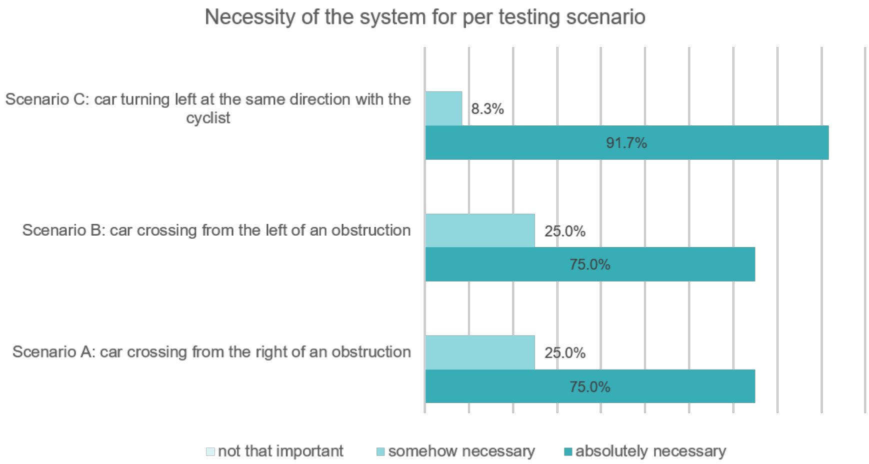

Figure 45: System necessity for each testing scenario.

The next question assesses the attitude of the volunteers on their willingness to use such as system if it was available in the market. 11 out of the 12 volunteers replied that they would be willing to use the system if it was available and one had a neutral opinion. (see Figure 46).

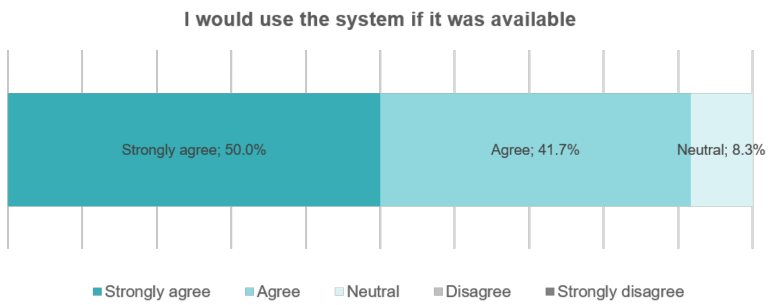

Figure 46: Attitude towards system willingness to use if it was available in the market.

The forthcoming question relates to the road environment the system should target, as well as the relevance it would bring to the road user (driver or cyclist) if it was marketed. The findings are summarised in Figure 47 below. It is interesting to observe that there is no clear consensus between the volunteers on the type of road environment that the system should primarily target. It can however be concluded that most volunteers believe the system would be more useful in an urban context especially if the user is unfamiliar with it. Furthermore, 8 out of the 12 users think that the system is more relevant for drivers (to receive information on the bicycle presence and movement) than for cyclists, probably due to the high complexity of the cyclist perception while riding.

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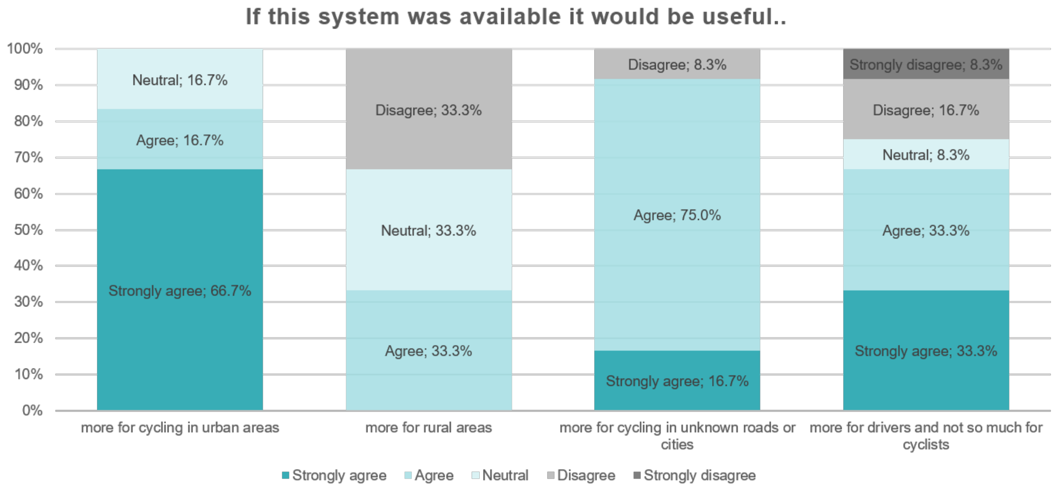

Figure 47: Usefulness of the system in relation to type of road environment and road user.

In the next question, the survey tries to assess the volunteers' concerns on key aspects related to the system use in a real-world environment. The results are presented in Figure 48. We can easily observe that volunteers are highly concerned on aspects of privacy and cybersecurity, as well as of system malfunctioning and moderately concerned on aspects of system reliability and the feeling of discomfort for the cyclist. With regard to the effect the system might have to the cyclist's smartphone battery, half of the volunteers seem to be concerned, whereas nearly the other half are not that concerned.

