D4.6 – TeamMate HMI design, implementation and V&V results from 3rd cycle

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Table of Contents

List of figures

List of tables

List of acronyms and abbreviations

Acronym	Concept
A2H	Automation to Human
AR	Augmented reality
ART	Automated Road Transport
D	Deliverable
DMS	Driver Monitoring System
E	Enabler
HMI	Human-Machine Interface; Human-Machine Interaction
HMT	Humatects
H2A	Human to Automation
REL	RE:Lab
REQ	Requirement
TOR	Take Over Request
ULM	Ulm University
V&V	Verification and Validation
VRU	Vulnerable Road Users
WP	Work Package

Executive summary (REL)

This document describes the activities performed in WP4 in the 3rd cycle, i.e. the design, implementation and validation of the TeamMate HMI that includes:

- E6.1 – Interaction modality,
- E6.2 – TeamMate Multimodal HMI,
- E6.3 – Augmented Reality.

In the third cycle, the enabler E6.1 was finalized with the definition of guidelines to design a robust and fail-safe procedure for bi-directional handing over the vehicle control between automation and driver, with a specific focus on mechanisms to enable the driver to assign driving tasks to the automation through appropriate multi-modal communication patterns.

The enabler E6.2, TeamMate Multimodal HMI, in the third cycle focused on:

- The development of a strategy for the take-over request that also includes the use of haptics to decrease the reaction time.
- The implementation of a new version of the HMI on the central stack display (to be installed on the demonstrator vehicles).
- The design of the HMI for a nomadic device (to address the visual distraction of the driver).
- The improvement of the ambient lights to take into consideration the feedback received by the users during the validation of the 2nd cycle.

Moreover, the development was about integration-related activities, such as the adaptation of the TeamMate Multimodal HMI to the use cases and the finalization of the software and the communication protocol to integrate the HMI into all demonstrators.

In the third cycle, the enabler of the Augmented Reality has been improved by considering both directions of the cooperation. Since the first two cycles mainly focused on the Automation to Human (A2H) support, in the third cycle the Augmented Reality was redesigned to implement the Human to Automation (H2A) support.

The design and the implementation of these components was refined according to the results of the V&V process performed in the previous cycles, and to the observations collected during the experiments.

The results of the validation showed the added value of the haptic to decrease the reaction of time, and the Augmented Reality for the understandability of the meaning of the information provided on the real context.

They also showed there is still potential for improvement for the ambient lights and the use of the Augmented Reality for the H2A support (that foresees a challenging communication strategy to be deployed through the Augmented Reality).

1 Introduction (REL)

The aim of the document is to summarize the final version of the design, implementation and validation of the enablers developed in WP4.

The structure of the document is the following:

- **Chapter 2** provides a synthetic overview of the activities performed and the main findings collected in cycle 1 and cycle 2.
- **Chapter 3** describes the status of the components after the third cycle, including the update of the information structure, the HMI strategy and the improvements in the design and implementation. The complete version of the guidelines on interaction modality, the final design of the Multimodal HMI and Augmented Reality HMI are reported in this chapter. Moreover, the development of tools is presented in this chapter too, such as the haptics HMI, defined only at a conceptual level in the previous cycles and concretely developed in the 3rd cycle.
- **Chapter 4** describes the results of the V&V process, including the assessment of the requirements reported in D4.5 and the qualitative data collected through experiments with real users.
- Finally, the conclusions of Work Package 4 activities are reported in **Chapter 5**.

2 Brief overview of the status of the activities in WP4 after 1st and 2nd cycle (REL)

The activities in the Automate project have been organized in three cycles to guarantee that the maturity of the technologies developed in the project is iteratively increased while assessing that the progresses are consistent with the needs of the demonstrators and, in turn, with the overall concept and objectives of the project.

As shown in Figure 1, the first two cycles focused on the development and technical validation of the components (i.e. the enablers) performed in WP4. The experience acquired in the 1st cycle (lesson learnt) has been used at the beginning of the 2nd cycle to review the requirements and metrics for the design and development of the enablers and, as a consequence, to improve them.
At the end of the 2nd cycle, the enablers were planned to be integrated into the demonstrator (simulators) in WP5, and the performances of the 1st version of the simulators were evaluated against their baseline in WP6.

In the 3rd cycle, WP4 were fed with the results of this evaluation process to deliver the final version of the enablers to be integrated into the demonstrator (vehicles). The 3rd cycle ends with the evaluation of the final version of the TeamMate cars.

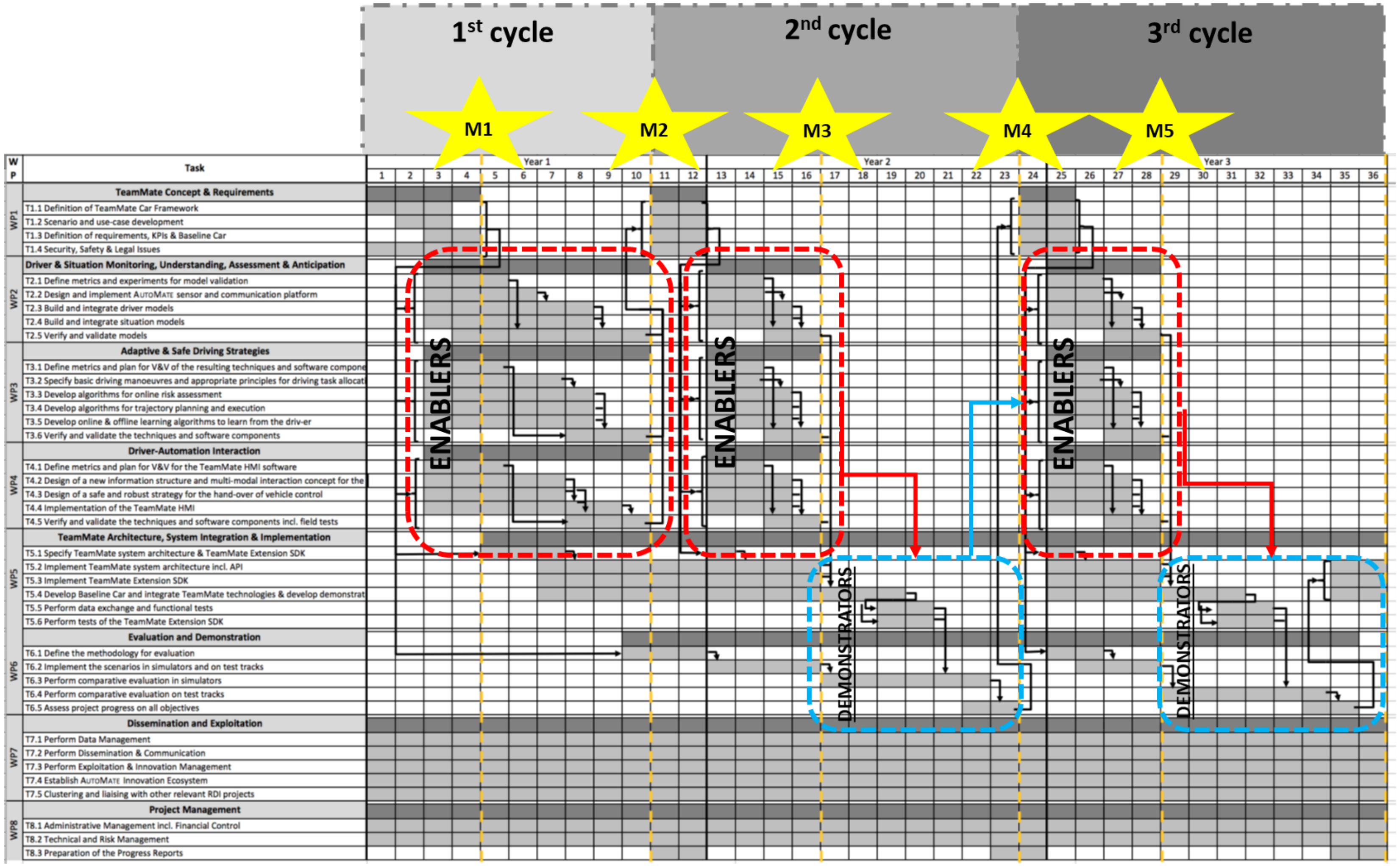


Figure 1: Project cycles, milestones and link between enablers (WP2, WP3 and WP4) and demonstrators (WP5 and WP6)

