D3.1 ACTIVE SAFETY SYSTEMS SPECIFICATION AND RISK ANALYSIS

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Executive summary

This Deliverable falls under the SAFE-UP Project Work Package 3 “Active safety systems for vehicle-VRU interaction” and specifically under the Task 3.1 “Active safety system specification and risk analysis”. It is a purely technical document that targets to support the efficient monitoring of the technical developments within WP3.

The actual version is a preliminary document that includes information collected and consolidated before the development of the three Demos. The updated and final version of this document will be available on Month 26 of the project.

Section 1 presents the methodology following for the two main activities of T3.1; Technical specifications and Risk Assessment.

Section 2 presents the outcomes of the technical specifications for each Demo separately. Detailed information on modules technical specifications have been annexed to facilitate the reader.

In Section 3, the preliminary risk assessment for each Demo is presented, for each of the main risk categories; technical, behavioural, organisational and legal risks.

Finally, Section 4 provides the discussion points and the conclusions of this Deliverable.

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List of abbreviations

Abbreviation	Meaning
AD	Autonomous Driving
AEB	Autonomous Emergency Braking
AES	Autonomous Emergency Steering
AV	Autonomous Vehicles
CA	Consortium Agreement
CAN bus	Controller Area Network
CAV	Connected Automated Vehicles
C-ITS	Cooperative Intelligent Transport Systems
CPM	Collective Perception Message
D	Deliverable
DA	Driver Assistance
EC	European Commission
ECU	Electronic Control Unit
ESP	Electronic Stability Program
FMEA	Failure Mode and Effects Analysis
GA	Grant Agreement
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interaction
IMU	Inertial Measurement Unit
LDM	Local Dynamic Map
N/A	Not Applicable
OBU	On Board Unit
OEM	Original Equipment Manufacturer
RN	Risk Number
ROS	Robot Operating System
RSU	Road-Side Unit
RTK	Real-time kinematic positioning

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Abbreviation	Meaning
SotA	State-of-the-Art
T	Task
TBD	To be defined
TSS	Toyota Safety Sense
V2X	Vehicle-to-everything
VRU	Vulnerable Road User
WP	Work Package

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1. Introduction

This Deliverable consolidates the preliminary technical overview and risk assessment of the three active safety systems under development within WP3; Demo 2, Demo 3 and Demo 4. The scope of Demo 2 is to enhance the interaction between vehicles and VRUs under bad weather conditions by analysing the effect of bad weather on different sensor types and configurations for State of the Art (SotA) and future technology. Demo 3 develops advanced vehicle dynamics intervention functions to avoid or mitigate critical events. The demonstrator will include a vehicle with combined trajectory control algorithm for both emergency braking and steering. Finally, Demo 4 develops a VRU safety system based on V2X technology that provides enhanced communication between vehicles, road infrastructure (RSU installed on traffic light) and VRUs (pedestrians and cyclists).

The purpose of this document is mainly to support the technical coordination and monitoring of the three relevant Demos, as well as to describe a-priori the foreseen risks during the development phase. It is therefore working as an internal technical document, supporting the work of the system developers throughout the process, as well as the related work that will be performed in T3.6 focusing on technical verification.

An updated version of this Deliverable is scheduled for Month 26 of the project (July 2022), when all three Demos have completed their development phase. This updated version will include the final technical specifications, as well as the a-posteriori risk assessment with any risks that occurred and the related mitigation strategies employed for each Demo respectively.

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2. Architecture and Technical Specifications

2.1 Introduction & Methodology

This Section presents the architecture diagrams and the main physical and software (where applicable) modules technical specifications for each of the three active safety systems developed within WP3; Demo 2, Demo 3 and Demo 4. Demo 2 focuses on advancing the vehicle VRU detection capabilities in bad weather conditions, Demo 3 develops an advanced system for vehicle reaction strategies to avoid collisions with VRUs under normal and bad weather conditions, whereas Demo 4 provides enhanced perception to the vehicle through V2X communication with infrastructure sensors (RSU) and connected VRUs, while providing on-time warnings to all connected traffic participants (drivers, pedestrians and cyclists).

All three Demos represent complex systems that require concise specification of their technical requirements, so that both development and integration phases run smoothly and the initial technical targets are reached. Further to supporting the development process, the technical specifications will also support the work that will be performed in the technical verification task (T3.6), providing a basis to assess and evaluate the technical performance of each Demo.

In order to collect the technical specifications of each WP3 Demo, a template was created and circulated among the partners (*see Appendix A*). The template is in a tabular form and is divided into 4 sections:

- Introduction: *including information about the manufacturer, the responsible partner, processing units and communication (I/O ports and communication network)*
- Performance section: *giving details about the item performances (e.g. for a sensor: physical quantity measured, along with accuracy, frequency,)*
- Physical specifications: *including information about integration aspects (weight, size, operating temperature range, power supply, …)*
- Environmental Specifications: *in case the item has or should have specific characteristics in terms of water resistance, vibration resistance.*

Additional specifications are provided for supporting components, such as HMI modules, interface elements and elaboration units, whereas any unnecessary specifications are

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omitted. Information that are not yet defined are marked with 'TBD' (to be defined), whereas not applicable information are marked with 'N/A'.

For facilitating the reading, the main Demo sub-sections present the summary tables of the main technical components, whereas the detailed technical specifications are annexed separately for each Demo.

Since this is the first version of the technical specifications captured before the three Demos (Demo 2, 3 and 4) are actually developed, the relevant information is preliminary and subject to changes. The final and complete information will be available on Month 26, in accordance to the description and timeline of Task 3.1.

2.2 Demo 2

The scope of Demo 2 is to enhance the interaction between vehicles and VRUs under bad weather conditions by analysing the effect of bad weather on different sensor types and configurations for SotA and future technology. Baseline tests with the actual sensor configuration will demonstrate the SotA performance. A test-based evaluation scheme will be validated with simulative effectiveness evaluation as a comparison to physical testing. Verification tests will show the object detection limits at adverse weather conditions for both SotA and future sensor configurations. The results will validate object detection as a function of weather conditions, distance, trajectory angles and speed differences.

Figure 1: Test vehicle under increasing bad weather conditions (THI).

A demonstration car with advanced sensor configuration and VRU detection algorithms for safe object detection in all weather conditions will be used (Bosch test vehicle). The focus will be VRU detection in heavy rain and fog conditions with different environment objects nearby.

Demo 2 will use environmentally robust sensor concepts and innovative sensor data post-processing features for safe object detection both in the near-field area and bad weather conditions.

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2.2.1 Architecture

2.2.1.1 Physical architecture

The physical architecture of Demo 2 vehicle consists of sensors, actuators and elaboration units.

One front, one rear, two front corner and two rear corner radar sensors with +/-60° field-of-view each, a front stereo video sensor, as well as a rooftop Lidar sensor with +/-360° field-of-view are used to detect moving and stationary objects within and next to the vehicle's path.

The object information of each sensor is directly sent to the car PC, where the information of the different sensors can be measured and evaluated.

The vehicle platform is a Bosch test vehicle, specifically used for Demo 2 within SAFE-UP.

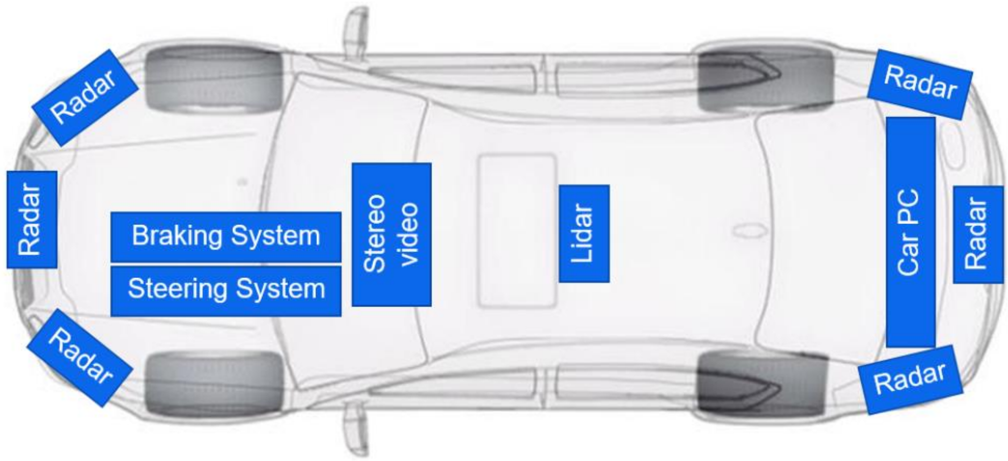

Figure 2: Demo 2 Physical architecture diagram.

2.2.1.2 Communication Architecture

Demo 2 communication architecture consists of Ethernet connections from all sensor ECUs to the car PC, enabling internal signal access for measurement and rapid prototyping purposes.

Actuation commands can directly be sent from the car PC to the braking and steering system over the chassis CAN.

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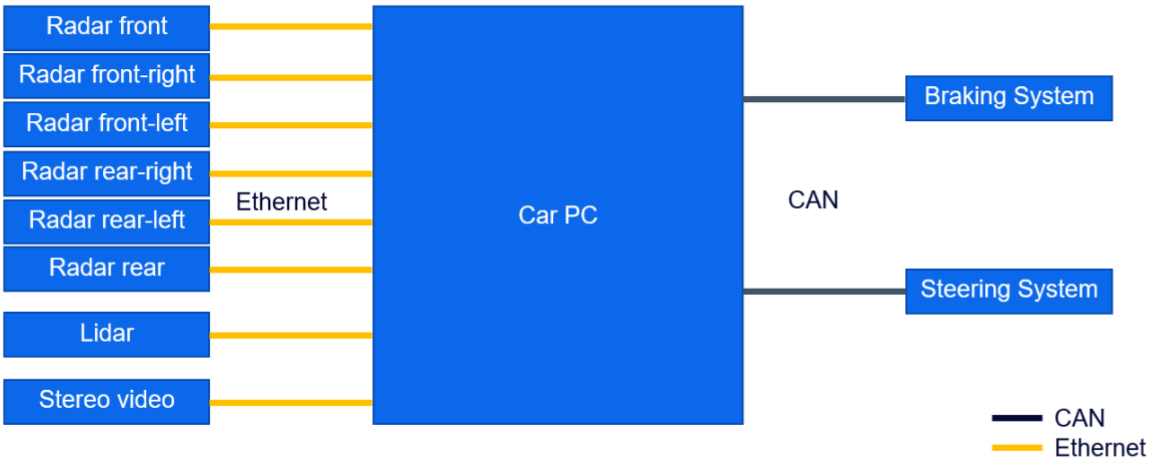

Figure 3: Demo 2 Communication architecture diagram.

2.2.2 Technical Specifications

2.2.2.1 Demo 2 Physical modules

The physical components of Demo 2 are presented in Table 1 below. The technical specifications for each of the listed sensors is available in *Appendix B* of this document (can be also assessed directly via hyperlink). Table 2 and Table 3 consolidate the Demo 2 interfaces and elaboration units respectively.

Table 1: Overview of Demo 2 physical modules.

Demo 2 Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M1	Front Radar Sensor	Radar Sensor	Bosch	Data Collection
M2	Rear Radar Sensor	Radar Sensor	Bosch	Data Collection
M3	Left Front Corner Radar Sensor	Radar Sensor	Bosch	Data Collection
M4	Right Front Corner Radar Sensor	Radar Sensor	Bosch	Data Collection

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Demo 2 Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M5	Left Rear Corner Radar Sensor	Radar Sensor	Bosch	Data Collection
M6	Right Rear Corner Radar Sensor	Radar Sensor	Bosch	Data Collection
M7	Front Stereo Video Sensor	Video Sensor	Dream Chip	Data Collection
M8	Rooftop Lidar Sensor	Lidar Sensor	Hesai	Data Collection

Table 2: Demo 2 communication interfaces.

Demo 2 Interfaces		
CAN		
Working Frequency	*N/A*	*GHz*
Data Rate	*500*	*kbps*
Ethernet		
Working Frequency	*N/A*	*GHz*
Data Rate	*100*	*Mbps*
USB 2.0		
Working Frequency	*N/A*	*GHz*
Data Rate	*480*	*Mbps*
Bluetooth 4.0		
Working Frequency	*2.4*	*GHz*
Data Rate	*1 to 3*	*Mbps*
LTE		
Working Frequencies	*700, 800, 900, 1800, 2600*	*MHz*
Data Rate	*up to 326.4 (down)* *up to 86.3 (up)*	*Mbps*

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Demo 2 Interfaces		
802.11p		
Working Frequency	*5.9*	*GHz*
Data Rate	*6*	*Mbps*

Table 3: Demo 2 elaboration units.

Demo 2 Elaboration Units				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
E1	ROS PC	Linux based PC	Bosch	Object Fusion and Tracking, Data collection
E2	Measurement PC	Windows based PC	Bosch	Data collection
E3	Rapid Prototyping ECU	Vector/dSpace ECU	Bosch	open

2.3 Demo 3

Demo 3 develops advanced vehicle dynamics intervention functions to avoid or mitigate critical events. The demonstrator will include a vehicle with combined trajectory control algorithm for both emergency braking and steering (Bosch test vehicle).

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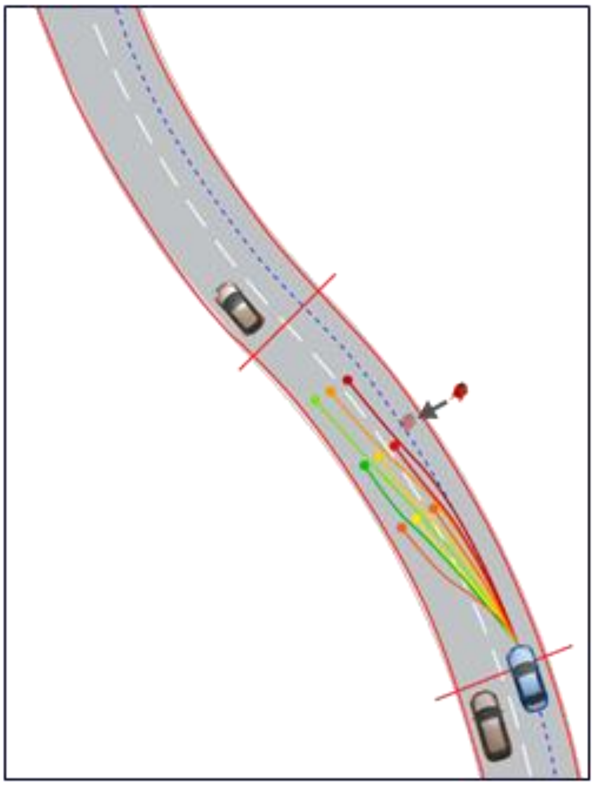

Figure 4: Demo 3 Emergency trajectory planning example (green lines show desirable trajectories, red trajectories are undesirable.).