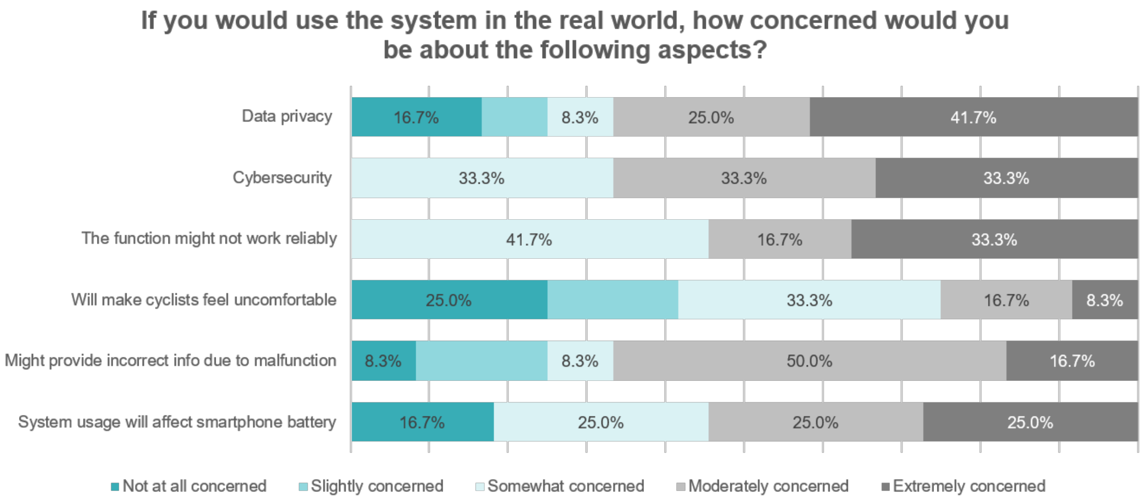

Figure 48: Volunteers' concerns on key aspects of system use in real road environments.

Although the development of a holistic HMI design for the safe interaction of the system with the cyclist was not in the scope of Demo 4, and only a basic HMI was deployed for the purposes of the testing phase, it was necessary for future research to sense the volunteers' preferences on the type of communication elements or combinations of them, they think would be effective, perceivable and safe for a marketed system. The results are summarised in Figure 49 below; it can be concluded that elements integrated in the cyclist's helmet, such as vibration (9 out of 12 volunteers) and audio (8 out of 12 volunteers) are the most popular amongst the volunteers. Vibration on the cyclist smartwatch is selected by 5 volunteers,

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whereas audio on smartphone (3 out of 12 volunteers) and visual information (2 out of 12 volunteers) are quite less popular. It should be also noted that three volunteers proposed combinations of elements that include: a) audio and vibration on both smartphone and smartwatch) and b) auditory communication on helmet and vibration on smartwatch.

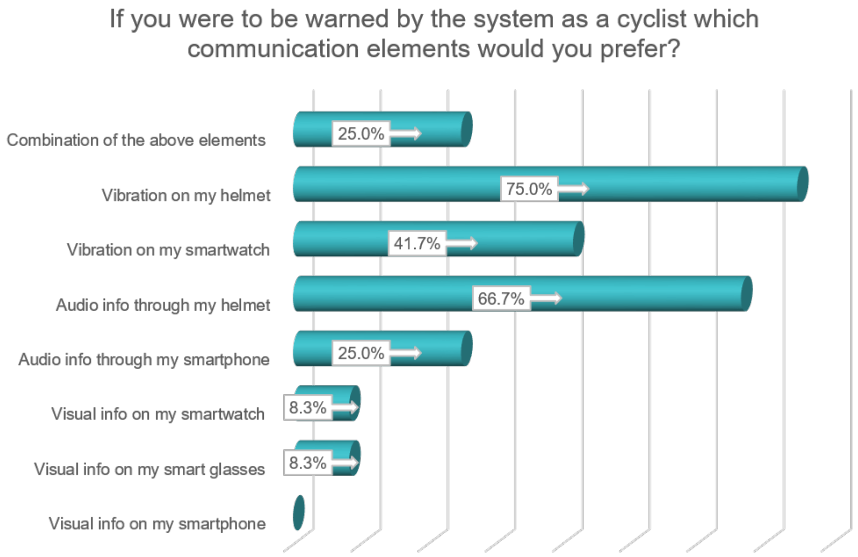

Figure 49: Volunteers' preferences on types of communication elements for a cyclists' safety system.

The third to last question of the survey asked the volunteers' opinion regarding the most relevant age groups that would benefit more by the use of such a system. From the results presented in Figure 50, we can conclude that the most selected age groups are with priority order those between 25-39, 18-24, under 18 and 40-59 years of age. 3 out of the 12 respondents believe that the system is also relevant for the age group of 60-79 years, as well as for all the age groups. Only 1 respondent selected as relevant the age group of over 80 years of age.