3 HMI-related results of ART workshop in Hamburg (REL)

On Wednesday the 21st of November, a joint workshop with representatives from several EU funded project in ART framework (InterACT, Vi-das, MAVEN, ADAS&ME) and AutoMate advisory board was organized by AutoMate, in order to share the first results of the project, and to discuss common research topics. The workshop was the opportunity to share approaches, methods and solutions on several topics including Human-Machine Interaction.
This discussion was focused on the current solutions developed and the possible positive influences deriving from the contact between the different projects that are facing similar research topics.

Figure 2: ART workshop in Hamburg

One of the most important topics discussed was trust and measures to define, build and calibrate this construct: it has been argued, for example, that in France Public Authorities are interested in having a "Trust barometer". The measurement and the creation of trust, that are highly dependent from the HMI, will be further considered also for the evaluation phase (in WP6).
The other relevant topic in the design of an effective interaction strategy in highly automated vehicles in order to clarify the role of the driver in each moment. The role of the driver in the context of automated driving needs to be flexible and able to adapt to different stimuli and circumstances.

Another key topic discussed in the workshop was the lesson that can be learnt from other domains, such as aeronautics and avionics, in which the interaction with highly automated systems is consolidated. An interesting topic was the concept of "dark-cockpit philology" used to adapt and minimise the information in certain given conditions.
The concept of minimization is also reinforced since, as far as discussed, the driver does not want to be disturbed in highly automated conditions when his/her intervention is not really needed.

Moreover, the communication with external actors (e.g. pedestrians and VRU in general, and also other vehicles) has been identified as important for the implementation of future human-automation interaction strategies. Since the focus of AutoMate is on human-automation cooperation mostly from a "driver-perspective" (i.e. focused on the interaction between the driver and the ego-vehicle, in which the most important topics are the understandability, the acceptance, the alertness and so on), this perspective has not been used in the project. However, being this topic complementary to the AutoMate's approach, these issues can be introduced and analysed in further projects.

Table 1 summarizes the main concepts emerged from the workshop and the related actions took by AutoMate partners.

Table 1: HMI-related issues emerged in ART workshop and related actions

Relevant topic	Action
Relevance of communication with external used	This concept, complementary with AutoMate approach will be explored in the future by the partners
Dark cockpit philology	In TeamMate HMI, when the car is in Automated Mode, the information is minimized and the representation is simplified in order to reduce the effort required to the driver

Trust	The concept of Trust and the role of the HMI in the effective building of trust will be analysed with more emphasis in WP6 experiments. Trust will be considered as one of the most important KPIs.

The refinements to the HMI made in the 3rd cycle and included in this deliverable are also inspired (to the extent that it is possible) to these principles discussed in the workshop.

Finally, the findings collected in the workshop will be used to further refine the enablers (including the HMI) after the project and to speed up the process to put these concepts and enablers on the market.

4 Status of WP4 enablers after cycle 3 (REL)

As stated in the introduction, the aim of the 3rd cycle in WP4 has been the improvement of the TeamMate HMI, by integrating the results of cycle 1 and cycle 2, and to refine the software to encourage the integration in the simulator and vehicle demonstrators.
The paragraphs that make up this chapter describe the three main components of the TeamMate HMI: Interaction modality, TeamMate Multimodal HMI and Augmented Reality HMI.

4.1 E6.1 - Interaction modality (ULM)

4.1.1 Guidelines for TeamMate HMI strategy

As a result of the experiments conducted within AutoMate regarding Enabler 6.1, interaction guidelines were derived. These interaction guidelines should help design a usable and safe system in TeamMate situations where the driver and the vehicle perform the driving task cooperatively.

4.1.1.1 General idea

According to the TeamMate car concept, driver and the TeamMate car should be considered as a joint system with a flexible task distribution (Hollnagel, Nåbo, & Lau, 2003). For this, the automation should be designed as a team player that can coordinate with driver (Christoffersen & Woods, 2002). With the consideration of the required mutual "Directability" for the successful cooperation (Klein, Woods, Bradshaw, Hoffman, & Feltovich, 2004), the automation have to be designed to support drivers during their problem solving and also adaptive. This is challenging for automation design facing complex situations, such as highly automated driving where the decisions should be made when the automations' capability is out of the scope. If the human is out-of-the-loop in such a situation and initiates the wrong maneuver, there can be a major safety hazard (e.g. non detected oncoming traffic).

In the mentioned situation where the automation reaches its sensor limitation and cannot decide for the best option, how to design a Take Over Request (TOR) is an important issue, which have been addressed in many studies (Gold, Damböck, Lorenz, & Bengler, 2013; Gold & Bengler, 2014). Moreover, the interaction strategy needs to be designed to help drivers to take the control back on time to achieve a safe and efficient driving. In the AutoMate scenarios the decision making on a maneuver level is done by the driver while the TeamMate car still continues to safely plan and executes the trajectory planning, thus keeps the lateral and the longitudinal control of the car. The precondition for such a safe and efficient completion of the driving task is a minimum of attention and involvement in the driving task from the driver, this has to be assured by the car. The natural interaction is a highly trained interaction style. While driving in manual mode, the driver learns action schemes which have to be executed to perform a specific maneuver. The learned thread of actions are activated and the driver should act in a way that is also shown while driving such a maneuver in manual mode. This learned action schemes can let the driver be more involved in the driving task and show a higher attention to the crucial information, which helps driver quickly and effectively to take the control back.

In addition, the application of the Augmented Reality (AR) in the automated driving has demonstrated positive effects, such as optimal distribution of the visual attention before executing a lane change maneuver (Eyraud et al., 2015). In addition, with the presented depth of the information by AR, the application of AR tends to also influence the reaction time after the TOR signal (Gold et al., 2013; Langlois & Soualmi, 2016). With these findings above, it can be considered to combine the natural interaction with AR together for designing effective interaction strategy for automated driving.
This cooperation between the driver and the autonomous car in these situations result in a TeamMate concept where the driving task is completed with a supplementary exchange of crucial information.

4.1.1.2 Guidelines ("rules")

Based on the requirements of successful cooperation and our empirical studies, following guideline are proposed to help design interaction strategy for highly automated driving:

Choice of control unit

The interaction should be done by already existing control units. That means that the steering wheel or the gas and breaking pedals can be used in situations where they are also used while driving manually. As an example, the steering wheel is highly used in overtaking maneuvers. Therefore, this is the control unit of choice while initiating an overtaking maneuver.

Definition of intention

The drivers intention of interacting with the car and thus initiate a specific maneuver should be recognized by the system with predefined thresholds. There are three different threshold that have to be defined:

1. Unintentional – the drivers intention was not to initiate the maneuver it was only an accidental interaction with the interaction modality
2. Intention to interact with the TeamMate system – the driver wants to fulfil his part as a team partner and interact with system in the right way
3. Intention to take back control – the driver wants to take back full control and deactivate the system

Feedback

The debriefing interviews of previous experiments within AutoMate showed, that users want to get a haptic feedback while using the natural interaction. The interaction should be designed considering the ideas of the H-Metaphor (Flemisch et al., 2003). The driver should experience a haptic feedback – other feedback modalities like auditory or visual feedback can additionally be included. A good example for a haptic feedback in today´s cars is the "kickdown" (downshifting an automatic transmission car for better acceleration) function. The driver feels a force feedback while pushing the cars gas paddle all the way to the floor.