For the emergency steering functionality, electronic power steering as well as differential braking and the combination of both will be investigated and compared regarding their accident avoidance potential in the defined scenarios.

In case of emergency, advanced intervention functions will be triggered to avoid critical events, including crash mitigation manoeuvres, enhanced emergency functions for crash avoidance (AES, AEB), and minimisation of the sidestep distance.

Demo 3 will show the target trajectory planning and trajectory control based on the detected objects. The verification results will define the time and precision limits of the trajectory generation as well as the trajectory control performance.

2.3.1 Architecture

2.3.1.1 Vehicle Physical architecture

The physical architecture of the Demo 3 vehicle is consisting of sensors, actuators and elaboration units.

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One front radar sensor with +/-55° field-of-view and two corner radar sensors with +/-75° field-of-view are combined with a mono video sensor with +/- 20.5° field-of-view to detect moving and stationary objects within and next to the vehicle's path.

The object information of each sensor is sent to a central driver assistance (DA) ECU, where the information of the different sensors is associated and fused.

A car PC and a rapid prototyping ECU are used as elaboration units for the developed Demo 3 algorithms to calculate emergency steering and braking requests that are sent to the braking and steering system.

The vehicle platform is a Bosch test vehicle, specifically used for Demo 3 within SAFE-UP different to the one deployed for Demo 2.

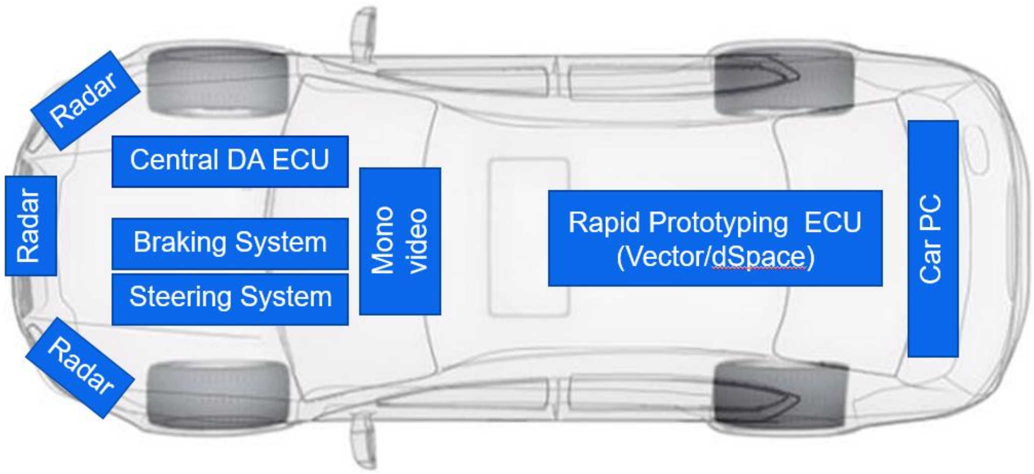

Figure 5: Demo 3 Vehicle physical architecture diagram.

2.3.1.2 Communication Architecture

Demo 3 communication architecture consists of a sensor CAN connecting all sensors with the central driver assistance ECU and a chassis CAN connecting the central driver assistance ECU with the braking and steering system.

For measurement and rapid prototyping purposes, all ECUs are connected to the car PC over Ethernet to enable internal signal access.

Actuation commands are directly sent from the car PC and the rapid prototyping ECU to the braking and steering system over the chassis CAN.

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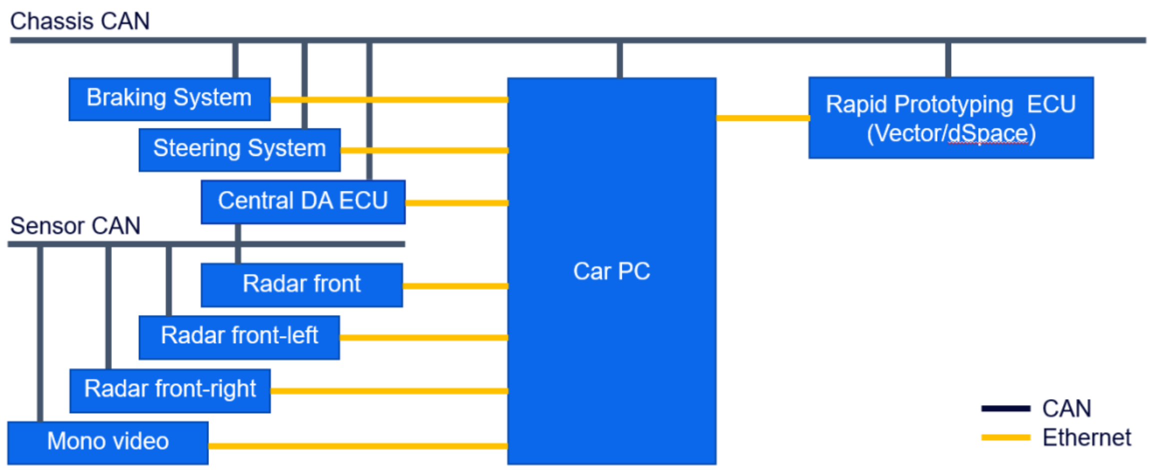

Figure 6: Demo 3 Communication architecture diagram.

2.3.1.3 Simulation Physical Architecture

The main goal of the simulation environment for Task 3.3 is to verify the integration of the software components. The software components will use the ROS2 (Robot Operating System 2) middleware for communication. The software components will run on the same platform as much as possible. Only the object fusion and tracking algorithm will run on a separate platform and communicate through a bridge with the rest of the system.

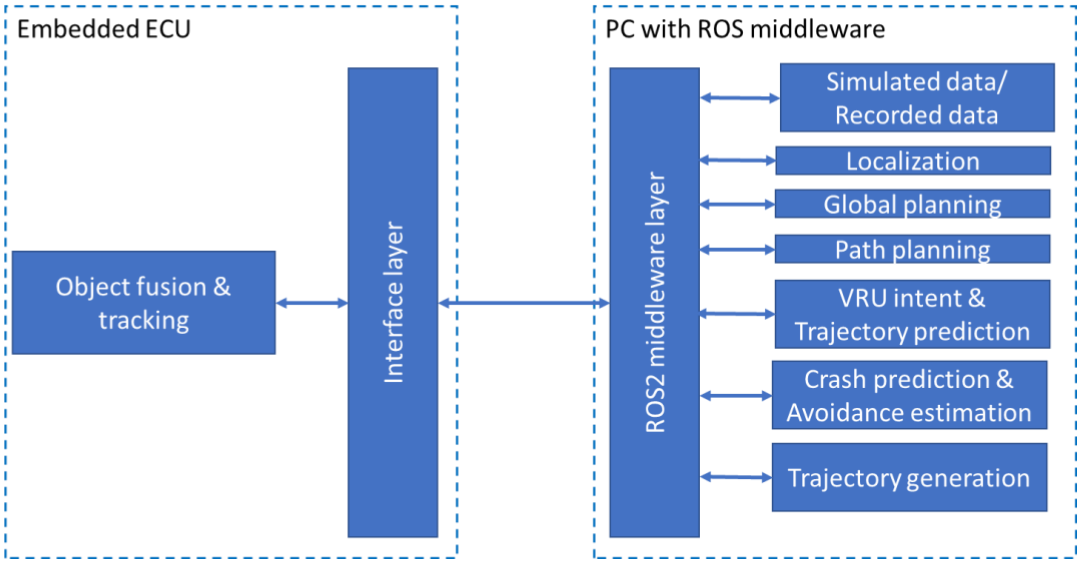

Figure 7: Demo 3 Physical layout of the simulation environment.

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2.3.1.4 Software Architecture

The general layout of Demo 3 software is summarised in Figure 8 below. This figure shows the main functionalities that are needed for the Demo. The arrows between the blocks indicate the information flow. In this figure, the main flow from sensor input to controller output is from left to right.

The sensor input (2) block processes the measurements coming from the vehicle sensors. The influence of weather conditions is calculated by the weather filter (3) which interacts with the sensor input. The object fusion and tracking (4) function provides tracked objects (e.g. VRUs) to the other functions that need this information. The VRU intent & trajectory prediction (6) predicts the intent and trajectory of VRUs.

The path planner (9) plans a path based on the predicted VRU trajectories and a global route, provided by the global planning (8). This global planning needs the current location of the vehicle, provided by the localization (5) module.

The trajectory generator (10) generates trajectories based on the planned path and the predicted VRU trajectories. The trajectories are evaluated on their risk for a collision, which is provided by the crash prediction and avoidance function (7). Finally, the vehicle control (11) generates the outputs to control the vehicle to follow the generated trajectory.

Note that the scenario selection & baseline simulation block (1) is not connected to any other block in Figure 8, as it is a supportive activity to T3.3 in order to define the actual scenarios and not a software module.

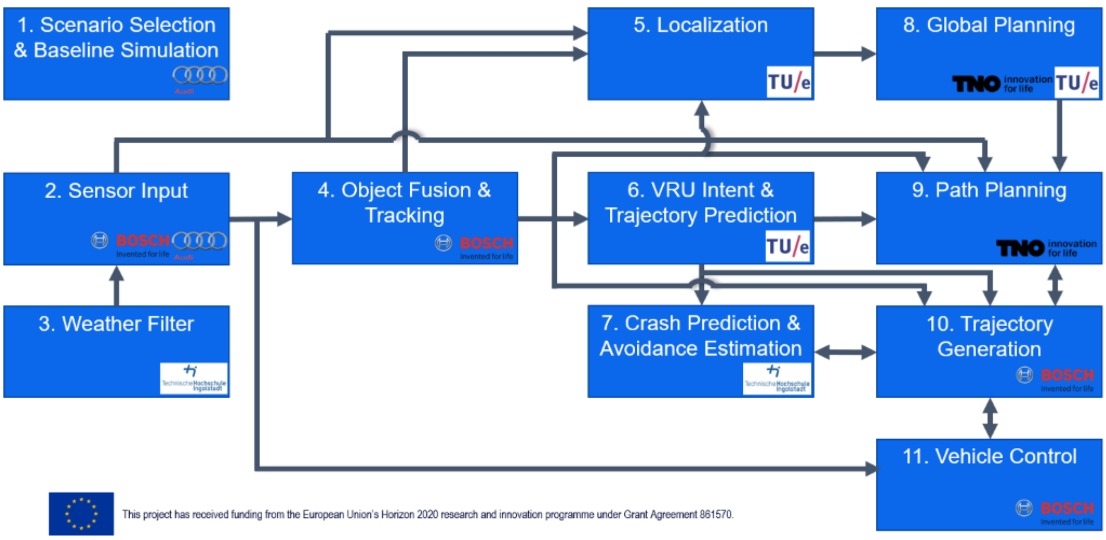

Figure 8: Demo 3 Software architecture diagram.

The software environment has two specific use-cases:

- Use in real-life environment, implemented on a distributed network of embedded platforms, interfacing with real sensors and actuators

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- Use in a simulated environment, interfacing with simulated sensors and actuators.

2.3.2 Technical Specifications

The technical specifications for Demo 3 are divided in two sections: a) vehicle technical specifications and b) software technical specifications and are presented in the following sub-sections separately. The detailed technical specifications tables are available in *Appendix C* of this document.

2.3.2.1 Vehicle modules

Tables 4-7 below consolidate the Demo 3 vehicle physical modules, actuators, interfaces and elaboration units respectively.

Table 4: Overview of Demo 3 vehicle physical modules.

Demo 3 Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M1	Front Radar Sensor	Radar Sensor	Bosch	Object Detection
M2	Left Corner Radar Sensor	Radar Sensor	Bosch	Object Detection
M3	Right Corner Radar Sensor	Radar Sensor	Bosch	Object Detection
M4	Front Video Sensor	Video Sensor	Bosch	Object Detection

Table 5: Demo 3 actuators.

Demo 3 Actuators				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
A1	Brake Booster + ESP	Braking System	Bosch	Trajectory Control
A2	Electronic Power Steering	Steering System	Bosch	Trajectory Control

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Table 6: Demo 3 communication interfaces.

Demo 3 Interfaces		
CAN		
Working Frequency	*N/A*	*GHz*
Data Rate	*500*	*kbps*
Ethernet		
Working Frequency	*N/A*	*GHz*
Data Rate	*100*	*Mbps*
USB 2.0		
Working Frequency	*N/A*	*GHz*
Data Rate	*480*	*Mbps*
Bluetooth 4.0		
Working Frequency	*2.4*	*GHz*
Data Rate	*1 to 3*	*Mbps*
LTE		
Working Frequencies	*700, 800, 900, 1800, 2600*	*MHz*
Data Rate	*up to 326.4 (down)* *up to 86.3 (up)*	*Mbps*
802.11p		
Working Frequency	*5.9*	*GHz*
Data Rate	*6*	*Mbps*

Table 7: Demo 3 elaboration units.

Elaboration Units				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
E1	Front Radar Sensor	Embedded ECU	Bosch	Object Detection
E2	Right Corner Radar Sensor	Embedded ECU	Bosch	Object Detection
E3	Left Corner Radar Sensor	Embedded ECU	Bosch	Object Detection

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Elaboration Units				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
E4	Front Video Sensor	Embedded ECU	Bosch	Object Detection
E5	Central DA ECU	Embedded ECU	Bosch	Object Fusion and Tracking
E6	ROS PC	Windows based PC	Bosch	All other Demo 3 modules
E7	Measurement PC	Windows based PC	Bosch	Parameter and Measurement Control of all embedded ECUs
E8	Rapid Prototyping ECU	Vector/ dSpace ECU	Bosch	open

2.3.2.2 Software modules

The specifications of the Demo 3 software modules are presented in the following Tables (Table 8 and Table 9). Module 1 (M1) of the software architecture diagram (see Figure 8) is not applicable to technical specifications (it is rather an input dataset), and therefore is not considered in the specification tables that follow.

Table 8: Overview of Demo 3 software modules.