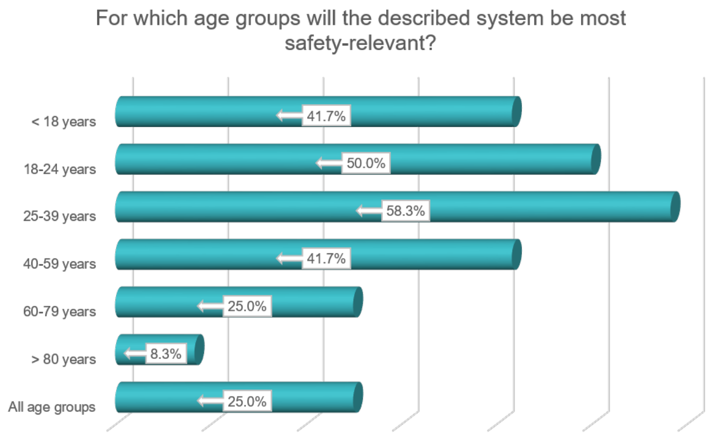

Figure 50: Volunteers' opinion on the safety relevance of the system per user age group.

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Just before its closing, the survey raised the question of system recommendation. All volunteers unanimously replied positively and therefore they would recommend this system to a friend or colleague.

The survey closes by asking the respondents about suggestions on future user-centred development of the system. The feedback received included suggestions such as: the improvement of the crash algorithm, the development of a user manual for safe operation and the preference of vibration over acoustic or visual elements for the effective communication with the cyclist.

6.4 Testing of system for pedestrians' safety

At this stage of the project, the final testing with the pedestrian system has still not been conducted. It is planned to be realised in late November 2022. Due to the fact that this deliverable will be submitted by then, this section will be reported in D3.8 that is due for May 2023.

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7 Discussion

7.1 Simulations

As stated in the previous section, in the conducted simulations only basic longitudinal vehicle correlation for braking has been conducted, but regarding to the sensors, only ideal sensors have been used (no modelling of the error, no perception nor data fusion algorithms are used other than perfect detection when there is line-of-sight with the objects). The lack of proper characterisation of the sensors and the lack of data fusion in the loop, prevented to reach more representative simulation results that could potentially serve better for the impact assessment analysis of WP5.

IDIADA's Demo 4 simulations only targeted the validation of the AEB system. Therefore, the results cannot be considered as fully representative to analyse the V2X impact on real scenarios and technology. For that, the test tracks and real cyclists' test results will be used instead. The relevant safety impact will be assessed, as mentioned before, within WP5.

7.2 Final demonstrator and recommendations for future R&D

Despite the fact that the final tests with the TME vehicle and the VRU dummies have still not been executed, there are potential issues that may affect the system performance and would need further research, so as to bring insights on the current V2X technology readiness for safety use cases.

One observation is that in order to introduce new data sources to a vehicle's Data Fusion system, such information must be extremely accurate or, at least, the system must be aware of its inaccuracy level. The current GNSS systems for portable devices (VRUs) show certain inaccuracy on the location data, depending on the signal level received, the buildings around and their height, reflections of the signal, number of satellites, etc.

Therefore, when the vehicle receives the location of the VRU via V2X, that location information may have some meters of inaccuracy that prevent the data fusion to extract a trusted representation of environmental objects (and their real location). The accuracy data from the GNSS VRU device is used to assess whether the information is good enough to be processed by the data fusion. In case of not doing such filter, the active system algorithms (e.g. AEB) will be operating with non-realistic data when trying to assess if there is a collision trajectory with the VRUs. IDIADA is still evaluating which accuracy range is acceptable.

When the vehicle sensors detect a non-occluded object, the data Fusion may be able to correct the inaccurate V2X information since it has other sensors with higher accuracy (radar and camera). However, in the situation where the V2X is the only source of information (when

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the VRU is occluded), that information must be extremely accurate otherwise the system will malfunction, potentially causing other safety-related issues due to unexpected braking reactions or other type of safety manoeuvres from other ADAS functions (e.g. AES).

There exist two different approaches to mitigate such situations:

- Using infrastructure to detect the VRUs

  Since the issue is the GNSS of the VRU devices, replace the direct communication between the VRUs and the vehicles with equipped infrastructure able to properly locate the VRUs using sensing capabilities. This way, the VRUs are not required to be equipped with any device. Such approach will be tested in this Demo 4 using an RSU.

- Increase the accuracy of the VRUs devices

  Other GNSS technologies (e.g. RTK) provide centimetre accuracy. Unfortunately, they are expensive and are not planned for small low-cost VRU devices soon. New technologies like Galileo can reduce the inaccuracy, even though in urban scenarios the conditions are not favourable for the high accuracy standards that safety-systems require.

This is not only a VRU issue, but can be also extrapolated to all cooperative perception use cases, in which vehicles (and all road users as well) receive the perception information generated by the nearby users in order to have the most complete understanding of the surrounding environment. If any of the stations, being a vehicle or a VRU, provide inaccurate location data, this information should be automatically identified as non-valid data and be discarded. The location accuracy is a huge barrier in the current and future cooperative perception systems.