Driver Monitoring

In a cooperative interaction mode the system should also be aware of the driver´s state. Therefore a continuous driver monitoring is crucial to adapt the interaction in an appropriate way. The driver monitoring should rate the involvement of the driver in the driving task based on values like sleepiness or distraction.

Adaptitivity

The definition of the thresholds (see Guideline 2) should adapt according to the drivers attention (see Guideline 5). A distracted driver should have a higher effort in the interaction with the system to rule out an unintentional interaction and enhance the immersion into the driving task.

Time to interact

The time to interact with the system should be reasonable and as fast as possible. As an adaption to Fitt´s law (MacKenzie & Buxon, 1992) one can say that the distance and size of natural interaction elements are appropriate and in comparison to a touch display more suitable for the interaction.

Second thoughts

A previous study within the AutoMate project showed that drivers tend to be more involved in the maneuver after initiating the maneuver using the natural interaction (see Figure 3). Results show that after initiating the maneuver the drivers observe the street longer when they initiated the maneuver via the natural interaction. Therefore, when the driver wants to abort the maneuver or take back the control of the car after initiating the maneuver, it is more likely they have a higher situation awareness after interacting by natural interaction.

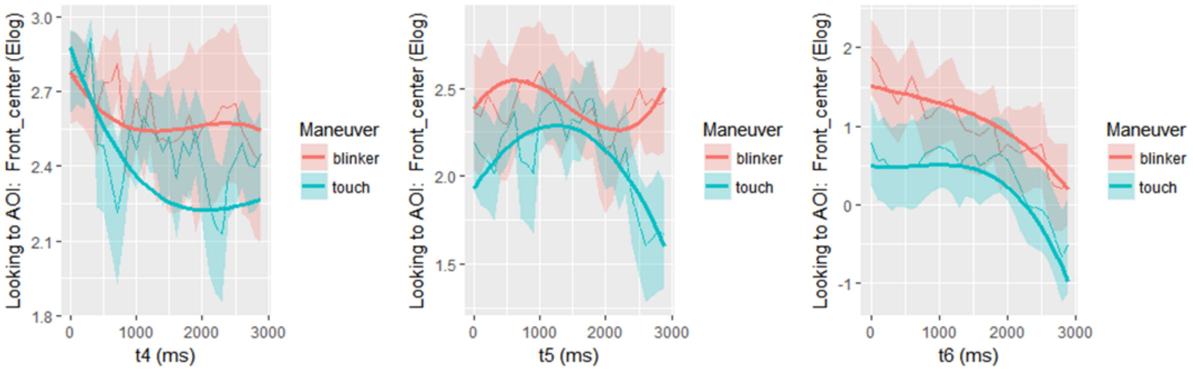


Figure 3: Blinker (natural interaction) versus touch interaction. Looking at front center AOI proportion transformed (Elog). Three seconds after initiating the overtake (t4), three to six seconds after initiating the overtake (t5) and three seconds before being b

4.2 E6.2 – TeamMate Multimodal HMI (REL)

4.2.1 Information Structure

The information structure is the means to select the information to be placed in the HMI. For each HMI state, the information needed to perform specific tasks have been chosen to be place on the HMI.
The driver's expected behavior has been defined through a task partition: each subtask served as input to define the HMI element to be designed and implemented on the interface, i.e. to create the HMI strategy.
Table 2 shows the TeamMate information structure for the 3rd cycle.

HMI state	Main driver task	Subtask
Manual Mode	Driving	Handle the current speed
		Be aware of the RPM
		Check the vehicle state
		Be aware of the automation state
	Monitoring	Be aware of the long-term surrounding situation

		Be aware of the estimated time to arrival
	Entertainment	Manage phone calls
		Manage multimedia entertainment functions
Automated Mode	Monitoring (not requested, but enabled)	Be aware of the current speed
		Check the vehicle state
		Be aware of the possible events for disengagement
		Check the estimated time to arrival
		Be aware of the automation state
	Entertainment	Manage phone calls
		Manage multimedia entertainment
		Select menu settings
A H2A Support in perception (in Automated Mode)	Monitoring	Check the current speed
		Check the vehicle state
		Check the automation state
	Support the automation	Be aware about what kind of support the automation needs
		Trigger the support
	Entertainment	Manage basic multimedia functions
B A2H support in perception (in manual driving)	Driving	Handle the current speed
		Be aware of the RPM
		Check the vehicle state
		Be aware of the automation state
	Receive a support from the automation	Understand the meaning of the support from the automation
C H2A support in action (in Automated Mode)	Monitoring	Be aware of the current speed
		Check the vehicle state
		Be aware of the automation state
	Understand the expected support, i.e. the transition	Receive the explanation of the expected support
		Be aware of the expected behaviour
D	Monitoring	Handle the current speed
		Be aware of the RPM

A2H support in action (in manual driving)		Check the vehicle state
	Understand the support needed	Be aware of the automation state
		Be aware of the support received
		Be aware of the reason of the support needed
	Entertainment	Limited access to entertainment functions (due to potential critical situation)
Safe Mode	(Information needed only if the driver comes back into the loop)	Check the current speed
		Be aware of the RPM
		Check the vehicle state
		Check the automation state
		Be aware of the safe manouver

Table 2: TeamMate information structure

4.2.2 Overall HMI Strategy

The HMI strategy is the means to implement the overall information structure and to drive the HMI design.
Starting from the subtasks performed by the driver and the information communicated to him/her in each automation mode, the related HMI element has been designed and the most appropriate target (in terms of screen or device) has been selected.
The first version of the HMI strategy was defined in cycles 1 and 2; in this chapter it has been improved according to the comments collected in the validation experiments performed at the end of the 2nd cycle.

The focus of the TeamMate Multimodal HMI has been placed on the modality in which the information is shown and explained to the user.

The aim of this enabler (in particular the visual part) is to give a "WHY LAYER", i.e. to make the automation transparent and to effectively communicate the reason of choices (including the reasons of limitations) and the expected behaviour.

This conceptual layer has been used to increase the trust and to create the Team: through the HMI the human and the vehicle understand and support each other, creating this new innovative approach to automated driving.
At the same time, the experiments carried out in the project showed that natural interaction (such as the "analogue" use of commands – e.g. the accelerator - to suggest an action) was considered the most effective to give

input to the system. For these reasons, no speech-based interfaces have been developed in the project. Although they're widely considered as one of the most effective tools to interact while driving, for the scope of the project it was considered that they were not the optimal solution.