Demo 3 Software Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M2	Sensor Input	Physical environment interaction with sensing equipment	Bosch & Audi	Object Detection
M3	Weather Filter	Real-time simulation of good and bad weather conditions	THI	Object Detection
M4	Object Fusion & Tracking	Sensor fusion	Bosch	Data fusion

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Demo 3 Software Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M5	Localisation	RTK GNSS based LDM	TU/e	Positioning
M6	VRU Intent & Trajectory Prediction	Calculate intent and/or trajectory of detected objects	TU/e	Object intent and prediction data
M7	Crash Prediction & Avoidance Estimation	Provide feedback on trajectories/ trajectory envelope on the ability to avoid a collision	THI	VRU intent & trajectory prediction
M8	Global Planning	Provide an optimal route from a starting point to a destination point	TNO & TU/e	Route planning
M9	Path Planning	plan a path (reference line) from the current vehicle position to a local goal on the global route	TNO	Path planning
M10	Trajectory Generation	Creating AES trajectory to avoid collisions	BOSCH	Trajectory Generation
M11	Vehicle Control	Translate trajectory to vehicle inputs	BOSCH	Trajectory Control

Because we use ROS2 as a middleware, all communication between the software blocks mentioned above is done via ROS2 topics. The table below shows all interfaces between the software modules.

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Table 9: Demo 3 software interfaces.

Demo 3 Software Interfaces		
From function	**To function**	**Type of information**
2. Sensor input	4. Object Fusion & Tracking	Object data + host data
3. Weather Filter	2. Sensor Input	Effect of simulated weather on sensor object data
4. Object Fusion & Tracking	6. VRU Intent & Trajectory Prediction	Object data + host data
4. Object Fusion & Tracking	9. Path Planning	Object data + host data
4. Object Fusion & Tracking	10. Trajectory Generation	Object data + host data
6. VRU Intent & Trajectory Prediction	7. Crash Prediction & Avoidance Estimation	Object intent and object trajectory prediction
6. VRU Intent & Trajectory Prediction	9. Path Planning	Object intent and object trajectory prediction
6. VRU Intent & Trajectory Prediction	10. Trajectory Generation	Object intent and object trajectory prediction
5. Localization	8. Global Planning	Host data
8. Global Planning	9. Path Planning	Semantic map data
9. Path Planning	10. Trajectory Generation	Path data
10. Trajectory Generation	9. Path Planning	Path infeasible feedback
10. Trajectory Generation	11. Vehicle Control	Trajectory data
2. Sensor input	5. Localization	Object data + host data
4. Object Fusion & Tracking	5. Localization	Host data
7. Crash Prediction & Avoidance Estimation	10. Trajectory Generation	Avoidance estimation data
2. Sensor input	9. Path Planning	Lane marking data
8. Global Planning	9. Path Planning	global route data
2. Sensor input	11. Vehicle Control	Vehicle state data
2. Sensor input	11. Vehicle Control	Driver state data

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2.4 Demo 4

Demo 4 develops a VRU safety system based on V2X technology that provides enhanced communication between vehicles, road infrastructure (RSU installed on traffic light) 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 both the equipped V2X vehicles and the infrastructure RSU, whereas the non-connected VRUs are monitored by the RSU that exchanges direct messages with the equipped V2X vehicles.

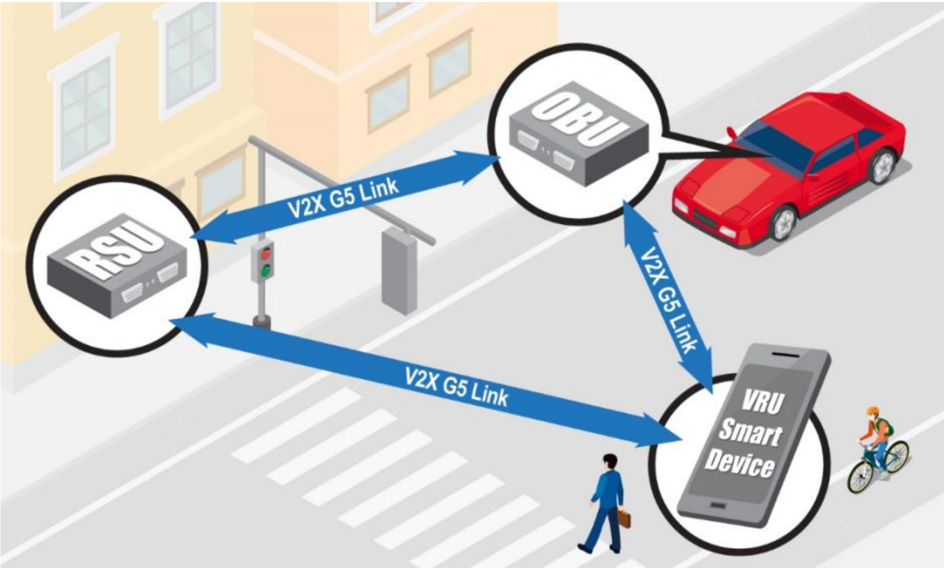

Figure 9: SAFE-UP Demo 4 overview.

The system deploys effective on-time warning messages on critical situations to both drivers and connected VRUs. For the drivers, the warning messages are delivered via in-vehicle display and audio elements, whereas for 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 increase its efficiency in certain scenarios in combination with V2X technology, since perception sensors data and V2X information will feed the AEB system in order to be engaged on-time and to perform a smoother stopping manoeuvre in occlusion situations

2.4.1 Architecture

Demo 4 consists of three main components:

- Vehicle equipped with V2X technology

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- Road-side unit: Infrastructure component equipped with sensors that detect traffic participants (vehicles and VRUs), in addition to V2X technology.
- VRU system equipped with V2X technology

The main architecture of Demo 4 is the communication architecture, presented in Figure 10 below. The physical architecture for each of the three main components mentioned above is presented in Figure 11 , Figure 12 and Figure 13 respectively.

2.4.1.1 Communication Architecture

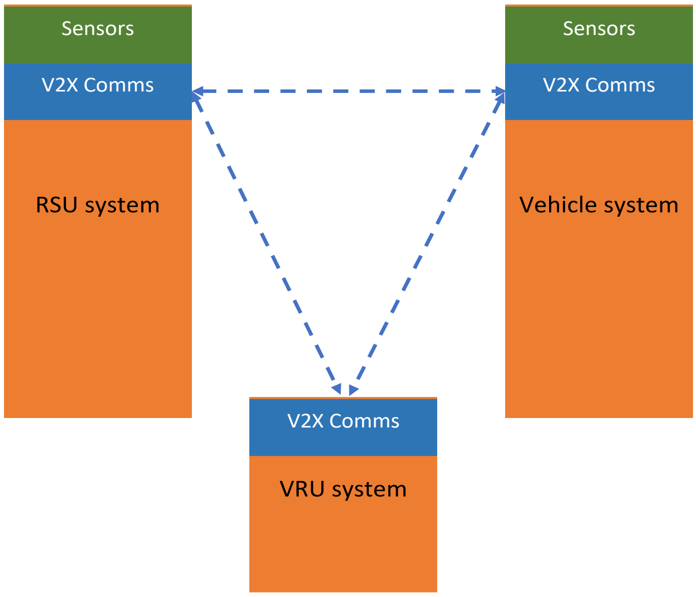

Figure 10: Demo 4 Communication architecture diagram.

The diagram above shows the relationship between all Demo 4 entities involved in high level. At the same time, each component's architecture (vehicle, RSU and VRU) are presented below. For this general communications architecture, RSU and VRU systems communicate with the vehicle via V2X. The information from sensors and V2X will be fused and, as a result, a list of targets/objects will be given. These targets are analysed to detect dangerous situations involving VRUs and the vehicle, and design a way to avoid or minimize them. Additional communications between the components are optional but technically feasible, which gives flexibility in case new communications are required.

2.4.1.2 Vehicle Physical Architecture

Figure 11 presents the vehicle physical architecture. The first diagram displays the position of each component on the vehicle, whereas the second diagram presents the interfaces between those components. The vehicle platform is a Toyota test vehicle (Lexus IS), whereas an IDIADA test vehicle will be used during the development phase as well.

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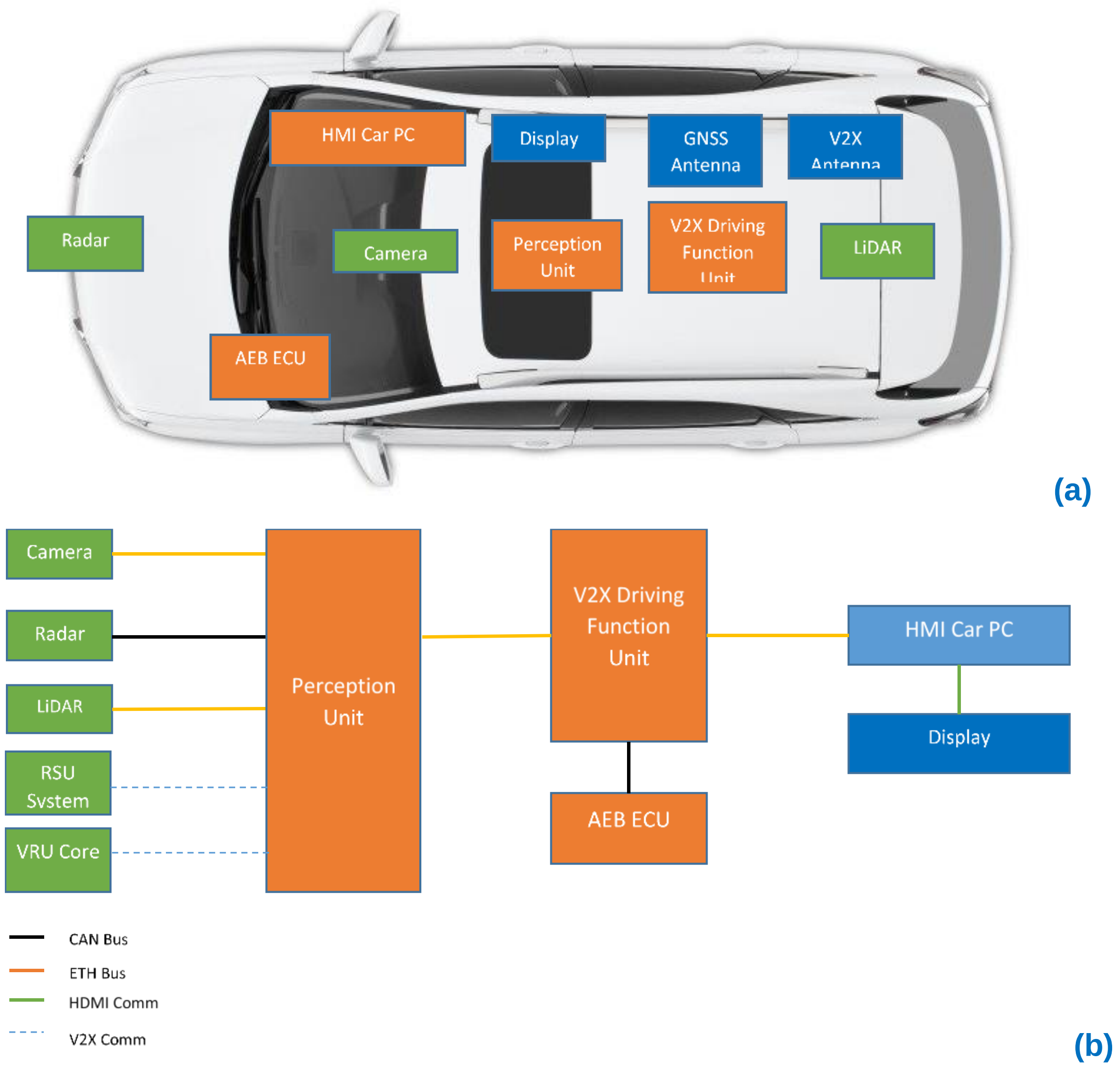

Figure 11: Demo 4 Vehicle physical architecture diagrams; (a) components' position on the vehicle, (b) components' interfaces.

The vehicle architecture is composed by the following components:

- Radar: Sensor able to detect static and dynamic objects. They usually have between ±15 and ± 60 degrees width and long-range detection.
- LiDAR: Sensor able to give information in 3D (distance, position and height). Range is limited in bad weather conditions like fog, since the measurements are light-based.
- Camera: It has a limited vision and it is very sensible to the conditions (light, fog, etc.)
- Perception Unit: Device able to decode the sensors and V2X data (from the V2X Antenna) and perform a data fusion to extract the detected objects list.

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- V2X Driving Function Unit: This component takes the output of the Perception Unit to analyse the situation between the ego vehicle position (from GNSS Antenna) and dynamics (from CAN bus) and the detected objects.
- AEB ECU: Admits control orders to make the device react as desired to avoid or minimize a dangerous situation.
- HMI Car PC: Computer able to build HMI messages to be shown to the drivers via the Display
- Display: Screen where alerts and information are shown to the driver.
- GNSS Antenna: Antenna used to position the vehicle.
- V2X Antenna: Antenna used to receive and send V2X data.

2.4.1.3 RSU Physical Architecture

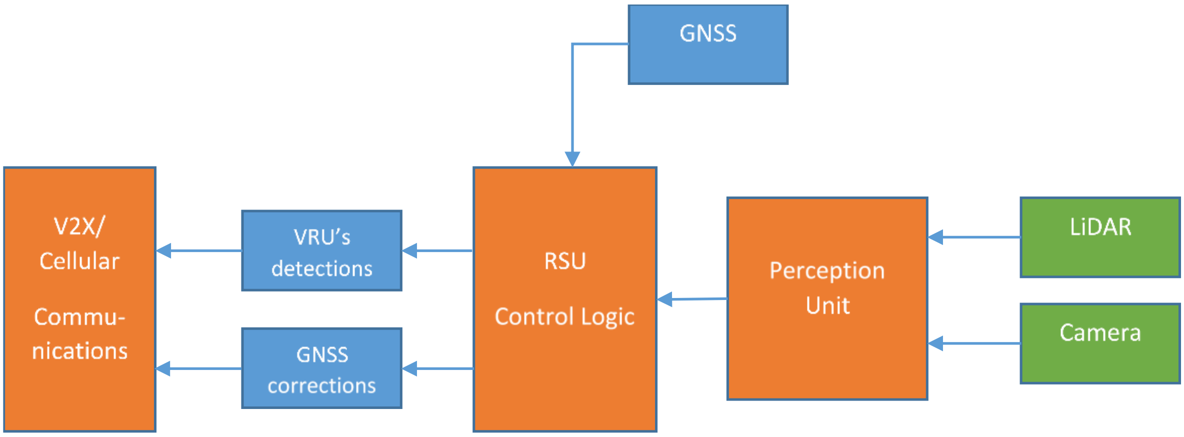

Figure 12: Demo 4 RSU physical architecture diagram.