IDIADA is currently evaluating how much inaccuracy is acceptable for the Data Fusion and the AEB to work properly, in order to be able to filter data based on such an accuracy parameter.

On another hand, the ITS-G5 technology used in Demo 4 adds the latency as important performance-critical parameter. In order to make use of the V2X data into a real-time safety-critical system as the data fusion, the information not only needs to be accurate but also low-latency. This is important in both non-occlusion (V2X + other sensors as perception) and occlusion situations (only V2X as perception sensor). Having high latency in the latter case means that the data fusion interprets the V2X information as real-time when the information is actually older. This way, the predictions and algorithms may detect situations which are not accurate to the real situation.

When there is no occlusion with a VRU, the (old) information of the V2X is merged with real-time data from the other sensors, which could potentially make the data fusion to discard the V2X data or set lower priority to it.

Fortunately, the latency calculated during preliminary test is low enough (<150ms) to not affect the system performance. However, in real situations with high penetration (more cars, pedestrians and cyclists involved), the V2X channel could get busy and the latency could increase substantially. New technologies like 5G are expected to solve such issues.

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Another important point is the introduction of an RSU device/actor into EuroNCAP-based scenarios is also a critical point in terms of the performance of the system for non-connected VRUs. The RSU location has been extensively discussed within Demo 4 to find the best suitable spot and distance based on the current technology available. The height of the RSU is a discarded parameter for Demo 4 since the purpose is the detection of a single VRU at a time, therefore there is no need to have a wider and higher perspective of the scenario as would be required for a real deployment in an intersection.

The current perspective of the RSU for Demo 4 scenarios is always in front of the VRU trajectory. The VRU (dummy) will travel towards the RSU so the perception will only need to focus on one movement axis (y) and, therefore, having a very accurate detection by the camera and the LiDAR. The distance to the impact point is always 6 meters, which is considered a close distance but safe from the scenario action.

In bicycle testing with real cyclists the system performed quite well in two of the three scenarios that were evaluated (Demo_4_08 and Demo_4_09). Obviously, more experiments with real users are required in order for the user warning time to be more accurately adjusted, by both avoiding early warnings and still give enough time for an action that will prevent an imminent collision. In turning scenario (Demo_4_13 – vehicle turns late in the path of the bicycle) tests showed that although the collision was detected, the user warning came too late for any avoiding action to be able to be performed. A possible improvement in such cases could be achieved by the addition of more parameters in the collision detection algorithm, like target’s steering wheel state, yaw rate, turning light indicator state, which may give the possibility for earlier predictions of the vehicle’s future positions.

Furthermore, in real urban environments the number of road users is significantly higher, therefore the TTC used in Demo 4 to calculate the potential collision between only one vehicle and one VRU, might dramatically increase the false positives. In addition, the network usage could be also affected by a high number of users, causing delays in the exchange of CAM messages and on-time warnings. On this ground, CEA has conducted simulations to investigate such issues that will be reported in D3.8 (May 2023) and could provide some insights for future research and development.

Finally, it should be noted that HMI studies were not part of the scope of Demo 4 within the SAFE-UP project. Within SAFE-UP, only the technical performance of the communication efficiency between the main subsystems was researched and developed. Therefore, interaction elements and combinations of them (i.e. visual, auditory, haptic) as well as their effectiveness on human perception of the situation are yet to be studied in future research initiatives. Such human factors studies are expected to feed a complete impact assessment of the overall system in the future.

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8 Conclusions

This report presents the work performed towards the final Demo 4 demonstrator development, integration and performance testing that is divided in four layers:

1. **SCENARIOS IN-DEPTH ANALYSIS:** The scenarios selected in the preliminary version of Demo 4 presented in D3.4 (Nikolaou, et al., 2021) are characterised and analysed to fulfil the requirements of the testing phase.
2. **FINAL DEVELOPMENT OF SUBSYSTEMS:** The final development for each Demo 4 subsystem (vehicle, RSU, pedestrian safety device and cyclist safety device) are summarised.
3. **INTEGRATION & PRE-TESTING:** The integration of the individual subsystems into the final integrated Demo 4 system, the problems faced and solutions selected and the pre-testing of the final systems is presented.
4. **FINAL DEMONSTRATOR:** The outcomes from the integration and pre-testing phase (simulations and physical tests) are analysed and technical limitations encountered are highlighted and upscaled to recommendations for future research and development.

For the first layer, work towards the selected scenarios characterisation was performed which was based on additional GIDAS analysis by TME focusing on those scenarios where an obstruction was present and reported in Section 4.1. Furthermore, for all selected scenarios, a technical characterisation was performed using the Euro NCAP protocol by IDIADA, in order to support the testing phase at IDIADA premises (Section 4.2).