4.2.2.1 Manual Mode

Main driver task	Subtask	Information / HMI element	Device / Display
Driving	Handle the current speed	Speedometer	Cluster
	Be aware of the RPM	RPM	Cluster
	Check the vehicle state	Icons, tell-tales	Cluster
	Be aware of the automation state	Automation State Label	Cluster + Central Display
Monitoring	Be aware of the long-term surrounding situation	Map	Cluster
	Be aware of the estimated time to arrival	ETA	Cluster + Central Display
Entertainment	Manage phone calls	Phone icon and label	Central Display
	Manage multimedia entertainment functions	Radio and multimedia functions	Central Display

Table 3 HMI strategy: Manual Mode

4.2.2.2 Automated Mode

Main driver task	Subtask	Information	Device / Display
Possible Monitoring	Be aware of the current speed	Resized Speedometer	Cluster + Central Display
	Check the vehicle state	Icons, telltales	Cluster

	Be aware of the possible events for disengagement	Trip representation	Cluster + Central Display
	Check the estimated time to arrival	ETA	Cluster
	Be aware of the automation state	Automation State Label	Cluster + Central Display
Entertainment	Manage phone calls	Phone icon and label	Central Display
	Manage multimedia entertainment	Radio and multimedia functions	Central Display
	Select menu settings	Menu settings labels	Central Display

Table 4 HMI strategy: Automated Mode

4.2.2.3 H2A Support in perception (A)

Main driver task	Subtask	Information	Device / Display: Driver attentive	Device / Display: Driver distracted
Monitoring	Check the current speed	Resized speedometer	Cluster	Cluster
	Check the vehicle state	Icons, tell-tales	Cluster	Cluster
	Check the automation state	Automation State Label	Cluster + Central Display	Cluster + Central Display
Support the automation	Be aware about what kind of support the automation needs	Support representation	Cluster + Central Display	Cluster + Central Display
	Trigger the support	Feedback from driver to automation	Cluster + Central Display	Cluster + Central Display
Entertainment	Manage basic multimedia functions	Functions labels	Central Display	Central Display

Table 5 HMI strategy: H2A support in perception

4.2.2.4 A2H Support in perception (B)

Main driver task	Subtask	Information / HMI element	Device / Display
Driving	Handle the current speed	Speedometer	Cluster
	Be aware of the RPM	RPM	Cluster
	Check the vehicle state	Icons, telltales	Cluster + Central Display
	Be aware of the automation state	Automation State Label	Cluster + Central display
Receive a support from the automation	Understand the meaning of the support from the automation	Support representation	Cluster + Central display
Entertainment	Manage phone calls	Phone icon and label	Central Display
	Manage multimedia entertainment	Radio and multimedia functions	Central display
	Select menu settings	Menu settings labels	Central display

Table 6 HMI strategy: A2H support in perception

4.2.2.5 H2A Support in action (C)

Main driver task	Subtask	Information	Device / Display	
			Driver attentive	Driver distracted
Monitoring	Be aware of the current speed	Speedometer	Cluster	Cluster

	Check the vehicle state	Icons, telltales	Cluster	Cluster
	Be aware of the automation state	Automation State Label	Cluster + Central display	Cluster + Central display
Understand the expected support, i.e. the transition	Receive the explanation of the expected support	Message about support	Cluster + Central display	Cluster + Central display + nomadic device + haptic seat + ambient lights
	Be aware of the expected behaviour	Message about expected behavior	Cluster + Central display	Cluster + Central display + nomadic device

Table 7 HMI strategy: H2A support in action

4.2.2.6 A2H Support in action (D)

Main driver task	Subtask	Information / HMI element	Device / Display
Monitoring	Handle the current speed	Speedometer	Cluster + Central Display
	Be aware of the RPM	RPM	Cluster
	Check the vehicle state	Icons, telltales	Cluster

	Be aware of the automation state	Automation State Label	Cluster + Central Display
Understand the support, i.e. the handover	Be aware of the support received	Support representation	Cluster + Central Display
	Be aware of the cause of the support needed	Message about support	Cluster + Central Display
Entertainment	Limited access to entertainment functions (due to potential critical situation)	Radio and multimedia functions	Central display

Table 8 HMI strategy: A2H support in action

4.2.2.7 Safe Mode

Main driver task	Subtask	Information / HMI element	Device / Display
Information needed only if the driver comes back into the loop	Check the current speed	Speedometer	Cluster
	Check the vehicle state	Icons, telltales	Cluster
	Check the automation state	Automation State Label	Cluster / Central display
	Be aware of the safe manouver	Warning (safe manouver activated)	Cluster / Central display

Table 9 HMI strategy: Safe Mode

As emerged from the HMI strategy, the most critical task is related to the transition of control between the driver and the vehicle. The approach used by AutoMate is to adapt the information according to the driver's state.
The request of support (i.e. the request of transition) is given by adapting the information according to the attentional level of the driver. Using the Driver Monitoring System (developed in WP2 and integrated in the demonstrators), the TeamMate system becomes able to tailor the feedback to the user.
For example, when the driver is distracted and the system asks for a transition of control, the information is given in different devices, according to the attentional state and the Area of Interest where the driver is looking.

4.2.3 Improvements in the 3rd cycle

This chapter describes the improvements made in the design and development of E6.2, TeamMate Multimodal HMI, in the 3rd cycle.
The components that are part of this enabler have been merged into a single enabler, as stated in D4.5. All the components developed in the framework of this enabler are described in this chapter. They are:

- Instrument cluster,
- Central display,
- Ambient lights,
- Haptic HMI (on seat cover),
- HMI on nomadic device (application on the phone).

4.2.3.1 Instrument Cluster

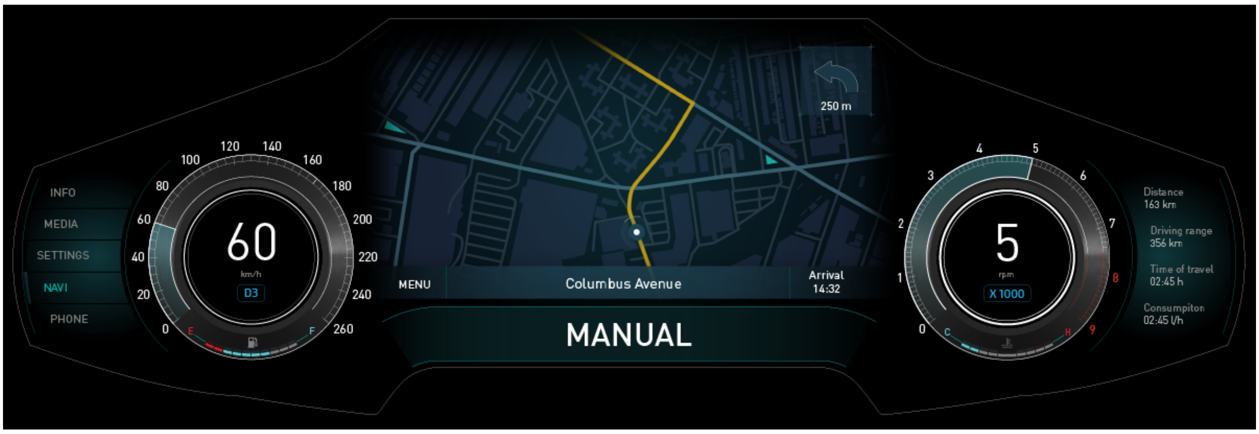


Figure 4: Instrument cluster in Manual Mode

Figure 5: Instrument cluster n Automated Mode

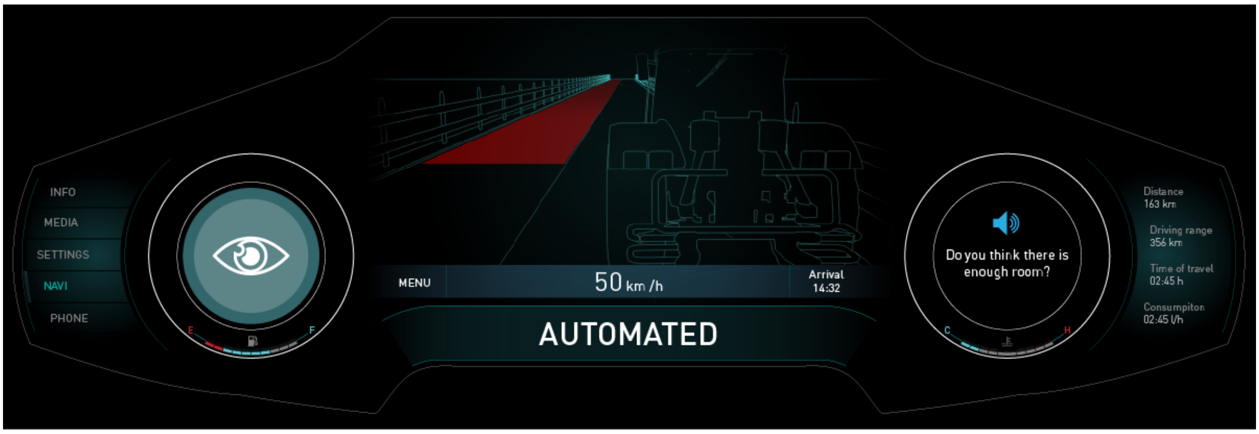


Figure 6: Instrument cluster in H2A support in perception

Figure 7: Instrument cluster in A2H support in action

The component “Instrument Cluster” can be considered one of the most important tools of the HMI system, since in it are allocated the majority of driving-related information. The main changes in the 3rd cycle concerned the development of the software with the new graphics and the integration in the demonstrators.