The RSU architecture is very similar to the vehicle architecture. The main difference is that received V2X data is not processed and used for perception. Therefore, the sensors data (LiDAR and Camera) are fused in the Perception Unit, which generates a list of detected objects that are passed to the RSU Control Logic to generate the V2X messaging for alerting about VRU presence to nearby vehicles. Also, GNSS corrections might be sent via V2X to correct and improve VRUs positioning.

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2.4.1.4 VRU Physical Architecture

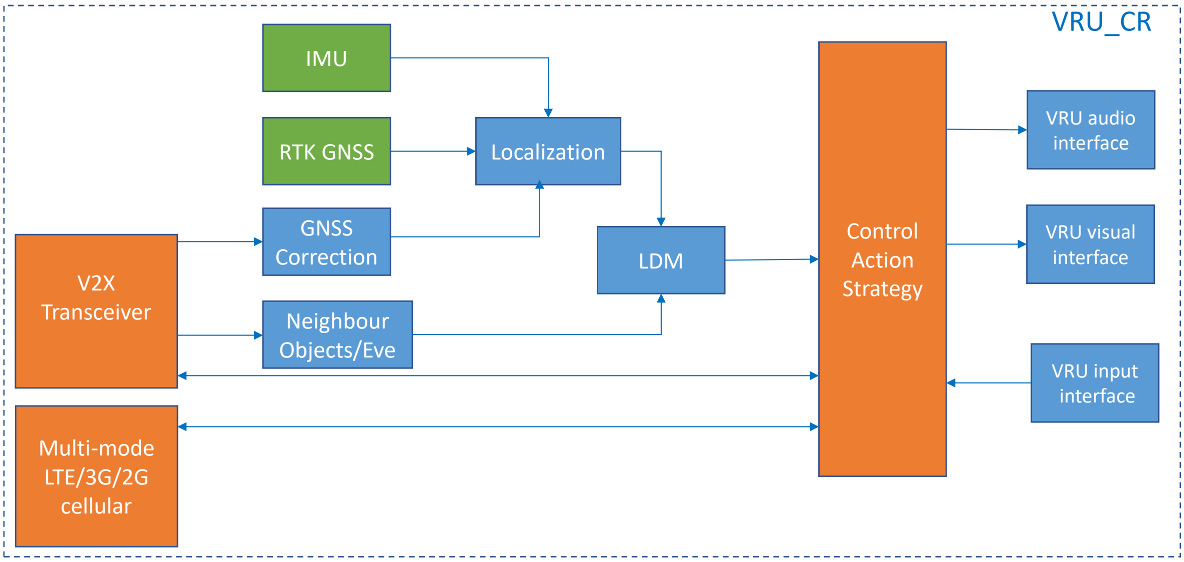

Figure 13: Demo 4 VRU core physical architecture diagram.

Figure 13 above presents the high level architecture of the VRU system, one of the three main components in Demo 4, the other two being the RSU and the vehicle components respectively. This device will be developed as a prototype for the purposes of Demo 4, in order to be used by the connected VRUs (pedestrians and cyclists) and exchange direct C-ITS G5 messages with the vehicle and the RSU, as well as provide warnings to the VRUs in critical situations. This prototype development is essential as current market smart phones do not integrate V2X technology.

VRU Core is therefore the host device of all hardware modules and software components that will realize the VRU system. V2X transceiver and multi-mode LTE/3G/2G cellular will implement C-ITS G5 short-range and any necessary long-range communications respectively. The RTK GNSS and IMU hardware modules together with the incoming GNSS corrections (via RTCMEM messages) will provide the necessary high precision device localization. The VRU device will operate as any conventional V2X device and will transmit its own awareness information (CAM messages). Based on the reception of common awareness and notification messages transmitted by the other actors of Demo 4, a Local Dynamic Map will be sustained keeping track of the incoming objects and events in the neighbourhood area. Visual and acoustic interfaces will be used to warn the VRUs (pedestrians and cyclists) via their smart device, whereas haptic warnings will be also explored via Bluetooth connection with a smartwatch haptic interface. Control action strategy is the core software running on the core's host processor. It will be responsible for the main VRU application and the decision for the warning messages to the VRU user.

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2.4.2 Technical Specifications

2.4.2.1 Demo 4 Physical modules

Demo 4 modules and sensors are consolidated in Table 10 below. The detailed technical specifications for each of those modules is available in *Appendix D* of this document (can be also assessed directly via hyperlink).

Table 10: Overview of Demo 4 physical modules.

Demo 4 Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M1	V2X Driving Function Unit	all in one Device for prototyping	IDIADA	Vehicle
M2	Perception Unit	Combined perception module with data received by the vehicle, RSU and VRU core	IDIADA	Vehicle
M3	Camera Vehicle	CMOS camera for VRU detection	IDIADA	Vehicle
M4	LiDAR Vehicle	Vehicle LiDAR sensor	IDIADA	Vehicle
M5	Radar Vehicle	Vehicle radar sensor	IDIADA	Vehicle
M6	Camera RSU	CMOS camera for VRU detection	IDIADA	RSU
M7	LiDAR RSU	RSU LiDAR sensor	IDIADA	RSU
M8	Radar RSU	RSU radar sensor	IDIADA	RSU

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Demo 4 Modules/ Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
M9	VRU Core	VRU device motherboard, CPU core and on-board memory	CERTH/ HIT	VRU_CR
M10	V2X Transceiver	Embedded transceiver for the development of V2X communications	CERTH/ HIT	VRU_CR
M11	Multi-mode LTE/3G/2G cellular	4G LTE/3G/2G multimode module for cellular communications	CERTH/ HIT	VRU_CR
M12	RTK GNSS	High performance positioning engine with RTK technology	CERTH/ HIT	VRU_CR
M13	IMU	Triaxial accelerometer, gyroscope and geomagnetic sensor with embedded fusion software	CERTH/ HIT	VRU_CR

2.4.2.2 Demo 4 HMI Modules

In Demo 4, warnings may be provided both to the driver and the connected pedestrians/ cyclists depending on the scenario in focus. In order to deliver the warning messages, HMI modules are deployed for the vehicle (display and audio), as well as on the VRU smart device (visual and auditory). Table 11 below summarises the relevant HMI modules.

Table 11: Demo 4 HMI modules.

Demo 4 HMI modules				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
HMI1	HMI Car PC visual & audio	In-vehicle Display & car speakers	IDIADA	Driver warning
HMI2	VRU Visual interface	Display MIPI, 1280x720 resolution, 16M colours	CERTH / HIT	VRU warnings
HMI3	VRU input interface	Touch Screen multipoint capacity	CERTH / HIT	VRU actions

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HMI4	VRU audio interface	Low power stereo codec audio for headset	CERTH / HIT	VRU warnings

2.4.2.3 Demo 4 Interfaces

Demo 4 communication interfaces are presented in Table 12 below. Main communication interface is the V2X 802.11p communication, whereas supporting communications encompass LTE, Ethernet, USB and Bluetooth SotA technologies.

Table 12: Demo 4 communication interfaces.

Demo 4 Interfaces		
LTE (Cat 4)		
Working Frequencies	*800, 850, 900, 1800, 2100, 2600*	*MHz*
Data Rate	*up to 150 (DL)* *up to 50 (UL)*	*Mbps*
802.11p		
Working Frequency	*5.9*	*GHz*
Data Rate	*6*	*Mbps*
CAN		
Working Frequency	*N/A*	*GHz*
Data Rate	*500*	*kbps*
Ethernet		
Working Frequency	*N/A*	*GHz*
Data Rate	*100*	*Mbps*
USB 2.0		
Working Frequency	*N/A*	*GHz*
Data Rate	*480*	*Mbps*
Bluetooth 4.0		
Working Frequency	*2.4*	*GHz*
Data Rate	*1 to 3*	*Mbps*

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3. A-priori Risk Assessment

The lifecycle of a system/service is depicted in the following scheme. There are 6 main phases for an innovation that is developed within the framework of a research projects, while there are two more when dealing with a marketable product.

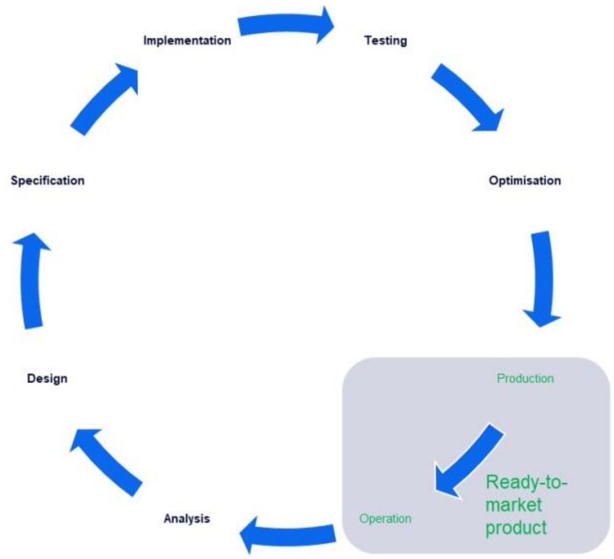

Figure 14: Product development lifecycle.

In principle, every new technological achievement might present some form of malfunctions or errors, especially during the initial analysis, design and specification phases. Moreover, in scientifically complex projects involving several institutions in various countries, it is unavoidable that problems occasionally occur. This is even more evident, in cases of highly innovative, high-risk, and complex projects that are characterised by strong interdependence among tasks and deliverables, as is the case of SAFE-UP. However, these problems can be overcome if they are detected at an early stage. It is therefore imperative that an effort be made to identify in advance and assess potential risks, and that the Consortium is prepared for contingency actions, when required. The SAFE-UP system possible malfunctions may be due to the following reasons:

- system or sub-system error or compatibility problems, or design flaws,
- inappropriate use by the users (thus, relating with the HMI),
- organisational barriers and/or
- legal restrictions

For the first case, the SAFE-UP demos developers need to put more effort and fix the possible problems, while for the second one, the users personal limits is the main concern,

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and an – as much as possible – easy-to-use system/service has to be developed. The third one refers to the structure of the involved companies or stakeholders and how it is affected, while the last case requires system adaptation to local, national or international law or standardisation activities.

Risks can be avoided, transferred, mitigated, or else accepted. The results of the Risk analysis must be comparable and mainly must be presented in an understandable and comprehensive format. Such an analysis involves various factors of each safety-security issue: severity, occurrence probability, detectability and recoverability, not only for technical risks, but also for behavioural, legal and organizational related risks. Summarising, the four risks categories are explained as follows:

- **Technical and interoperability** - dealing with the system or its sub-elements/ modules (hardware and software) functionalities, their (future) technological limitations and possible failures or complications (interoperability issues) with other components; these are related to the technical maturity of the solution.
- **Behavioural** – related to HMI and human error, i.e. the user's behaviour, regarding their interaction with the system, concentrating on the possible unexpected /erroneous actions.
- **Legal** - in relation to the possible legislative compliance or conflicts in various EU countries where the system is planned to be introduced.
- **Organisational/operational** - risks involved within the organization structure of the involved actors and stakeholders companies of the SAFE-UP ecosystem or the road automation sector, their current procedures, shift of work times, etc.

Although the risks categories are clear, many of these risks are intricately and inherently interrelated to one another.

In SAFE-UP, the risks analysis work will take place in two phases:

- Phase 1: estimation of a *priori/foreseen risks*, along with mitigation/alternative solutions.
- Phase 2: *a posteriori risks* analysis, in order to identify *actual & unforeseen risks* that occurred after the project developments and examine the compensation solutions that were applied.

It has to be noted that risks related to the project execution (e.g. partners problems, delays, payments, etc.) are not part of WP3 and thus of the current deliverable; such risks are handled within the project management WP.

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3.1 Methodology

A risk analysis must follow an effective and clear stepwise procedure in order to be successful. Within the WP3 of the SAFE-UP project, we will follow the Failure Modes, Effects and Criticality Analysis (FMEA / FMECA), in order to identify the potential system risks and also propose adequate mitigation solutions. More specifically, the extended FMEA methodology has been applied here, developed within the ADVISORS project (Bekiaris & Stevens 2005), which is based on FMEA, but includes the indicators of *hazard consequence severity, occurrence probability, detectability* and *recoverability*, and extends the typical FMEA methodology by covering not only technical risks, as done in FMEA, but also behavioural, legal and organisational – related risks.

The Failure Mode and Effects Analysis (FMEA) is a methodology designed to:

- Identify potential failure modes for a product service or process.
- Assess the risk associated with those failure modes and prioritize issues for corrective actions.
- Identify and carry out corrective actions to address the most serious concerns.

There are many ways that FMEAs help with Risk Management (https://fmea-training.com):

1. They start by providing a framework to develop a comprehensive identification of potential risks.
2. They assist with evaluation of those risks in terms of how severe they could be, their likelihood of occurring and the chance the potential failure has to be detected before failure.
3. They are a tool to decide which risks are the most serious.
4. They help point to ways to reduce the most serious risks.
5. They enable re-evaluation to determine if the risk has been sufficiently reduced or if more work needs to be done.

The FMEA or FMECA procedure is a flexible tool that has been adapted for different purposes, covering the design and development phases for products, services and processes, resulting in higher reliability, better quality, increased safety, enhanced customer satisfaction and reduced costs. An FMEA or FMECA is often required to comply with safety and quality requirements, such as ISO 9001, QS 9000, ISO/TS 16949, Six Sigma, FDA Good Manufacturing Practices (GMPs), Process Safety Management Act (PSM), etc. The overall process proposed by the extended FMEA methodology is summarised in Figure 15 below. As mentioned earlier, it includes different types of risks (technical, behavioural, legal and organizational/ operational); some of these risks may be interrelated, meaning that one can affect or even produce the other. As it is depicted below, FMEA is only the first part of the process which deals with technical and interoperability related risks, while the rest of the boxes are part of the extended FMEA methodology.