For the second layer, a detailed description of the final development for each of the four main components was presented in Section 5 based on the final architecture of Section 3 that was presented in detail within Deliverable 3.9 (Nikolaou & Panou, 2022). Specifically, IDIADA has implemented an architecture with perception capabilities, a driver warning algorithm and an AEB function integrated with a Toyota vehicle, for which a close collaboration with TME has been required. The perception system is able to work with V2X information coming from the VRU and from the RSU, as well as with a camera and a radar as perception sources, to evaluate the impact of the V2X technology in safety-critical scenarios where AEB is required (including a driver warning). Furthermore, two V2X devices were developed by CERTH during Demo 4 that enable a pedestrian and a cyclist VRU to become a part of the G5 C-ITS ecosystem. Transmitted VRU awareness information enhances the perception of the surrounding V2X stations even in cases where their other perception sensors have limitations due to obstructions. Incoming V2X information open up the possibility for collision detections and consequently user warnings in advance. The main difficulties during development were the small dimensions of the pedestrian device due to its handheld nature and the integration of the cyclist device in the actual bicycle. Especially for the bicycle's case, it is quite challenging to install a V2X communication device on a narrow metallic frame with space and

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power restrictions, maintaining in parallel riding comfort and safety. Finally, IDIADA has developed an architecture for an RSU capable of detecting VRUs and transmitting the information of those via V2X to the vehicle. The detection of VRUs consists in using a data fusion algorithm fed with information from a camera and a LiDAR. During the track testing, the RSU will be used in those runs where the VRU dummy is not carrying the VRU V2X device, so the information of its position, speed and direction will be reported to the vehicle via the RSU using V2X.

With regard to the third layer, the individual subsystems of Demo 4 where integrated into the final system and technical tests were performed to assess the readiness of the system for the testing phase (Section 6.1). To facilitate the testing phase and to minimise the required runs for the real testing, a set of simulations of the Demo 4 scenarios have been conducted with the main purpose of validating the AEB system (Section 6.2). Furthermore, some insights of the potential of the V2X technology in such safety-critical scenarios has also been extracted from such simulations. The results of those simulations in relation to the safety impact assessment will be reported in Deliverable 5.6 of WP5. However, it is expected that the final results coming from the track testing, where the pedestrian device will be used, and the real VRU tests, where the cyclist device has been used, will provide deeper knowledge for the impact assessment of the V2X technology. Moreover, real tests at IDIADA premises where conducted for the cyclists' scenarios (Section 6.3) with the participation of 12 real cyclists, a real bicycle equipped with the cyclists' VRU system and a virtual vehicle with all the required Demo 4 parameters for safety reasons. In addition to the performance results of those tests, a survey was also conducted to retrieve participants'' feedback on the system potential.

Finally, the fourth layer presents the overall outcomes of Demo 4, the current technical limitations and the main recommendations for future research and development (Section 7). Specifically, the V2X technology brings some challenges on the table, especially when using V2X information from external entities into a vehicle's data fusion system (see section 7.2). These challenges are currently being analysed to determine the impact of this technology in a SOTA perception system in order to find suitable working conditions for the Demo 4 use cases. With regard to the cyclists' tests, the results showed that although the system looks promising and worthy to the users that participated in the tests, there is still work that needs to be performed in the future on the parameterisation of the systems in real urban environments in order to adjust the triggering of the warning at an accepted but yet safe, in terms of human reaction time, timeframe. Moreover, remaining work is to still to be performed for the final testing using the pedestrian VRU device, the Demo 4 vehicle and the RSU at IDIADA test tracks at beginning of December 2022. These tests will focus on the VRU (pedestrian) warning, the driver warning and the active function (AEB) impact assessment. Due to the safety implication of such tests, pedestrian and cyclist dummies will be deployed. As during the preparation of this Deliverable this work was still pending, it will be reported within D3.8 of Task 3.6 and WP5 deliverable D.5.3. Finally, for an overall system design approach, future human factors research should be conducted in order to assess the human perception (driver, pedestrian, cyclist) and the interaction framework that should be deployed for each case, along with the selection of the most suitable HMI elements for each target group.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

Appendix A: Pedestrians testing matrix per scenario

Demo_4_01

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_01 _TT_1	25	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_01 _TT_2	25	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_01 _TT_3	25	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_01 _TT_4	30	8	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_01 _TT_5	30	8	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_01 _TT_6	30	8	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_01 _TT_7	35	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_01 _TT_8	35	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_01 _TT_9	35	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_01 _TT_10	40	8	Active	Active	Active	w/ Connected VRU

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SAFE-UP Demo_4_01 _TT_11	40	8	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_01 _TT_12	40	8	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_01 _TT_13	45	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_01 _TT_14	45	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_01 _TT_15	45	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_02

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_02 _TT_1	35	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_2	35	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_3	35	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_4	40	5	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_5	40	5	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_6	40	5	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_7	45	5	Active	Active	Inactive	w/ Connected VRU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_02 _TT_8	45	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_9	45	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_10	50	5	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_11	50	5	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_12	50	5	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_13	55	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_14	55	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_15	55	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_16	60	5	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_17	60	5	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_02 _TT_18	60	5	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_02 _TT_19	65	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_02 _TT_20	65	5	Active	Inactive	Active	w/ Non-connected VRU

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SAFE-UP Demo_4_02 _TT_21	65	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_05