Moreover, the instrument cluster is the tool in which the negotiation (that is the core of the “negotiation-based approach”) happens. This innovative approach reflects the concept of the project, building a “team” between the human and the automation sharing responsibilities and decisions, with a sophisticated communication and articulated interaction modality.

The HMI mode in which the cooperation is exploited at its best is the H2A support in perception, in which the vehicle communicates through a 3D video embedded into the instrument cluster:

- explaining the limit,
- recalling the driver attention
- explaining the expected behavior
- giving a feedback after the driver’s input

These 4 information levels can be considered the core of the negotiation-based approach.

4.2.3.2 Central Display

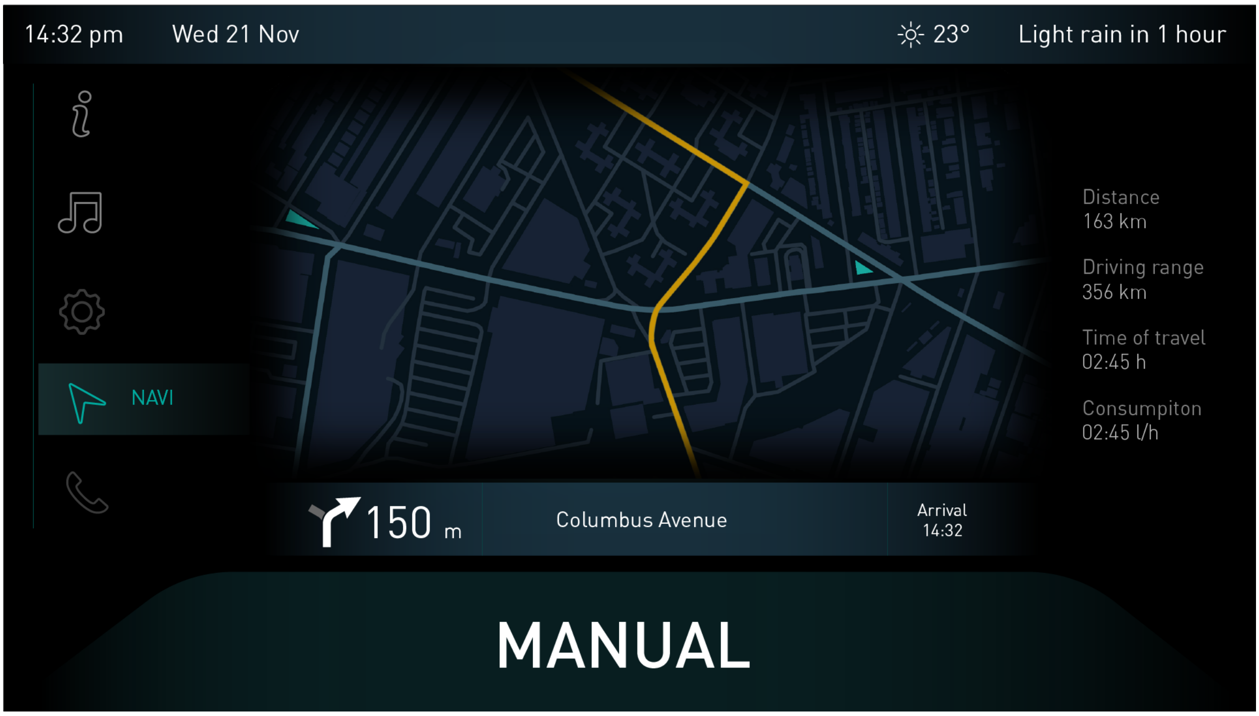