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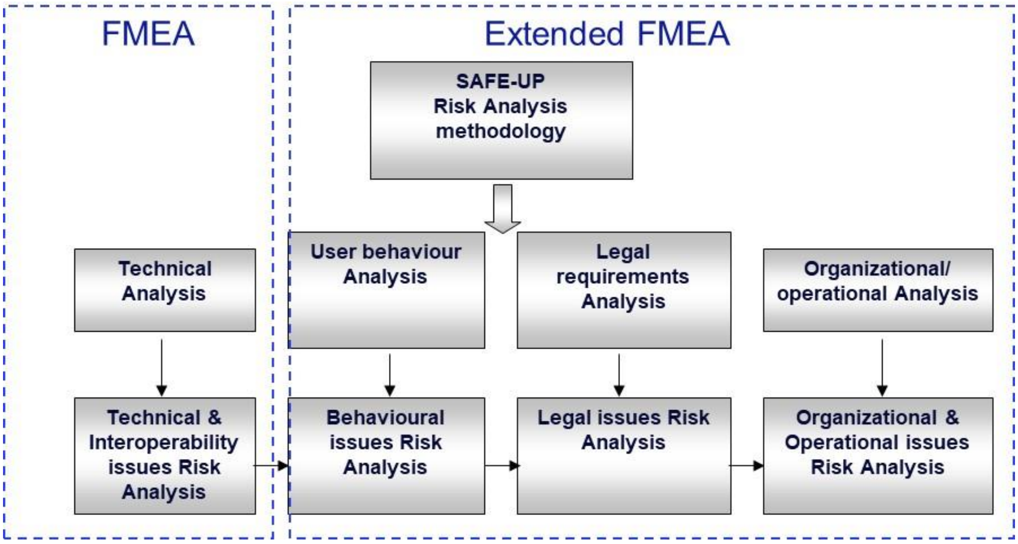

Figure 15: Risk analysis process.

The Risk number (for each risk) is calculated using the following equation:

$$RN = S \times O \times \frac{D+R}{2} \quad (1)$$

Where:

S=Severity

O=Occurrence probability

D=Detectabilty

R=Recoverability

Each of the above factors is measured based on the tables below. The table explain the levels of severity, occurrence, detectability and recoverability for each type of risk.

Table 13: Severity level analysis.

Level of severity	Technical issue	Behavioural issue	Legal issues	Organizational issues
9-10 (extremely severe)	The failure could put user safety at risk.	The user error in operating the system could lead to an incident worseness (i.e. safety effects).	Are there laws in each country that do not allow the system to be implemented?	Wide and different organizational framework is needed, that is completely missing (i.e. new services).

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Level of severity	Technical issue	Behavioural issue	Legal issues	Organizational issues
7-8 **(severe)**	The failure implies the total loss of the system functions, resulting in user's dissatisfaction.	User behavioural error may abort the system benefits (i.e. safety effects due to changes in ways of acquiring info).	New laws are required for system implementation and no relevant work has been performed yet.	Organizational framework adaptation is needed (some initial actions have been taken on this domain).
5-6 **(slightly severe)**	The failure implies the partial loss of the system function, resulting in user's dissatisfaction.	User's behavioural changes may significantly reduce the positive effects of the system.	New laws are required for system implementation and work required has already been performed.	Organizational framework adaptation is needed which has already started being realized.
3-4 **(significant)**	The failure implies slight dissatisfaction to the user.	User's behavioural changes may somehow influence the positive effects of the system.	New laws are required for system implementation but consensus on them exist.	There is a need for limited and easily realized organizational changes.
1-2 **(insignificant)**	The failure does not imply perceptible effects to the system function and to the user's satisfaction.	User's behaviour is not expected to reduce the system benefits significantly, or may even further enhance them.	No new laws are required for implementation.	There is no need at all for organizational changes.

Table 14: Occurrence level analysis.

Occurrence level	Technical issue	Behavioural issue	Legal issues	Organisational issue
9-10 **(high)**	It is certain that some failures will sometimes occur.	It is certain that some behavioural effects will occur (by the system users).	It is certain that some legal problems will occur.	It is certain that there will be a need for organizational restructuring.

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Occurrence level	Technical issue	Behavioural issue	Legal issues	Organisational issue
6-8 (medium)	A failure could occasionally occur.	Some behavioural effects could occasionally occur.	Some legal problems could occasionally occur.	A need for organizational restructuring could occasionally occur (depending on the needs of the service that will arise after the operation of the system).
3-5 (slight)	There is only a slight probability that an error/failure will occur.	There is only a slight probability that some behavioural effects will occur.	There is only a slight probability that some legal problems will occur.	There is only a slight probability that a need for organizational restructuring will occur.
1-2 (improbable)	It is unlikely that a fault will occur.	It is unlikely that some behavioural effects will occur.	It is unlikely that some legal problems will occur.	It is unlikely that a need for organizational restructuring will occur.

Table 15: Detectability level analysis.

Detectability level	Technical issue	Behavioural issue	Legal issue	Organisational issue
9-10 (improbable)	It is impossible or improbable that a problematic area will be detected.	It is impossible or improbable that a user's behavioural effect will be detected.	It is impossible or improbable that a legal problem will be detected.	It is impossible or improbable that an organizational problem will be detected.
7-8 (slight)	The problematic area is detected only in particular cases.	The user's behavioural effect is detected only in particular cases.	The legal problem is detected only in particular cases.	The organizational problem is detected only in particular cases.
5-6 (moderate)	It is probable that the problem will be	It is probable that the user's behavioural	It is probable that the legal	It is probable that the organizational

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Detectability level	Technical issue	Behavioural issue	Legal issue	Organisational issue
	detected (depending on the situation).	effect will be detected.	problem will be detected.	problem will be detected.
3-4 (high)	It is very probable that a problem will be detected.	It is very probable that the user's behavioural effect will be detected.	It is very probable that the legal problem will be detected.	It is very probable that the organizational problem will be detected.
1-2 (very high)	It is certain that a problem will be detected.	It is certain that the user's behavioural effect will be detected.	It is certain that the legal problem will be detected.	It is certain that the organizational problem will be detected.

Table 16: Recoverability level analysis.

Recoverability level	Technical issue	Behavioural issue	Legal issues	Organisational issues
9-10 (null)	No recovery action is provided.	System is inflexible to user's behavioural effects.	System is either accepted or rejected by the legal framework.	System requires a fixed organizational environment to operate.
6-8 (low)	The user is only advised on the failure.	Behavioural effects are taken into account by the system.	System may be slightly adapted to meet legal restrictions.	System requires a fixed organizational framework with limited adaptations.
3-5 (high)	Effective recovery action is provided.	System customization might compensate for user's behavioural effects.	System encompasses different versions to meet particular legal demands.	System may operate within various organizational frameworks.
1-2 (full recoverability)	The failure effect is completely avoided by the	System does not allow user's behavioural effects.	System is easily reconfigurable	System does not require organizational changes.

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Recoverability level	Technical issue	Behavioural issue	Legal issues	Organisational issues
	recovery action.		to meet legal demands.	

3.1.1 Risks severity and mitigation possibility

The total risk that will be calculated has been matched to five levels of severity (and then added in the 'Problem severity" column of the above table), as follows:

Table 17: Correlation of the Risk Number with the overall risk Severity level.

Overall risk factor	Overall severity
512-1000	I- Extremely severe
216-512	II- Severe
64-216	III - Moderate
8-64	IV - Slight
1-8	V - Insignificant

Then, according to the severity level, the mitigation possibility can be defined as follows. This indicates the possibility of a successful corrective strategy (over a 10 year horizon).

Table 18: Severity and mitigation possibility scales.

Risk/issue severity	Mitigation possibility
Extremely severe	
Severe	High
Moderate	Medium
Slight	Low
Insignificant	Improbable

Risk reduction is an iterative process involving dependencies between the different issues. In terms of mitigation strategies, a risk can be reduced in a number of generic ways:

- reducing the magnitude (severity) of the consequences of the potential risk;
- reducing the probability occurrence of the risk;
- increasing risk detection speed and probability;

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- protecting against the risk - countermeasures to compensate for a failure (e.g. back-up solutions).

The exact definitions of what is actually meant by the mitigation possibility are given below, according to the different levels of possibility.

Table 19: Failure mitigation possibility levels and their definition

Possibility of mitigation (10 year horizon)	Definition
High	A solution is available at relatively little cost.
Medium	An achievable solution may be possible at reasonable cost, or a reasonable solution is available at modest cost.
Low	An expensive solution may be possible, but system benefits may not justify these, and/or a solution needs further investigation or is highly complicated.
Improbable	Solutions are too expensive (likely to remain so) in relation to the reduction of risk(s) and the benefits gained from the functionality of the system, and/or a solution is not available for the (extremely) severe risk that has been identified

3.1.2 Risks analysis template

In order for the results of the Risk analysis to be comparable and mainly presented in an understandable and comprehensive format, a dedicated excel template was created and distributed to the WP3 partners involved in the development of Demos 2, 3 and 4 that identify potential risks that fall in any of the four risks types explained above. With it, the main risks identified were summarised according to the following common format and assigned to an overall risk rating, based on which the risk severity and mitigation possibility was defined.

Table 20: Detailed Risk analysis template, including mitigation strategy.

Risk type* (select one)	Problem short description *	S*	O*	D*	R*	Risk Number	Risk severity	Relevant Architecture Component	Mitigation strategy*	Mitigation possibility
❑Technical ❑Behavioural ❑Legal ❑Organis.								•	•	
…								•	•	

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*Mandatory field

3.2 Results

The template presented above was used to gather the risks/problems identified in the initial stage of the project and before the system has been developed and tested. Input has been provided by the partners working on Demos 2, 3 and 4.

Overall, 71 risks have been gathered during the first phase of the risk analysis task, which are divided per Demo and are presented in the following table. As it can be seen, there are few risks that are common for Demos 2 and 3, and thus are presented separately.

Table 21: Number of potential risks gathered per WP3 Demo and severity level.

Demos	**2**	**3**	**2 & 3**	**4**
Severity level				
Extremely severe		3		
Severe	1	13	4	6
Moderate	2	2	4	14
Slight				21
Insignificant				1
Total	**3**	**18**	**8**	**42**

The risks gathered are presented below per Demo. For each problem, the calculated risk magnitude is provided, as well as the severity level and the mitigation solution proposed.

Table 22: Demo 2 potential risks.

Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Technical issue	Failure related to test hall (rain and fog)	2	7	4	1	5	84	III - Moderate	[THI Test Hall]	Thoroughly and regularly check the Test Hall's state, especially before measurement campaigns
Organisational issue	Available test hall days insufficient for desired maturity level of system	2	5	5	7	8	187,5	III - Moderate	-	Plan additional optional back-up test days

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Organisational issue	Short term test hall availability	2	5	7	7	8	262,5	II - Severe	-	- Thoroughly plan all test hall related activities - Plan additional optional back-up test days

Table 23: Demo 3 potential risks.

Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Technical issue	No activation of AEB/AES avoidance due to failure or insufficient quality of processing algorithm leads to crash w/ VRU dummy	3	8	10	8	10	720	I - Extremely Severe	Sensor Input, Object Fusion & Tracking, VRU Intent & Trajectory Prediction, Crash Prediction & Avoidance Estimation, Path Planning, Trajectory Generation, Vehicle Control	- Add anomaly detection - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	False positive activation of AEB/AES avoidance manoeuvre due to failure or insufficient quality of target object detection leads to loss of vehicle control	3	10	5	10	10	500	II - Severe	Sensor Input, Object Fusion & Tracking, VRU Intent & Trajectory Prediction, Crash Prediction & Avoidance Estimation	- Add anomaly detection - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data - add additional measures: emergency shut-off button, limited intervention intensity, only trained drivers
Technical issue	Activation of AEB/AES avoidance	3	8	10	8	10	720	I - Extremely Severe	Sensor Input, Object	- Add anomaly detection - Define unit

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	manoeuvre w/ failure or insufficient quality of processing algorithm leads to crash w/ VRU dummy								Fusion & Tracking, VRU Intent & Trajectory Prediction, Crash Prediction & Avoidance Estimation, Path Planning, Trajectory Generation, Vehicle Control	tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Activation of AEB/AES avoidance manoeuvre leads to crash w/ VRU dummy due to driver intervention	3	8	8	10	10	640	I - Extremely Severe	Vehicle Control	Develop HMI measures to motivate the driver to follow the steering intervention: visual/acoustic warning, directional steering recommendation
Technical issue	Activation of AEB/AES avoidance manoeuvre leads to loss of vehicle control due to driver intervention	3	10	5	10	10	500	II - Severe	Vehicle Control	Add additional measures: emergency shut-off button, limited intervention intensity, only trained drivers
Technical issue	Failure of computing platform (Rapid prototyping ECU), leading to no control inputs to the vehicle	3	9	3	9	9	243	II - Severe	Elaboration Units E1, E5, E6, E8 Front Radar Sensor Central DA ECU ROS PC Rapid Control ECU	- Add redundant hardware to monitor the health of the computing platforms - Warn the driver to take over control (for eventual application) - Use experienced test drivers (during test phase) - Add redundant hardware to

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
										take over control (e.g. limp home function or minimal safety fall-back)
Technical issue	Wrong output of object fusion and tracking because of computation error, leading to wrong control inputs	3	8	4	8	7	240	II - Severe	Object fusion and tracking	- Add anomaly detection in the object fusion and tracking algorithm - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Delayed output of object fusion and tracking , because of high computational load, leading to late reaction	3	8	4	8	9	272	II - Severe	Object fusion and tracking	- Thoroughly test the algorithm using data/ simulation - ensure enough computing power is available - Continuously monitor the CPU load and warn the driver when the CPU load is too high
Technical issue	Wrong output of VRU intent and trajectory prediction, leading to wrong control inputs	3	8	4	8	7	240	II - Severe	VRU Intent & Trajectory Prediction	- Add anomaly detection - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Late output of VRU intent and trajectory prediction, leading to late control inputs	3	8	4	8	9	272	II - Severe	VRU Intent & Trajectory Prediction	- Thoroughly test the algorithm using data/simulation - Ensure enough computing power is available - Continuously monitor the CPU load and

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
										warn the driver when the CPU load is too high
Technical issue	Wrong output of Localization algorithm, leading to wrong control inputs	3	8	4	8	7	240	II - Severe	Localization	- Add anomaly detection - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Late output of Localization algorithm, leading to late control inputs	3	8	4	8	9	272	II - Severe	Localization	- Thoroughly test the algorithm using data/simulation - Ensure enough computing power is available - Continuously monitor the CPU load and warn the driver when the CPU load is too high
Technical issue	Wrong output of path planning algorithm, leading to wrong control inputs	3	8	4	8	7	240	II - Severe	Path Planning	- Add anomaly detection - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Late output of path planning algorithm, leading to late control inputs	3	8	4	8	9	272	II - Severe	Path Planning	- Thoroughly test the algorithm using data/simulation - Ensure enough computing power is available - Continuously monitor the CPU load and warn the driver when the CPU load is too high
Technical issue	Wrong output of trajectory generation algorithm, leading	3	8	4	8	7	240	II - Severe	Trajectory Generation	- Add anomaly detection - Define unit tests incl. edge