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_05 _TT_1	10	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_05 _TT_2	10	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_05 _TT_3	10	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_05 _TT_4	15	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_05 _TT_5	15	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_05 _TT_6	15	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_05 _TT_7	20	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_05 _TT_8	20	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_05 _TT_9	20	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_05 _TT_10	25	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_05 _TT_11	25	5	Active	Inactive	Active	w/ Non-connected VRU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_05 _TT_12	25	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_05 _TT_13	30	5	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_05 _TT_14	30	5	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_05 _TT_15	30	5	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_06

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_06 _TT_1	10	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_06 _TT_2	10	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_06 _TT_3	10	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_06 _TT_4	15	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_06 _TT_5	15	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_06 _TT_6	15	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_06 _TT_7	20	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_06 _TT_8	20	8	Active	Inactive	Active	w/ Non-connected VRU

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SAFE-UP Demo_4_06 _TT_9	20	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_06 _TT_10	25	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_06 _TT_11	25	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_06 _TT_12	25	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_06 _TT_13	30	8	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_06 _TT_14	30	8	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_06 _TT_15	30	8	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_08

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_08 _TT_1	10	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_2	10	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_3	10	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_4	10	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_5	10	20	Active	Inactive	Active	w/ Non-connected VRU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_08 _TT_6	10	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_7	15	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_8	15	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_9	15	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_10	15	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_11	15	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_12	15	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_13	20	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_14	20	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_15	20	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_16	20	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_17	20	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_18	20	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_08 _TT_19	25	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_20	25	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_21	25	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_22	25	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_23	25	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_24	25	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_25	30	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_26	30	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_27	30	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_08 _TT_28	30	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_08 _TT_29	30	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_08 _TT_30	30	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_09

Test Code	Vs	Vt	Cs	Ct	Cr	Comments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_09 _TT_1	10	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_09 _TT_2	10	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_09 _TT_3	10	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_09 _TT_4	15	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_09 _TT_5	15	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_09 _TT_6	15	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_09 _TT_7	20	20	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_09 _TT_8	20	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_09 _TT_9	20	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_09 _TT_10	25	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_09 _TT_11	25	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_09 _TT_12	25	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_09 _TT_13	30	20	Active	Active	Inactive	w/ Connected VRU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_09 _TT_14	30	20	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_09 _TT_15	30	20	Inactive	Inactive	Inactive	Baseline w/o Connectivity

Demo_4_13

Test Code	Vs	Vt	Cs	Ct	Cr	Comments
SAFE-UP Demo_4_13 _TT_1	10	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_2	10	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_3	10	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_4	10	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_5	10	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_6	10	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_7	15	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_8	15	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_9	15	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_10	15	20	Active	Active	Active	w/ Connected VRU

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

SAFE-UP Demo_4_13 _TT_11	15	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_12	15	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_13	20	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_14	20	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_15	20	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_16	20	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_17	20	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_18	20	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_19	25	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_20	25	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_21	25	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_22	25	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_23	25	20	Active	Inactive	Inactive	w/ Non-connected VRU

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SAFE-UP Demo_4_13 _TT_24	25	20	Inactive	Inactive	Active	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_25	30	15	Active	Active	Inactive	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_26	30	15	Active	Inactive	Active	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_27	30	15	Inactive	Inactive	Inactive	Baseline w/o Connectivity
SAFE-UP Demo_4_13 _TT_28	30	20	Active	Active	Active	w/ Connected VRU
SAFE-UP Demo_4_13 _TT_29	30	20	Active	Inactive	Inactive	w/ Non-connected VRU
SAFE-UP Demo_4_13 _TT_30	30	20	Inactive	Inactive	Active	Baseline w/o Connectivity

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Appendix B: Cyclists Testing Phase Survey

About this study

This study is conducted in the framework of the H2020 European project SAFE-UP (www.safe-up.eu). 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.

The project builds four demonstrators, each one targeting different passive and active safety technologies with main target being the reduction of Vulnerable Road Users (pedestrians and cyclists) serious injuries and fatalities.

This study is related to Demonstrator 4 (Demo 4), which develops a VRU safety system based on V2X technology that provides enhanced communication between vehicles, road infrastructure and VRU (pedestrians and cyclists). The actual target is to provide additional environmental perception to vehicles regarding the presence of VRU in critical situations, especially in cases where the vehicle sensors reach their limits (i.e. obstructed areas). Connected VRU are able to directly exchange V2X messages with the equipped V2X vehicles, whereas the non-connected VRUs are monitored by the RSU that exchanges direct messages with the equipped V2X vehicles.

The survey is related to the assessment of the prototype safety system for cyclists developed by Demo 4 team and includes **three different scenarios (A, B and C)** that were identified as the most critical ones in terms of impact severity for cyclists by the SAFE-UP accidentology experts.

For any questions related to this study, please contact:

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For more information regarding SAFE-UP project please visit our media pages:

Website: www.safe-up.eu
LinkedIn: https://www.linkedin.com/company/safe-up-h2020/
Twitter: https://twitter.com/SAFE_UP_
YouTube: https://www.youtube.com/channel/UCpgc_D_TOS8ztMg9iG_P4Ng

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

The SAFE-UP project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

Briefing - General questions

How familiar are you with the V2X technology (Connectivity)?