Figure 8: Central Display in Manual Mode

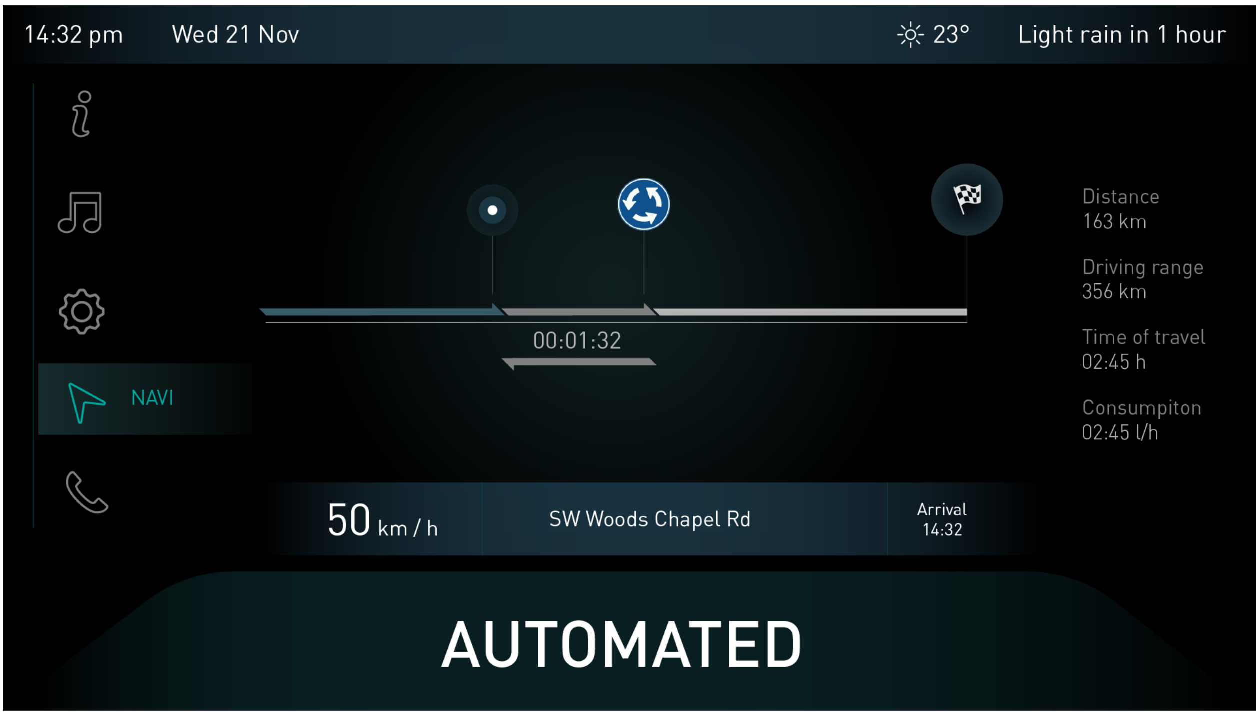


Figure 9: Central Display in Automated Mode

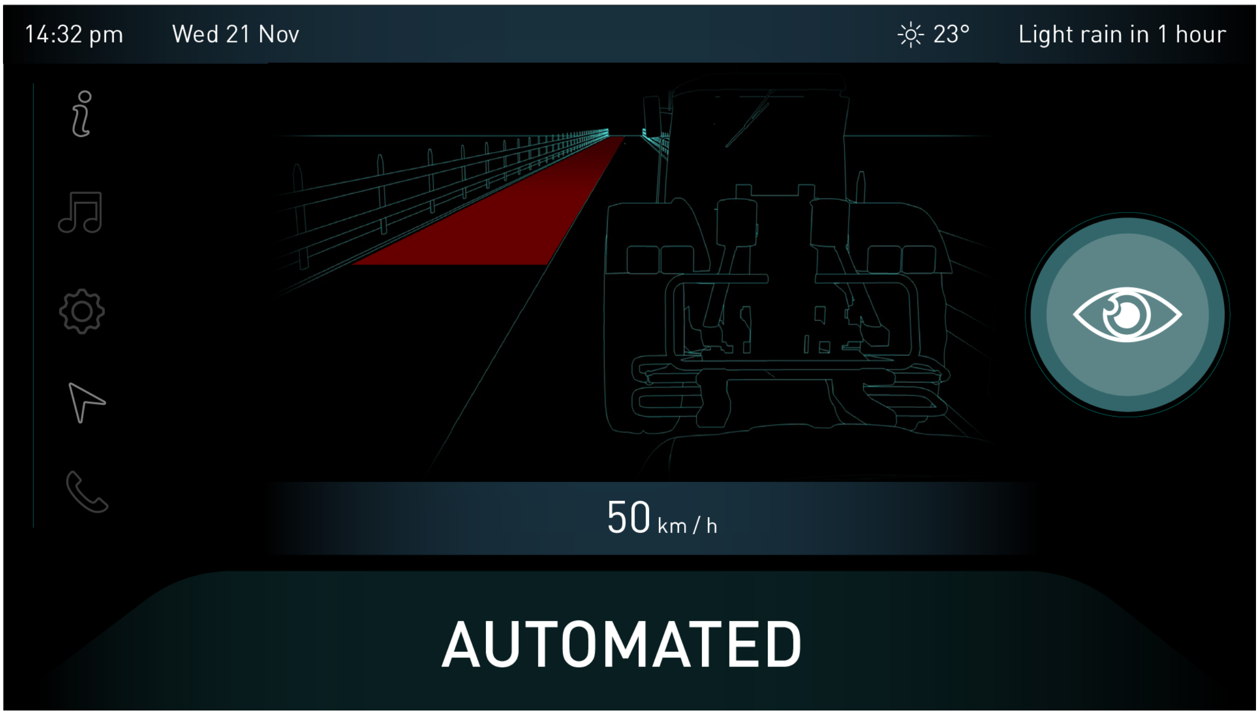


Figure 10: Central Display in H2A support in perception

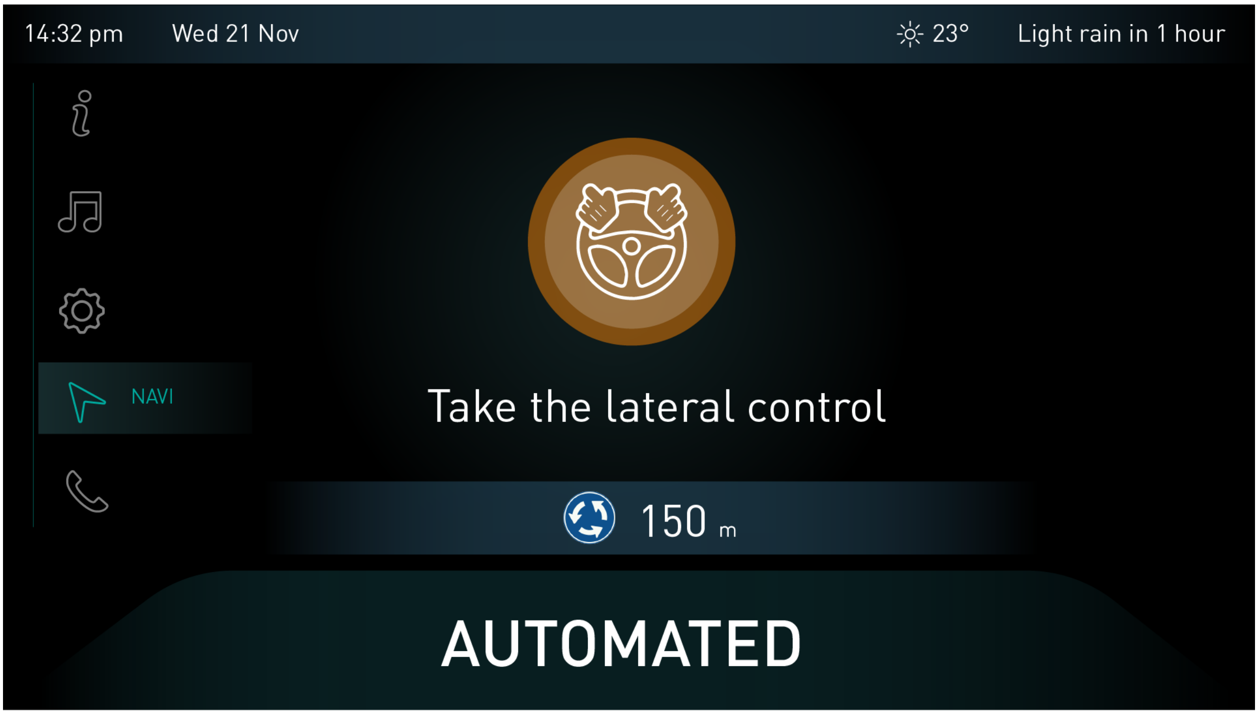


Figure 11: Central display in "Shared Control" request

Figure 12: Central Display in A2H support in action

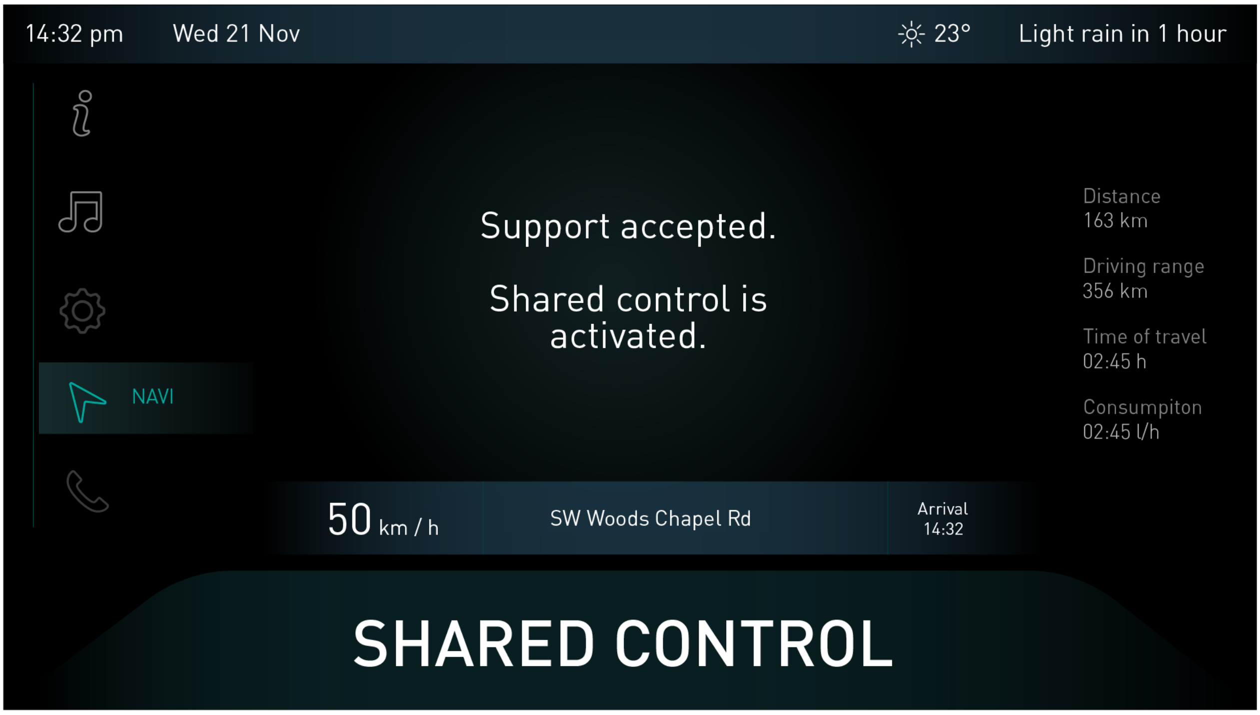


Figure 13: "Shared Control Accepted" on Central display

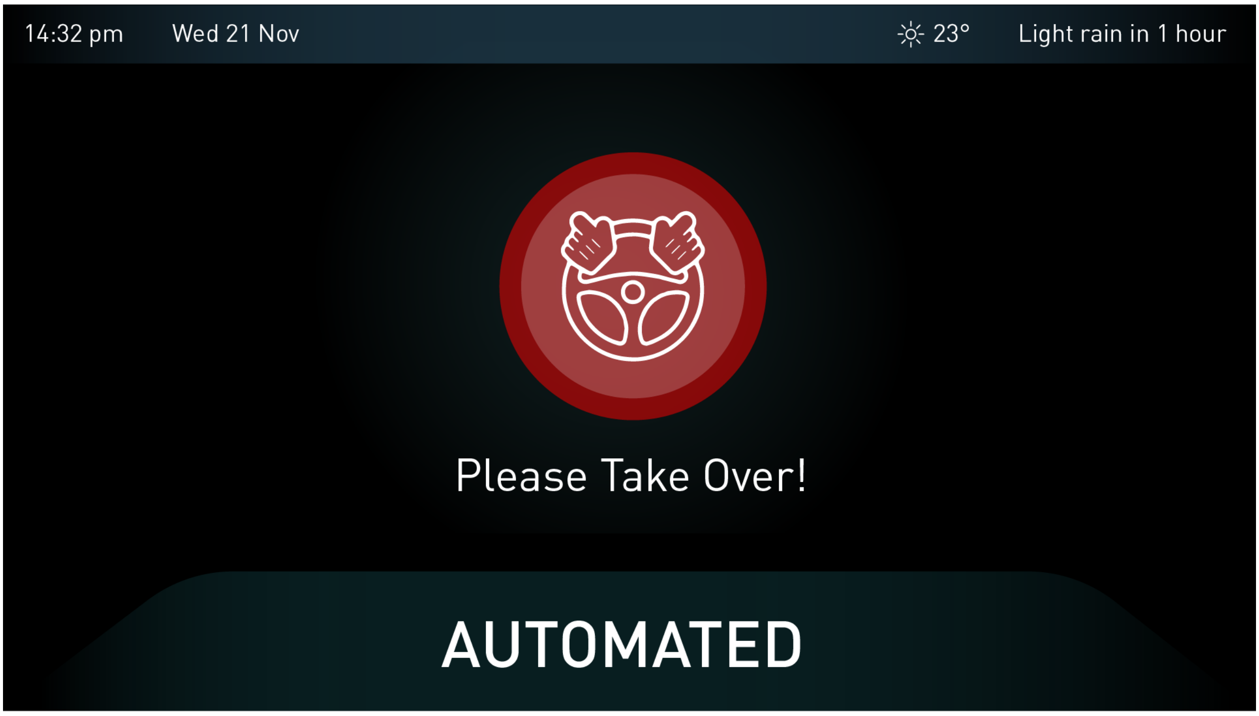


Figure 14: Take Over Request on Central Display

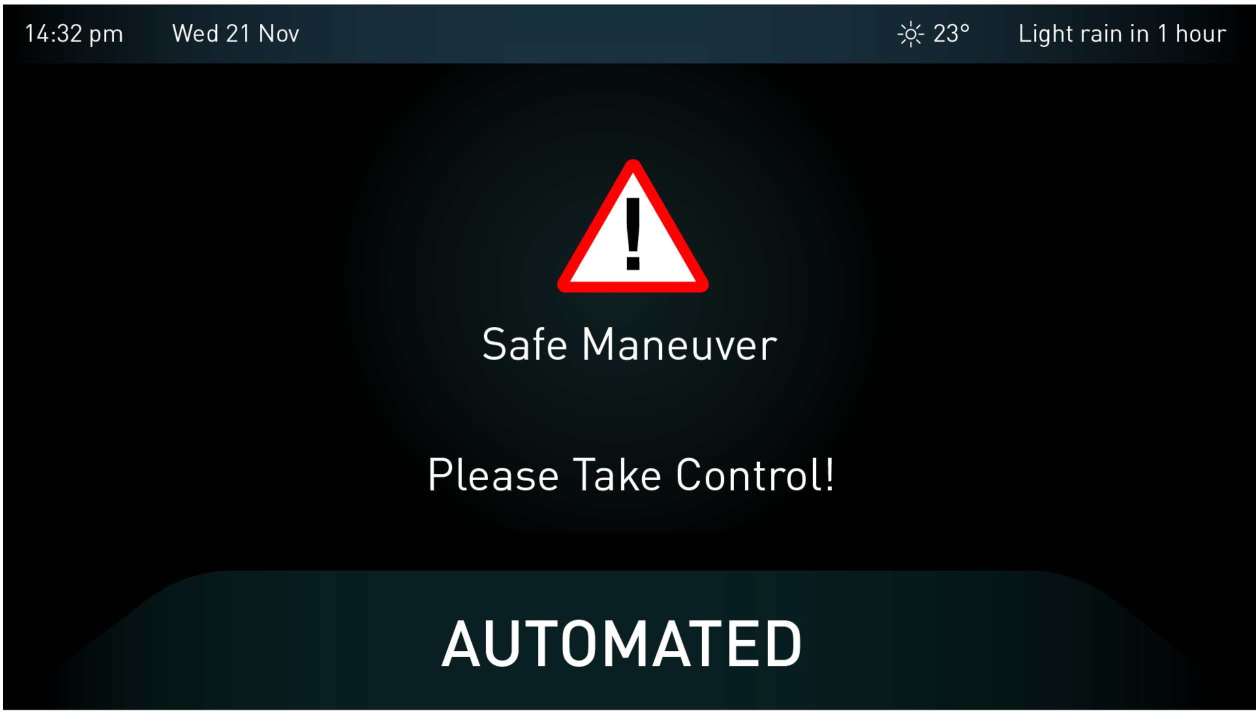


Figure 15: Central Display in Safe Mode

The “Central display” component was only conceptualized in the 2nd cycle. In this cycle, it has been designed and developed in order to be semantically and graphically consistent with the instrument cluster.
The most relevant information is mirrored in this device, while not-driving related services are shown only on it.

4.2.3.3 Ambient lights

In the 2nd cycle, the concept of ambient lights as a means to improve the communication between the vehicle and the driver in critical situations has been investigated with an experiment of validation. The ambient lights are designed with LED strips in order to work with daylights.

The results, reported in full in D4.4, has shown that ambient lights have been perceived as an encouraging tool to improve the interaction with highly automated vehicles, but the colors selected and tested in the 2nd cycle have been considered as not effective for the intended purpose.
According to the results of the validation, the color has been changed as follows.