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	to wrong control inputs									cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Late output of trajectory generation algorithm, leading to late control inputs	3	8	4	8	9	272	II - Severe	Trajectory Generation	- Thoroughly test the algorithm using data/simulation - Ensure enough computing power is available - Continuously monitor the CPU load and warn the driver when the CPU load is too high
Behavioural issue	The user may (unconsciously) try to override the steering action by the system	3	8	6	3	3	144	III - Moderate	N.A. (driver)	- Training/ education of the driver - Include haptic feedback in the steering system
Behavioural issue	The user could disable the functionality	3	7	5	1	9	175	III - Moderate	N.A. (driver)	- Education of the driver - Accept driver decision

Table 24: Demos 2 & 3 common potential risks

Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Technical issue	Sensors (Radar, Lidar and Camera) HW failure	2,3	8	6	1	6	168	III - Moderate	Sensors S1-S8	- Check validity of sensor input by cross-checking with different input sources - Warn the driver to take over control (for eventual application) - Use experienced test drivers (during test phase) - Add redundant

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
										hardware to take over control
Technical issue	Sensors (Radar, Lidar and Camera) SW/processing failure	2,3	7	7	1	2	73,5	III - Moderate	Sensor Input, Object Fusion & Tracking	- Add anomaly detection in the object fusion and tracking algorithm - Define unit tests incl. edge cases for the algorithm - Thoroughly test the algorithm using rich data
Technical issue	Demo vehicle failure (excl. Sensors)	2,3	8	4	3	5	128	III - Moderate	Actuators A1 & A2 [Demo vehicle]	Thoroughly and regularly check the vehicles' state, especially for safety critical components (steering & braking actuators, tyres, airbag, seat belts, ...)
Technical issue	Dummy failure	2,3	7	8	1	3	112	III - Moderate	[Dummy]	Thoroughly and regularly check the Dummy system's state, especially before measurement campaigns
Organisational issue	Short term demo vehicle availability	2,3	6	6	7	8	270	II - Severe	-	- Thoroughly plan all demo vehicle related activities - Plan additional optional back-up test days
Organisational issue	Available demo vehicle days insufficient for desired maturity level of system	2,3	6	5	7	8	225	II - Severe	-	- Thoroughly plan all demo vehicle related activities - Plan additional optional back-up test days
Organisational issue	Planned test days insufficient for desired maturity level of system /	2,3	6	5	7	8	225	II - Severe	-	- Thoroughly plan all test activities - Plan

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	overestimation of development progress									additional optional back-up test days
Organisational issue	Insufficient technological advancement between first and second delivery date of demo	2,3	6	6	4	9	234	II - Severe	-	- Clear definition of demo ambitions per delivery - Thoroughly plan algorithm development - Change Demo ambition in time if initial goals can't be met

Table 25: Demo 4 potential risks

Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Technical issue	Battery depletion of VRU device	4	8	5	1	2	60	IV - Slight	VRU Core	Available replacement battery on site
Technical issue	Short V2X range coverage due to "improper" device holding / placement leading to inadequate communication	4	6	3	5	2	63	IV - Slight	VRU V2X transceiver	User briefing for proper device holding (i.e. pedestrian VRU) during tests. Installation with bicycle device holder in case of cyclist VRU, or use of external antennas
Technical issue	Wrong heading estimation by the VRU device due to improper use of the smart device by the pedestrian	4	8	7	5	7	336	II - Severe	VRU IMU and Localization	User (pedestrian) briefing for proper device usage during the testing phase.
Technical issue	Poor GNSS coverage area	4	8	3	2	10	144	III - Moderate	Full Demo 4	Different site location selection
Technical issue	Delayed and/or wrong risk algorithm calculations leading to	4	8	5	8	7	300	II - Severe	VRU Control Action Strategy	Thorough tests of the algorithms and optimization of the

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	inefficient user warnings									implemented solutions
Technical issue	Contradictory localization information from different sources (GNSS, CPMs by RSU and vehicle), (related to VRU GNSS, GNSS Corrections, Collected Neighbour/ Object Events, Localization and LDM)	4	5	5	3	6	112,5	III - Moderate	VRU GNSS, GNSS Corrections, Collected Neighbour/Object Events, Localization and LDM	Extensive VRU GNSS localization performance evaluation with experiments under various conditions
Technical issue	Reported GPS information is below certain quality/ accuracy threshold	4	9	7	2	2	126	III - Moderate	Vehicle (V2X Driving function unit)	GPS quality filters will be applied to give less weight or discard the sample in case the GPS data is not accurate enough.
Technical issue	Communication adds too much delay for a timely reaction.	4	9	6	3	2	135	III - Moderate	Vehicle (V2X Driving function unit)	V2X data has lower weight than perception data, which will make the AEB system to rely only on perception sensors.
Technical issue	High system load leads to delayed car reaction	4	9	5	3	2	112,5	III - Moderate	Vehicle (V2X Driving function unit)	Weighting (e.g. based on target distance) will be applied to relax the computational demand. CPU/load monitoring will also be applied.
Technical issue / Legal issue	Unauthorized station transmits data	4	10	4	9	1	200	III - Moderate	Vehicle (V2X Driving function unit)	Public Key Infrastructure (PKI) and/or other security/authentication and authorization mechanisms will be applied

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
Technical issue	Control commands' transmission fails	4	9	1	1	2	13,5	IV - Slight	Vehicle (V2X Driving function unit)	Add anomaly detection. Periodic communication checks. Warn the driver about this critical situation
Technical issue	Data fusion transmission fails	4	9	1	1	2	13,5	IV - Slight	Vehicle (V2X Driving function unit)	Add anomaly detection. Periodic communication checks. Warn the driver about this critical situation
Technical issue	HMI warning info transmission fails	4	6	1	1	1	6	V - Insignific ant	Vehicle (V2X Driving function unit)	Add anomaly detection. Periodic communication checks.
Technical issue	VRU warning transmission fails	4	7	3	1	1	21	IV - Slight	Vehicle (V2X Driving function unit)	Add anomaly detection. Periodic communication checks. Warn the driver about this critical situation
Technical issue	No target recognition. Perception receives a limited information	4	9	6	1	1	54	IV - Slight	Vehicle and RSU (Camera)	Warning to the driver (e.g. camera temporarily unavailable)
Technical issue	Risk of electric shock or thermal events	4	9	1	1	9	45	IV - Slight	Vehicle and RSU (Camera)	Internal mechanisms can be implemented to prevent the electric overload and switch-off/reset the electric circuit.
Technical issue	Camera may stop working. Perception receives a limited information	4	9	1	1	1	9	IV - Slight	Vehicle and RSU (Camera)	Internal mechanisms can be implemented to prevent the electric overload and switch-off/reset

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
										the electric circuit.
Technical issue	Loss of target recognition. Perception receives a limited information	4	9	1	1	1	9	IV - Slight	Vehicle and RSU (Camera)	Dedicate user manuals/warnings to prevent the incorrect configuration.
Technical issue	Loss of target recognition. Perception receives a limited information	4	9	3	1	1	27	IV - Slight	Vehicle and RSU (Camera)	Shield/block magnetic fields
Technical issue	Due to mechanical stresses, the lenses may break and provide an incorrect image	4	9	5	4	1	112,5	III - Moderate	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g. camera failure, driver check or go to garage)
Technical issue	Visual effect is the same as the one that can be noticed on TV displays, when a pixel stops working properly and it appears as a black spot on the screen.	4	4	7	4	1	70	III - Moderate	Vehicle and RSU (Camera)	The fault is controllable. No mitigation strategy is necessary
Technical issue	The accuracy of the image is lower. Additional lines will be present in the image	4	6	2	4	1	30	IV - Slight	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g. camera failure, driver check or go to garage)
Technical issue	The image is "corrupted"	4	6	7	1	1	42	IV - Slight	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g. camera failure, driver check or go to garage)
Technical issue	The ice might prevent the acquisition of the image	4	8	6	1	1	48	IV - Slight	Vehicle and RSU (Camera)	Warn the driver about the temperature and the possibility of the ice formation and subsequent camera limitation
Technical issue	The camera does not transmit anything	4	9	1	1	1	9	IV - Slight	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g.

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	or transmit the last image acquired									camera unavailability, go to garage)
Technical issue	The camera transmit the image with delay	4	9	1	1	1	9	IV - Slight	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g. camera unavailability, go to garage)
Technical issue	The camera transmits an incorrect image. This might lead the perception system to make wrong decisions (e.g. unexpected deceleration of the vehicle or unexpected lateral movement)	4	9	1	5	1	27	IV - Slight	Vehicle and RSU (Camera)	Visual/acoustic warning to the driver (e.g. camera unavailability, go to garage)
Technical issue	The camera might perceive/ recognize an object and command an unexpected deceleration or an unexpected lateral movement	4	9	6	9	1	270	II - Severe	Vehicle and RSU (Camera)	Inform the nearby vehicles to be attentive and to always maintain a safe gap/distance with the ego vehicle
Technical issue	The radar cannot fulfil the object detection and the distance/ velocity estimation due to the unavailability of power supply	4	9	1	1	1	9	IV - Slight	Vehicle (Radar)	Visual/acoustic warning to the driver (e.g. radar unavailability, go to garage)
Technical issue	The radar cannot fulfil the object detection and the distance/ velocity estimation due to an internal damage (e.g. mechanical stress due to an uneven road)	4	9	5	1	1	45	IV - Slight	Vehicle (Radar)	Visual/acoustic warning to the driver (e.g. radar unavailability, go to garage)
Technical issue	The radar cannot fulfil the object detection and the distance/ velocity estimation due to	4	9	2	5	1	54	IV - Slight	Vehicle (Radar)	Visual/acoustic warning to the driver (e.g. radar unavailability, go to garage)

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	an interference (e.g. noise)									
Technical issue	The Lidar cannot perceive/ recognize pedestrians or vehicles. A loss of deceleration might occur	4	9	2	1	1	18	IV - Slight	Vehicle and RSU (Lidar)	Visual/acoustic warning to the driver (e.g. Lidar unavailability/ malfunction, go to garage)
Technical issue	Loss of deceleration due to a wrong computed distance	4	9	1	5	1	27	IV - Slight	Vehicle and RSU (Lidar)	Simply remind the driver, at the beginning of each trip, about its responsibility to always be attentive and take control in case he thinks the gap with the forward road user/stationary objects is not sufficient
Technical issue	Missing signals of the vehicle required for the proper execution of the test	4	9	5	3	5	180	III - Moderate	Vehicle (Toyota Safety Sense)	Signals require to do the test should be defined in advance
Technical issue	Damage of the vehicle during the preparation, test set up or execution of the test	4	6	9	6	3	243	II - Severe	Vehicle	Preparation of a manual of instructions for handling and ensure a safe test environment.
Technical issue	Compatibility related to the integration of the systems into the vehicle	4	10	3	3	2	75	III - Moderate	Vehicle (Toyota Safety Sense)	Properly define and execute an extra check to verify integration compatibility within the systems.
Technical issue	Signals from the TSS cannot be collected	4	7	5	4	2	105	III - Moderate	Vehicle (Toyota Safety Sense)	Define require signals before the execution of the test
Behavioural issue	Poor user perception of the HMI warnings, both visual and acoustic, due to "improper" device holding / placement,	4	7	5	1	5	105	III - Moderate	VRU audio and visual interface	Instructions for proper device holding by pedestrian VRUs during tests. Thorough planning of the

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Risk Type	Short Description	Demo	S	O	D	R	Risk number	Risk Severity	Relevant Architect. Compon.	Mitigation Strategy
	leading to inefficient or non-existent reaction (related to VRU audio and visual interface)									device installation (with a holder at the most suitable place regarding human perception of warnings) in case of bicycle
Behavioural issue	VRU creating an intentional inappropriate interaction with the vehicle (i.e. jumping in front of it) in order to check the overall system's performance but in a dangerous way (related to full Demo 4)	4	9	4	1	9	180	III - Moderate	Full Demo 4	Instructions for normal user behaviour during tests, stressing out the safety issues involved with such inappropriate actions
Organisational issue	Vehicle's schedule is not available for the initial required time	4	9	6	4	5	243	II - Severe	Vehicle	Define schedule based on vehicle availability which has to be confirmed
Organisational issue	Additional time for vehicle preparation for the test	4	7	9	3	7	315	II - Severe	Vehicle	Close monitoring to ensure and guarantee the schedule via regular meetings

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4. Discussion & Conclusions

The initial *technical specifications* identified the design of the main architecture diagrams relevant for each Demo; as presented, each Demo has its own specificities in terms of physical and software components, as well as the time-to-development, those specifications were captured on.

For each of the key modules of each Demo, the preliminary technical specifications are defined and presented. Since the development phase has either just started (i.e. Demo 4) or is still in process (Demo 2 and Demo 3), the final information will be provided after the development is finalised and delivered in Month 26 as it is defined within T3.1 description.

The relevant work performed is of essential internal use for WP3 developers, in order to monitor their work on technical level, until the final testing of the system in T3.6 on verification level and beyond in T5.3 on safety impact assessment level.

With regard to the *a-priori risk assessment,* a concrete methodology was deployed to capture the potential risks for each of the targeted WP3 Demo systems. This preliminary assessment supports the early identification of vulnerabilities, in order to efficiently manage them by incorporating them into the design and development phase. They will have a direct or indirect effect on the SAFE-UP system smooth operation and functionality.

As it was expected, the majority of the identified risks are of technical nature, while there are also a few behavioural, legal and organisational risks. This is normal due to the nature of the project and the specific Demos of WP3 that are technologically oriented. Most of the identified risks have a severity level ‘severe’, ‘moderate’ or ‘slight’. All risks and especially those with higher severity level will be closely monitored during the next project steps.

Currently, 71 risks have been identified, most of which refer to Demo 4, i.e. 42 risks. Next, 18 risks are for Demo 3, while there are 8 additional risks that are common for Demos 2 and 3; finally, 3 risks relate to Demo 2. The reason behind Demo 4 having identified more risks is that its architecture is more complex (system of systems), whereas the V2X technology is not as mature as it is the case for Demo 2 and Demo 3 technologies.

Following the initially detected risks, the risks that will be actually met and the way they will be dealt with (either during the development or during the tests), as well as actual, unpredicted flaws that will occur will be presented in Month 26, thus performing a Phase 2 Risk analysis. The same methodology will be used, along with a similar template that will be provided in due time.

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References

Bekiaris, E., Stevens, A. (2005), "Common risk assessment methodology for advanced driver assistance systems", Transport Reviews, Vol. 25, No. 3, p. 283-292, May 2005.