1 = very familiar	2	3	4	5 = not familiar at all
[ ]	[ ]	[ ]	[ ]	[ ]

If you are familiar with the V2X technology, do you think that it can contribute to road safety enhancement?

	1 = strongly AGREE	2	3	4	5 = strongly DISAGREE
Connectivity has a potential safety benefit.	[ ]	[ ]	[ ]	[ ]	[ ]

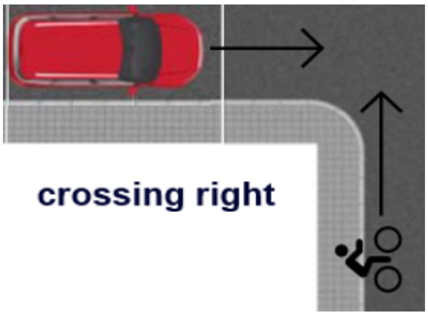
Please select your age group

[ ] < 18 years
[ ] 18-24 years
[ ] 25-39 years
[ ] 40-59 years
[ ] 60-79 years
[ ] > 80 years

Please specify your gender

[ ] Male
[ ] Female
[ ] Other
[ ] Prefer not to say

A/ Scenario Demo_04_08



This scenario is related to a conflict between a passenger car and a cyclist, while the car is **crossing from the right of an obstruction (left from cyclist's view)**. This obstruction prevents both the driver and the cyclist to detect on time each other.

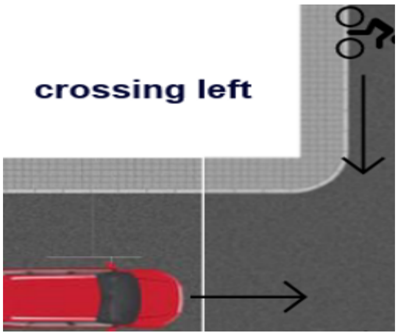
The hypothesis is that connectivity (V2X technology) will enhance the perception of both road users by providing on time warnings on both sides in order for the accident to be avoided.

Information and guidance for testing this scenario

- There will be no safety-related implication whatsoever with a car, other vehicle or human. The testing area is closed for the purposes of this study.
- The Demo 4 team tried to represent as realistic as possible the scenario, however due to the fact that we are in a closed controlled testing area, please try to have a perspective of being in an urban environment with traffic and how you'd react in a real world.
- For this scenario five (5) different runs are considered as most critical, which calculate different speeds for the vehicle and the bicycle. For this reason, we would like to kindly as you to try your best in keeping the recommended speeds each time that will be indicated to you by the test leader. This is really important for assessing the safety impact of the prototype system.
    - Run No1: please escalate the bicycle speed up to 20 kph
    - Run No2: please escalate the bicycle speed up to 18 kph
    - Run No 3, 4 & 5: please escalate the bicycle speed up to 15 kph
- After testing this scenario, you will be asked by the test leader to fill-in a short debriefing questionnaire (common for all scenarios evaluated at this study). It will maximum take 5 minutes of your time. Your feedback is important for the researchers to assess the users' perspective on the safety potential of this system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

B/ Scenario Demo_04_09



This scenario is related to a conflict between a passenger car and a cyclist, while the car is **crossing from the left of an obstruction (right from the cyclist's view)**. This obstruction prevents both the driver and the cyclist to detect on time each other.

The hypothesis is that connectivity (V2X technology) will enhance the perception of both road users by providing on time warnings on both sides in order for the accident to be avoided.

Information and guidance for testing this scenario

- There will be no safety-related implication whatsoever with a car, other vehicle or human. The testing area is closed for the purposes of this study.
- The Demo 4 team tried to represent as realistic as possible the scenario, however due to the fact that we are in a closed controlled testing area, please try to have a perspective of being in an urban environment with traffic and how you'd react in a real world.
- For this scenario only one (1) run is considered as most critical. For this reason, we would like to kindly as you to try your best in keeping the recommended speeds each time that will be indicated to you by the test leader. This is really important for assessing the safety impact of the prototype system.
    - Run No1: please escalate the bicycle speed up to 20 kph
- After testing this scenario, you will be asked by the test leader to fill-in a short debriefing questionnaire (common for all scenarios evaluated at this study). It will maximum take 5 minutes of your time. Your feedback is important for the researchers to assess the users' perspective on the safety potential of this system.

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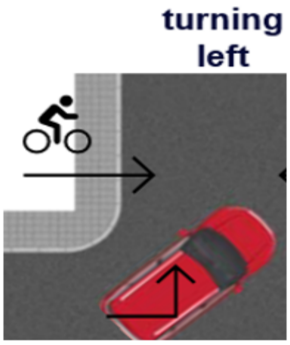
C/ Scenario Demo_04_13



This scenario is related to a conflict between a passenger car and a cyclist, while the car is **turning left at the same direction with the cyclist**. In this scenario the cyclist and the driver can only detect each other either very late or even during the impact.

The hypothesis is that connectivity (V2X technology) will enhance the perception of both road users by providing on time warnings on both sides in order for the accident to be avoided.