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Appendix A: Technical specifications template

Architecture

Add the system architecture diagrams and a short description for each of them:

- *Physical*
- *Communication*
- *Software*

Demo module specifications (to be completed per architecture component)

<table>
<tr><td>Module Name</td><td colspan="3"></td></tr>
<tr><td>Module ID</td><td colspan="3"></td></tr>
<tr><td>Manufacturer</td><td colspan="3"></td></tr>
<tr><td>Responsible Partner</td><td colspan="3"></td></tr>
<tr><td>General Description</td><td colspan="3"></td></tr>
<tr><td>Micro</td><td colspan="3"></td></tr>
<tr><td>Memory</td><td colspan="3"></td></tr>
<tr><td>Battery</td><td colspan="3"></td></tr>
<tr><td>Supported OS</td><td colspan="3"></td></tr>
<tr><td>I/O Ports</td><td colspan="3"></td></tr>
<tr><td>Communication network details</td><td colspan="3"></td></tr>
<tr><td rowspan="7">Module Performances</td><td>Definition</td><td>Value</td><td>Unit</td></tr>
<tr><td>Resolution</td><td></td><td></td></tr>
<tr><td>Refresh rate</td><td></td><td></td></tr>
<tr><td>…</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Physical Module Specifications</td><td>Definition</td><td>Value</td><td>Unit</td></tr>
</table>

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	Dimensions		mm
	Weight		g
	Operating Temperature Range		°C
	Temperature Gradient		°C/min
	Max humidity @40 °C		% r.h.
	Supply Voltage		V
	Peak Voltage		V
	Supply Current		A
	Battery (Type /Ah)		Ah
Environmental Specifications	Functional Safety		
	Environment		
	Vibration, Shock, Bump		
	EMI/EMC		
	Load Dump		
Note			

Sensors consolidated specifications

Sensors				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
S1				
S2				
S3				
S4				
S5				

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HMI Modules

HMI modules				
ID	**Name**	**Type**	**Responsible Partner**	**Usage in Demo**
HMI1				
HMI2				
HMI3				
HMI4				
HMI5				

Demo Interfaces

Demo Interfaces		
CAN		
Working Frequency	*N/A*	*GHz*
Data Rate	*500*	*kbps*
Ethernet		
Working Frequency	*N/A*	*GHz*
Data Rate	*100*	*Mbps*
USB 2.0		
Working Frequency	*N/A*	*GHz*
Data Rate	*480*	*Mbps*
Bluetooth 4.0		
Working Frequency	*2.4*	*GHz*
Data Rate	*1 to 3*	*Mbps*
LTE		
Working Frequencies	*700, 800, 900, 1800, 2600*	*MHz*
Data Rate	*up to 326.4 (down)* *up to 86.3 (up)*	*Mbps*
802.11p		

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Working Frequency	*5.9*	*GHz*
Data Rate	*6*	*Mbps*

Interface components

Interface Components				
ID	**Name**	**Type**	**Responsible Partner**	**Used in Demo**
IM1				
IM2				
IM3				
IM4 IM5				

Elaboration Units

Elaboration Units				
ID	**Name**	**Type**	**Responsible Partner**	**Used in Demo**
E1				
E2				
E3				
E4				
E5				

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Appendix B: Demo 2 Detailed Technical Specifications

B1. Vehicle Radar sensors

Module Name	Front, Rear, Left Front, Right Front, Left Rear, Right Rear Radar Sensor		
Module ID	S1, S2, S3, S4, S5, S6		
Manufacturer	internal development		
Responsible Partner	Bosch		
General Description	Radar Sensors mounted at the vehicle front, front corners, rear, and rear corners		
Micro	-		
Memory	-		
Battery	-		
Supported OS	-		
I/O Ports	1Gbps Ethernet		
Communication network details	PTP triggered		
Module Performances	***Definition***	***Value***	***Unit***
	Detection range (radial)	100	m
	Separability (radial)	0.2	m
	Field of view (horizontal)	+/-60	Degree
	Field of view (vertical)	+/-15	Degree
	Separability (horizontal)	-	Degree

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	Radial velocity	+/-30	kph
	Separability (radial velocity)	0.1	m/s
	Measurement update cycle	60	ms
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	230x130x70	mm^3
	Weight	3000	g
	Supply Voltage	12	V
	Peak Voltage	12	V
	Supply Current	5	A
Environmental Specifications			
Note			

B2. Front stereo video sensors

Module Name	Front Stereo Video Sensor
Module ID	S7
Manufacturer	Dream Chip
Responsible Partner	Bosch
General Description	Video Sensor mounted at the vehicle front wind shield
Micro	-
Memory	-
Battery	-
Supported OS	-
I/O Ports	SDI output (2x HD-BNC), Genlock Sync (2x HD-BNC), Control(RS485 / RS422 / UART 3.3V)
Communication network details	

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	Definition	*Value*	*Unit*
Module Performances	Resolution	1920 x 1080	px
	Sensor Type	1 / 1.23	"
	Shutter type	Global	
	Dynamic	12 bit / 72 dB	
	Measurement update cycle	60	ms
Physical Module Specifications	*Definition*	*Value*	*Unit*
	Dimensions	300x300x100	mm³
	Weight	400	g
	Supply Voltage	6-36	V
	Supply Current	300mA@12V	A
Environmental Specifications			
Note	https://www.dreamchip.de/products/atom-one-family/atom-one.html		

B3. Rooftop Lidar sensor

Module Name	Rooftop Lidar Sensor
Module ID	S8
Manufacturer	Hesai Pandar 64
Responsible Partner	Bosch
General Description	Lidar Sensor mounted at the vehicle's rooftop
Micro	-
Memory	-
Battery	-
Supported OS	-
I/O Ports	100Mbps Ethernet

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Communication network details			
Module Performances	***Definition***	***Value***	***Unit***
	Rotation Rate	10	Hz
	FOV (Vertical)	40° (-25° to +15°)	degree
	FOV (Horizontal)	360	degree
	Angular Resolution (Horizontal)	0.2	degree
	Angular Resolution (Vertical)	0.2	degree
	Measurement Range	0.3-200 m	m
	Separability (radial velocity)	0.1	m/s
	Measurement update cycle	60	ms
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	Height: 116.7 mm, Top Diameter: 118.0 mm,	
	Weight	1600	g
	Supply Voltage	12	V
	Power Consumption	22	W
	Supply Current	2	A @12V
Environmental Specifications			
Note			

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Appendix C: Demo 3 Detailed Technical Specifications

C1. Front Radar Sensor

Module Name	Front Radar Sensor		
Module ID	S1		
Manufacturer	Bosch		
Responsible Partner	Bosch		
General Description	Radar Sensor mounted at the vehicle front		
Micro	?		
Memory	-		
Battery	-		
Supported OS	Bosch internal		
I/O Ports	CAN, Ethernet		
Communication network details	CAN, XCP over Ethernet		
Module Performances	***Definition***	***Value***	***Unit***
	Detection range (radial)	300	m
	Separability (radial)	0.4-0.8	m
	Field of view (horizontal)	± 55	Degree
	Separability (horizontal)	1	Degree
	Radial velocity	-110 - +50	m/s
	Separability (radial velocity)	0.2	m/s
	Measurement update cycle	66	ms
Physical Module Specifications	***Definition***	***Value***	***Unit***

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	Box volume	143 x 110 x 30	mm³
Note			

C2. Corner Radar Sensor

Module Name	Corner Radar Sensor		
Module ID	S2, S3		
Manufacturer	Bosch		
Responsible Partner	Bosch		
General Description	Radar Sensor mounted at the vehicle front corner		
Micro	?		
Memory	-		
Battery	-		
Supported OS	Bosch internal		
I/O Ports	CAN, Ethernet		
Communication network details	CAN, XCP over Ethernet		
Module Performances	***Definition***	***Value***	***Unit***
	Detection range (radial)	120	m
	Separability (radial)	0.4	m
	Field of view (horizontal)	± 75	Degree
	Separability (horizontal)	4.5	Degree
	Radial velocity	± 80	m/s
	Separability (radial velocity)	0.2	m/s
	Measurement update cycle	66	ms
Physical Module Specifications	***Definition***	***Value***	***Unit***

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	Box volume	143 x 110 x 30	mm³
Note			

C3. Front Video Sensor

Module Name	Front Video Sensor		
Module ID	S4		
Manufacturer	Bosch		
Responsible Partner	Bosch		
General Description	Video Sensor mounted at the vehicle front wind shield		
Micro	?		
Memory	-		
Battery	-		
Supported OS	Bosch internal		
I/O Ports	CAN, Ethernet		
Communication network details	CAN, XCP over Ethernet		
Module Performances	***Definition***	***Value***	***Unit***
	Field of view (far-view, horizontal)	± 20.5	Degree
	Angular resolution (far-view, horizontal)	0.033	Degree/pixel
	Field of view (far-view, vertical)	-14.2 - +6.8	Degree
	Angular resolution (far-view, vertical)	0.033	Degree/pixel
	Base resolution (far-view)	1280 x 640	pixel²
	Field of view (wide-view, horizontal)	± 44.1	Degree

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	Angular resolution (wide - view, horizontal)	0.053	Degree/pixel
	Field of view (wide -view, vertical)	-23.7 - +17	Degree
	Angular resolution (wide - view, vertical)	0.063	Degree/pixel
	Base resolution (wide - view)	1664 x 640	$pixel^2$
Note			

C4. Brake Booster + ESP

Module Name	Brake Booster + ESP
Module ID	A1
Manufacturer	Bosch
Responsible Partner	Bosch
General Description	Integrated power brake booster (IPB 1.0) and ESP 9
Micro	-
Memory	-
Battery	-
Supported OS	Bosch internal
I/O Ports	CAN, Ethernet
Communication network details	CAN, XCP over Ethernet
Note	

C5. Electronic Power Steering

Module Name	Electronic Power Steering
Module ID	A1
Manufacturer	Bosch

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Responsible Partner	Bosch
General Description	Electronic power steering unit
Micro	-
Memory	-
Battery	-
Supported OS	Bosch internal
I/O Ports	CAN
Communication network details	CAN
Note	

C6. Sensor Input

Module Name	Sensor Input	
Module ID	M2	
Responsible Partner	Bosch & Audi	
General Description	Physical environment interaction with sensing equipment. Object Data output will be provided by 1 front radar sensor, 2 corner radar sensors, and 1 front camera.	
Interface	For simulation: ROS topics For hardware: interface to physical components, see C1, C2, C3	
Inputs		
Source	*Name*	*Description*
<none>		
Outputs		
	Name	*Description*
	Object Data	Detected objects per sensor
	Host data	Host data per sensor
Note(s)		

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C7. Weather Filter

Module Name	Weather Filter	
Module ID	M3	
Responsible Partner	THI	
General Description	Based on weather settings in the Weather Filter, compute a probability of object detection field, to facilitate real-time simulation of bad weather conditions even in good weather testing.	
Interface	For simulation: ROS topics For hardware: interface to physical components T.B.D.	
Inputs		
Source	*Name*	*Description*
	Rain_level_setting Fog_level_setting	Parameter describing severity of precipitation
Outputs		
	Name	*Description*
	Object data	Detected objects per sensor, adjusted for possibility of detection by weather filter
Note(s)		

C8. Object Fusion & Tracking

Module Name	Object Fusion & Tracking
Module ID	M4
Responsible Partner	Bosch
General Description	• Fusing multiple sensor inputs into best-estimate object tracks • Transforming frame of reference both baselink and odometry frame, as well as fusing size estimations of objects to provide centre of body position estimations. • Object Data output will be provided by 1 front radar sensor, 2 corner radar sensors, and 1 front camera. Object Data from all sensor will be fused on object level.
Interface	For simulation: ROS topics For hardware: interface to physical components T.B.D.
Inputs	

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Source	Name	Description
	Object data	Detected objects per sensor, adjusted for possibility of detection by weather filter
Outputs		
	Name	*Description*
	Object data	Fused object track
	Host data	Fused host data
Note(s)		

C9. Localisation

Module Name	Localization	
Module ID	M5	
Responsible Partner	TU/e	
General Description	The localization module uses RTK GNSS or an indoor system to determine the pose of the vehicle w.r.t. a map frame. The map will be used as a look-up reference. The absolute position is determined by absolute/relative motion & position sensors, returning the position in the map. Consequently, the map can be used to get information that is not measured by vehicle fixed sensors. In this way, the lane information can be "measured" from the map, while the vehicle may not be equipped with a lane-detection camera at all.	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
	Host data Localization specific sensors Map feature measurements	Host data per sensor Depends on sensors available (e.g. UWB, GNSS) Lane markings, etc, only if needed
Outputs		
	Name	*Description*
	2D pose	Pose (position + heading) of the ego vehicle w.r.t. a certain (map) coordinate frame
Note(s)		

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C10. VRU Intent & Trajectory Prediction

Module Name	VRU Intent & Trajectory Prediction	
Module ID	M6	
Responsible Partner	TU/e	
General Description	• Calculate intent and/or trajectory of detected objects • Provide a likelihood map of future object locations as function of time	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
Object fusion and tracking	Object data	Current observations on observed objects. Perhaps lower level sensor data might be used as well (to be decided)
Outputs		
	Name	*Description*
	Object intent and prediction data	Data representing a probability representation of the future time-dependent locations of objects
Note(s)		

C11. Crash Prediction & Avoidance Estimation

Module Name	Crash Prediction & Avoidance Estimation	
Module ID	M7	
Responsible Partner	THI	
General Description	• Provide feedback on trajectories/trajectory envelope on the ability to avoid a collision	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
VRU intent & trajectory prediction	Object intent and prediction data	Data representing a probability representation of the future time-dependent locations of objects

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Trajectory generation	Trajectory data	Considered trajectories for AES behavior
Outputs		
	Name	*Description*
	Avoidance_estimation_data	A per trajectory estimation of chance to avoid collision
Note(s)		

C12. Global Planning

Module Name	Global Planning	
Module ID	M8	
Responsible Partner	TNO & TU/e	
General Description	• Provide an optimal route from a starting point to a destination point. Optimality can be defined as shortest route, fastest route, safest route, avoiding congestions, etc…	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
Localization	2D Pose Map	Pose (position + heading) of the ego vehicle w.r.t. a certain (map) coordinate frame Offline map that contains information such as road geometry and semantic information (e.g. lane type)
Outputs		
	Name	*Description*
	Path	Path data based solely on map information,
Note(s)		

C13. Path Planning

Module Name	3.3.9 Path Planning
Module ID	M9
Responsible Partner	TNO

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General Description	• The results of the localization, the perception of the scene in the immediate surroundings of the vehicle and the information from (static) map are used to plan a path (reference line) from the current vehicle position to a local goal on the global route.	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
Global planning	Path	Path data based solely on map information,
Camera sensor	Line marking data	Observed line markings as polyline, to allow fitting to map
Outputs		
	Name	*Description*
	Path	The reference line (path) that the vehicle should nominally follow
Note(s)		