Information and guidance for testing this scenario

- There will be no safety-related implication whatsoever with a car, other vehicle or human. The testing area is closed for the purposes of this study.
- The Demo 4 team tried to represent as realistic as possible the scenario, however due to the fact that we are in a closed controlled testing area, please try to have a perspective of being in an urban environment with traffic and how you'd react in a real world.
- For this scenario only one (1) run is considered as most critical. For this reason, we would like to kindly as you to try your best in keeping the recommended speeds each time that will be indicated to you by the test leader. This is really important for assessing the safety impact of the prototype system.
    - Run No1: please escalate the bicycle speed up to 20 kph
- After testing this scenario, you will be asked by the test leader to fill-in a short debriefing questionnaire (common for all scenarios evaluated at this study). It will maximum take 5 minutes of your time. Your feedback is important for the researchers to assess the users' perspective on the safety potential of this system.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

Debriefing questions – All Scenarios

The system can provide different types of information to the cyclist while he/she is cycling in an urban area. What do you think about the relevance of the following types of information at this point?

	absolutely necessary to know	good/interesting to know	not that important
Real-time location of the vehicle	[ ]	[ ]	[ ]
Information about what the vehicle “sees” (e.g. detected pedestrians, cyclists)	[ ]	[ ]	[ ]
Information about what the vehicle is doing or about to do (e.g. breaking, turning left/right)	[ ]	[ ]	[ ]
Other information *(please specify)*: ______________________________	[ ]	[ ]	[ ]

How would you evaluate the described system if you were in a real world?
Using the system is …

a positive experience	[ ]	[ ]	[ ]	[ ]	[ ]	a negative experience
exciting	[ ]	[ ]	[ ]	[ ]	[ ]	boring
useful	[ ]	[ ]	[ ]	[ ]	[ ]	useless
safe	[ ]	[ ]	[ ]	[ ]	[ ]	dangerous
easy to use	[ ]	[ ]	[ ]	[ ]	[ ]	complicated

How would you evaluate the time that the warning was provided?
The warning was received …

	1 = TOO EARLY	2	3	4	5 = TOO LATE
I would use the system if it was available.	[ ]	[ ]	[ ]	[ ]	[ ]

How would you evaluate the necessity of this system for each of the three scenarios?

	absolutely necessary	somehow necessary	not that important
Scenario A: car turning right with an obstruction	[ ]	[ ]	[ ]
Scenario B: car turning left with an obstruction	[ ]	[ ]	[ ]
Scenario C: car turning left at the same direction with the cyclist	[ ]	[ ]	[ ]

To what extent do you agree or disagree with the following statement?

	1 = strongly AGREE	2	3	4	5 = strongly DISAGREE
I would use the system if it was available.	[ ]	[ ]	[ ]	[ ]	[ ]

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To what extent do you agree or disagree with the following statements?
I would prefer use this system if it was available …

	1 = strongly AGREE	2	3	4	5 = strongly DISAGREE
... more for cycling in urban areas.	[ ]	[ ]	[ ]	[ ]	[ ]
... more for in rural areas.	[ ]	[ ]	[ ]	[ ]	[ ]
... more for cycling in unknown roads or cities.	[ ]	[ ]	[ ]	[ ]	[ ]
... more for drivers and not so much for cyclists.	[ ]	[ ]	[ ]	[ ]	[ ]

If you would use the system in the real world, how concerned would you be about the following aspects?

	1 = NOT AT ALL concerned	2	3	4	5 = EXTREMELY concerned
Data privacy (e.g. abuse of private data)	[ ]	[ ]	[ ]	[ ]	[ ]
Cyber security (e.g. the system can be hacked)	[ ]	[ ]	[ ]	[ ]	[ ]
The function might not work reliably	[ ]	[ ]	[ ]	[ ]	[ ]
The system will make cyclists feel uncomfortable	[ ]	[ ]	[ ]	[ ]	[ ]
The information provided by the system might be incorrect due to malfunction or data loses	[ ]	[ ]	[ ]	[ ]	[ ]
Using the system will influence smartphone battery (e.g. due to system usage)	[ ]	[ ]	[ ]	[ ]	[ ]
Other concerns *(please specify)*: ______________________	[ ]	[ ]	[ ]	[ ]	[ ]

If you were to be warned by the system as a cyclist which communication elements would you prefer?

[ ] Visual information on my smartphone (attached on the bicycle handlebar)
[ ] Visual information on my smart glasses
[ ] Visual information on my smart watch
[ ] Audio information through my smartphone
[ ] Audio information through my helmet
[ ] Vibration on my smart watch
[ ] Vibration on my helmet
[ ] Combination of the above elements *(please specify)*:
____

For which age groups will the described system be most safety-relevant?

[ ] < 18 years
[ ] 18-24 years
[ ] 25-39 years
[ ] 40-59 years
[ ] 60-79 years
[ ] > 80 years

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Would you recommend this system to a friend or colleague?

[ ] No, I don’t think it provides any benefit to road safety.
[ ] Yes, I believe it will contribute to the reduction of cyclists’ deaths and serious injuries.

Do you have any suggestions on how to develop the system from a user perspective?

[ ] ____

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