C14. Trajectory Generation

Module Name	Trajectory Generation	
Module ID	M10	
Responsible Partner	Bosch	
General Description	• Creating nominal trajectory for reference line following • Creating AES trajectory to avoid collisions considering actuator related as well as human factors related dynamical constraints	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
Path planning	Path	The reference line (path) that the vehicle should nominally follow
Object data	Object data	Fused object track
Object data	Host data	Fused host data
VRU intent and trajectory prediction	Object intent and prediction data	Data representing a probability representation of the future time-dependent locations of objects

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Crash prediction & avoidance estimation	Avoidance_estimation_data	A per trajectory estimation of chance to avoid collision
Outputs		
	Name	*Description*
	Trajectory data	Considered trajectories for nominal and AES behavior
Note(s)		

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C15. Vehicle control

Module Name	Vehicle Control	
Module ID	M11	
Responsible Partner	Bosch	
General Description	• Translate trajectory to vehicle inputs • Ensure that vehicle control is performed in a way that both the AES trajectory is followed and the vehicle remains in a safe state in combination with any additional driver input.	
Interface	ROS-topics	
Inputs		
Source	*Name*	*Description*
Trajectory generation	Trajectory data	Considered trajectories for nominal and AES behavior
Outputs		
	Name	*Description*
	Vehicle control outputs	Inputs to actuators in vehicle
Note(s)		

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Appendix D: Demo 4 Detailed Technical Specifications

D1. V2X Driving Function Unit

Module Name	V2X Driving Function Unit		
Module ID	Module_1		
Manufacturer	IDIADA		
Responsible Partner	IDIADA		
General Description	All in one Device for prototyping		
Micro	NVIDIA Jetson TX2		
Memory	2 TB (TBC)		
Battery	2600mAh battery		
Supported OS	Ubuntu 18.04		
I/O Ports	Ethernet / CAN / Digital / Analog IO		
Communication network details	DSRC ITS-G5, Bluetooth 4.0		
Module Performances	***Definition***	***Value***	***Unit***
	TBD		
	TBD		
	TBD		
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	31(W) x 4(H) x 23(D)	cm
	Weight	1.5	kg
	Operating Temperature Range	-40~+80	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.
	Supply Voltage	9/32	V
	Peak Voltage	32	V
	Supply Current	0.5~2.0	A

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	Battery (Type /Ah)	Lithium	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	
	EMI/EMC	N/A	
	Load Dump	N/A	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D2. Perception Unit

Module Name	Perception Unit		
Module ID	Module_2		
Manufacturer	NVIDIA		
Responsible Partner	IDIADA		
General Description	Perception module		
Micro	NVIDIA Tegra family		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	TBD		
	TBD		
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	303x213x84.3	mm
	Weight	N/A	g
	Operating Temperature Range	0~45	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.

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	Supply Voltage	12	V
	Peak Voltage	N/A	V
	Supply Current	N/A	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	
	EMI/EMC	N/A	
	Load Dump	N/A	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D3. Vehicle Camera

Module Name	Camera Vehicle		
Module ID	Module_4		
Manufacturer	Basler		
Responsible Partner	IDIADA		
General Description	CMOS Camera		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Resolution (H x V)	1936 x 1216 (full resolution) 1920 x 1200 (default resolution)	pixel
	Frame Rate	51	fps
	Definition	***Value***	***Unit***

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Physical Module Specifications	Dimensions	48.9x29x29	mm
	Weight	<100	g
	Operating Temperature Range	-10~+60	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	80	% r.h.
	Supply Voltage	12~24	VDC
	Peak Voltage	N/A	V
	Supply Current	N/A	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	
	EMI/EMC	N/A	
	Load Dump	N/A	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D4. Vehicle LiDAR

Module Name	Lidar module Vehicle
Module ID	Module_5
Manufacturer	Ouster
Responsible Partner	IDIADA
General Description	LiDAR Sensor
Micro	*TBD*
Memory	N/A
Battery	N/A
Supported OS	N/A
I/O Ports	N/A
Communication network details	N/A

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	Definition	*Value*	*Unit*
Module Performances	Range (80% Lambertian Reflectivity)	110 m @ >90% detection probability, 100 klx sunlight 150 m @ >50% detection probability, 100 klx sunlight	m
	Range (10% Lambertian Reflectivity)	50 m @ >90% detection probability, 100 klx sunlight 65 m @ >50% detection probability, 100 klx sunlight	m
	Precision (10% Lambertian Reflectivity; 1 standard deviation	0.8 - 1 m: ± 1 cm 1 - 20 m: ± 1.1 cm 20 - 50 m ± 3 cm >50 m: ± 5 cm	m
Physical Module Specifications	*Definition*	*Value*	*Unit*
	Dimensions	N/A	mm
	Weight	455	g
	Operating Temperature Range	-40~+55	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.
	Supply Voltage	N/A	V
	Peak Voltage	*TBD*	V
	Supply Current	*TBD*	A
	Battery (Type /Ah)	*TBD*	Ah
Environmental Specifications	Functional Safety	*TBD*	
	Environment	*TBD*	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
	Load Dump	*TBD*	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D5. Vehicle Radar

Module Name	Radar Vehicle		
Module ID	Module_5		
Manufacturer	Continental		
Responsible Partner	IDIADA		
General Description	Radar sensor		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Range	0.20 ...250 m far range 0.20...70m/100m at 0...±45° near range 0.20...20m at ±60° near range	m
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	138x91x31	mm
	Weight	320	g
	Operating Temperature Range	-40~+85	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.
	Supply Voltage	8~32	VDC
	Peak Voltage	N/A	V
	Supply Current	0.55	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	

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	EMI/EMC	N/A
	Load Dump	N/A
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.	

D6. RSU Camera

Module Name	Camera RSU		
Module ID	Module_4		
Manufacturer	Basler		
Responsible Partner	IDIADA		
General Description	CMOS Camera		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Resolution (H x V)	1936 x 1216 (full resolution) 1920 x 1200 (default resolution)	pixel
	Frame Rate	51	fps
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	48.9x29x29	mm
	Weight	<100	g
	Operating Temperature Range	-10~+60	°C

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	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	80	% r.h.
	Supply Voltage	12~24	VDC
	Peak Voltage	N/A	V
	Supply Current	N/A	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	
	EMI/EMC	N/A	
	Load Dump	N/A	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D7. RSU LiDAR

Module Name	Lidar module RSU		
Module ID	Module_5		
Manufacturer	Ouster		
Responsible Partner	IDIADA		
General Description	LiDAR Sensor		
Micro	*TBD*		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Range (80% Lambertian Reflectivity)	110 m @ >90% detection probability, 100 klx sunlight 150 m @ >50% detection probability, 100 klx sunlight	m

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	Range (10% Lambertian Reflectivity)	50 m @ >90% detection probability, 100 klx sunlight 65 m @ >50% detection probability, 100 klx sunlight	m
	Precision (10% Lambertian Reflectivity; 1 standard deviation	0.8 - 1 m: ± 1 cm 1 - 20 m: ± 1.1 cm 20 - 50 m ± 3 cm >50 m: ± 5 cm	m
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	N/A	mm
	Weight	455	g
	Operating Temperature Range	-40~+55	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.
	Supply Voltage	N/A	V
	Peak Voltage	*TBD*	V
	Supply Current	*TBD*	A
	Battery (Type /Ah)	*TBD*	Ah
Environmental Specifications	Functional Safety	*TBD*	
	Environment	*TBD*	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
	Load Dump	*TBD*	
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.		

D8. RSU Radar

Module Name	Radar RSU
Module ID	Module_5
Manufacturer	Continental

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Responsible Partner	IDIADA		
General Description	Radar sensor		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	N/A		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Range	0.20 ...250 m far range 0.20...70m/100m at 0...±45° near range 0.20...20m at ±60° near range	m
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	138x91x31	mm
	Weight	320	g
	Operating Temperature Range	-40~+85	°C
	Temperature Gradient	N/A	°C/min
	Max humidity @40 °C	N/A	% r.h.
	Supply Voltage	8~32	VDC
	Peak Voltage	N/A	V
	Supply Current	0.55	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	N/A	
	Environment	N/A	
	Vibration, Shock, Bump	N/A	

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	EMI/EMC	N/A
	Load Dump	N/A
Note	Gaps on the table due to is not necessary for specification of the project from my point of view.	

D9. VRU Core

Module Name	VRU Core		
Module ID	VRU_CR		
Manufacturer	CERTH / HIT		
Responsible Partner	CERTH / HIT		
General Description	VRU device motherboard, CPU core and on-board memory		
Micro	*NXP i.MX8MM*		
Memory	*2 GB LPDDR4, 16 GB eMMC*		
Battery	*2200 mAh LiPo*		
Supported OS	Linux, Android		
I/O Ports	Micro USB, USB-C		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Quad core A53		
	CPU Frequency per core	1.6	GHz
	RAM speed	3000	MT/s
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	85x145x10	mm
	Weight	200	g
	Operating Temperature Range	0 - +55	°C
	Temperature Gradient	*TBD*	°C/min
	Max humidity @40 °C	*TBD*	% r.h.
	Supply Voltage	3.7	V
	Peak Voltage	4.2	V
	Supply Current	0.5	A

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	Battery (Type /Ah)	(LiPo / 2.2)	Ah
Environmental Specifications	Functional Safety	*TBD*	
	Environment	*TBD*	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
	Load Dump	*TBD*	
Note			

D10. VRU V2X Transceiver

Module Name	V2X Transceiver		
Module ID	VRU_V2X_TXRX		
Manufacturer	u-blox (model VERA-P1)		
Responsible Partner	CERTH / HIT		
General Description	Embedded transceiver for the development of V2X communications		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	USB 2.0, SPI		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Max output power	+23	dBm
	Rx sensitivity (in 3 Mbps data rate)	-98	dBm
	Definition	***Value***	***Unit***
	Dimensions	30x25x3.5	mm
	Weight	N/A	g
	Operating Temperature Range	-40 - +95	°C
Physical Module Specifications	Temperature Gradient	*TBD*	°C/min
	Max humidity @40 °C	*TBD*	% r.h.
	Supply Voltage	5 plus 3.3	V

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	Peak Voltage	5	V
	Supply Current	0.4	A
	Battery (Type /Ah)	N/A	Ah
	Functional Safety	*TBD*	
	Environment	*TBD*	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
Environmental Specifications	Load Dump	*TBD*	
Note			

D11. VRU LTE communication module

Module Name	Multi-mode LTE/3G/2G cellular		
Module ID	VRU_LTE		
Manufacturer	u-blox (model TOBY-L210)		
Responsible Partner	CERTH / HIT		
General Description	4G LTE/3G/2G multimode module for cellular communications		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	UART, USB 2.0, SDIO, I^2C compatible DDC		
Communication network details	4G LTE (800/850/900/1800/2100/2600 MHz) 3G (850/900/1900/2100 MHz) 2G (850/900/1800/1900 MHz)		
Module Performances	***Definition***	***Value***	***Unit***
	LTE Rx input sensitivity (depending on used channel and bandwidth)	-97 – -109	dBm
	3G Rx input sensitivity performance	-111	dBm
	2G Rx input sensitivity performance	-110	dBm
	Definition	***Value***	***Unit***

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Physical Module Specifications	Dimensions	35.6x24.8x2.6	mm
	Weight	4.8	g
	Operating Temperature Range	Normal: -20 – +65 Extended: -40 – +85	°C
	Temperature Gradient		°C/min
	Max humidity @40 °C		% r.h.
	Supply Voltage	3.8	V
	Peak Voltage	5	V
	Supply Current	~0.6	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	*TBD*	
	Environment	*TBD*	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
	Load Dump	*TBD*	
Note			

D12. VRU RTK sensor

Module Name	RTK GNSS
Module ID	VRU_GNSS
Manufacturer	u-blox (model NEO-M8P)
Responsible Partner	CERTH / HIT
General Description	High performance positioning engine with RTK technology
Micro	N/A
Memory	N/A
Battery	N/A
Supported OS	N/A
I/O Ports	UART, USB, SPI, I^2C compatible DDC

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Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Horizontal position accuracy (standalone)	2.5	m
	Horizontal position accuracy (RTK)	0.025	m
	Velocity accuracy	0.05	m/s
	Max navigation update rate	4 - 10	Hz
	Time to first fix (cold start)	≤ 30	s
	Time to first fix (hot start)	1	s
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	16x12.2x2.4	mm
	Weight	N/A	g
	Operating Temperature Range	-40 - +85	°C
	Temperature Gradient		°C/min
	Max humidity @40 °C		% r.h.
	Supply Voltage	3	V
	Peak Voltage	3.6	V
	Supply Current	~0.035	A
	Battery (Type /Ah)	N/A	Ah
Environmental Specifications	Functional Safety	*TBD*	
	Environment	Operational limits: Dynamics ≤ 4g Altitude ≤ 50 Km Velocity ≤ 500 m/s	
	Vibration, Shock, Bump	*TBD*	
	EMI/EMC	*TBD*	
	Load Dump	*TBD*	
Note			

D13. VRU IMU sensor

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

Module Name	IMU		
Module ID	VRU_IMU		
Manufacturer	Bosch (model BNO055)		
Responsible Partner	CERTH / HIT		
General Description	Triaxial accelerometer, gyroscope and geomagnetic sensor with embedded fusion software		
Micro	N/A		
Memory	N/A		
Battery	N/A		
Supported OS	N/A		
I/O Ports	UART, I^2C		
Communication network details	N/A		
Module Performances	***Definition***	***Value***	***Unit***
	Acceleration ranges	±2/±4/±8/±16	g
	Gyroscope ranges	±125 to ±2000	°/s
	Magnetic field range	±1300 (x, y) ±2500 (z)	uT
	Magnetic field resolution	~0.3	uT
Physical Module Specifications	***Definition***	***Value***	***Unit***
	Dimensions	5.2x3.8x1.13	mm
	Weight	N/A	g
	Operating Temperature Range	-40 – +85	°C
	Temperature Gradient		°C/min
	Max humidity @40 °C		% r.h.
	Supply Voltage	2.4 – 3.6	V
	Peak Voltage	3.6	V
	Supply Current	0.012 (@ 3V)	A
	Battery (Type /Ah)	N/A	Ah
	Functional Safety	*TBD*	

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Environmental Specifications	Environment	Complies with RoHS, RoHS2, RoHS3 directives
	Vibration, Shock, Bump	*TBD*
	EMI/EMC	*TBD*
	Load Dump	*TBD*
Note		

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