Table 10: Ambient lights colour in the 3rd cycle

Light color	HMI state
Green	H2A support in perception
Orange	H2A support in action

The ambient lights have been integrated in REL driving simulator and tested in order to evaluate if the improvements made in the 3rd cycle can be considered as satisfactory. The research questions for the validation of ambient lights are the same of the 2nd cycle, i.e. the understandability and the effectiveness.

4.2.3.4 Haptics HMI

The haptics HMI, conceptualized in cycle 1 and cycle 2, has been developed in cycle 3 with a haptic seat cover designed and integrated in REL driving simulator.

Figure 16: Haptic seat cover integrated in REL driving simulator

The haptics HMI is based on a Phidgets programmable board that, connected with a sensorized seat cover.
The board is programmed through Phidgets API: the logics of activation of the haptic seat have been embedded into the QT project of the visual HMI, in order to synchronize the vibration with the visual and audio feedbacks.

In the implementation logic, the seat cover vibrates only when the driver is distracted, in order to take him/her back in the control loop. The message communicated with haptics is the H2A support in action, i.e. the Take Over Request.

The introduction of haptics elements has been one of the most important topics of the third cycle, and one of the main focus of the validation of TeamMate multimodal HMI. The results of the experiment conducted to assess the effectiveness of this tool is reported in Chapter 5.3 of this document.

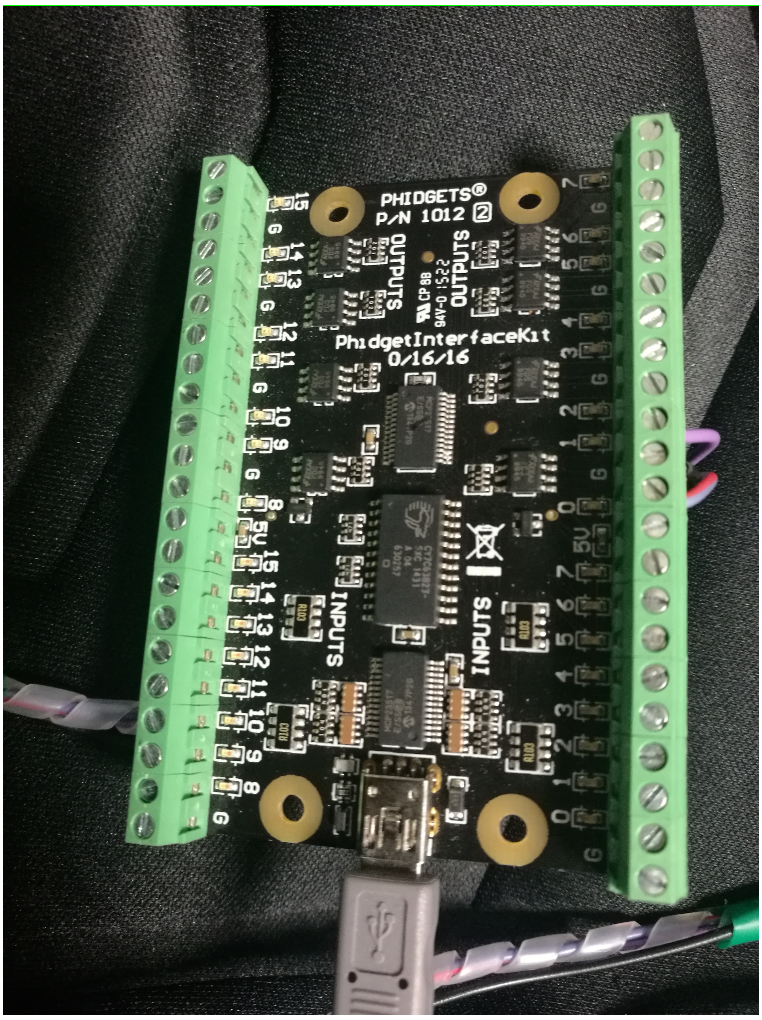


Figure 17: Phidgets board used to implement the haptics in the seat cover

4.2.3.5 HMI on nomadic device (mobile app)

In the previous cycles, the use of additional HMI on nomadic devices has been discussed, with a review of the preliminary concepts and attempts of designing a distributed HMI, by exploiting connected mobile devices.

Figure 18: HMI on mobile app

In the 3rd cycle, the wireframe of a mobile application has been developed, in order to be implemented in demonstrators. The application also demonstrates the potential of AutoMate SDK, since it works within this system.
Since the telephone will be connected to the vehicle, the application will be able to read the vehicle data and to inform the driver (through a pop-up) of an imminent risk, such as a transition of control. Moreover, the application will read the Driver Monitoring System (DMS) data, showing the information on the app only when the driver is looking at the Area of Interest related to that device. The refinement and the integration of this tool will be described in the framework of WP5.

4.2.4 Demonstrator in which E6.2 has been / will be integrated

Since the 3rd project cycle was the last for the design, development and validation of the technological enablers, the activities also focused on the integration of these technologies in the demonstrators.

The enabler E6.2 “TeamMate multimodal HMI” has been integrated into all the demonstrators. The status of integration is included in Table 11.

Table 11: Mapping between E6.2 and demonstrators

Demonstrator	Status of the integration at M28
REL simulator	Integrated
VED simulator	Integrated
ULM simulator	Integrated
CFR vehicle	The integration will be finalized in February 2019
VED vehicle	Integrated (minor changes will be done to adapt the HMI to the scenario)
ULM vehicle	Integrated

Figure 19 shows the state machine, that simplifies the explanation of the states’ transition of the TeamMate car. In the picture, the Central displays are represented.

Figure 19: HMI State machine with Central Display

4.3 E6.3 – Augmented reality (HMT)

4.3.1 Adaptation of the HMI strategy for the augmented reality

4.3.1.1 Manual Mode

In manual mode, the AR-HMI doesn´t display any element in order to avoid overloading the driver with information already displayed in the cluster or the central panel.

4.3.1.2 Automated Mode

Main Driver Task	Subtask	Information/HMI element	Device/display	
			Driver attentive	Driver distracted
	Be aware of automation´s actions/behaviour	Overtaking corridor/holding line corridor	AR-HMI	none

Table 12: AR-HMI strategy: Automated Mode

In automated mode, the AR-HMI is used to display the information related to the actions/behaviours of the automation.

4.3.1.3 H2A Support in perception (A)

Main Driver Task	Subtask	Information/HMI element	Device/display	
			Driver attentive	Driver distracted
Support the automation	Be aware about what kind of support the automations needs	Support representation	AR-HMI	AR-HMI

Table 13: AR-HMI strategy: H2A Support in perception

In automated mode, the driver will support the automation via different media. In the case of the AR-HMI, a support representation as a graphical visualization will be displayed in order to inform the type of requested support, e.g. in case of the sensors of the vehicle cannot detect opposite traffic during an overtaking manoeuvre due to an obstruction in front of the EGO vehicle. Another possible case is when the driver is requested to observe the traffic inside a roundabout because of the limitation of the sensors.

4.3.1.4 A2H Support in perception (B)

Main Driver Task	Subtask	Information/HMI element	Device/display
Receive a support from the automation	Understand the meaning of the support from the automation	Support representation	AR-HMI

Table 14: AR-HMI strategy: A2H Support in perception

In manual mode, the AR-HMI will display a support representation as a graphical visualization to inform possible situations that the driver may not be aware or he/she completely doesn´t know, e.g. when the automation detects that the driver will make a very risky manoeuvre like an overtaking without checking the opposite traffic or in case of a construction site ahead. In such scenarios the AR-HMI could advise of the obstacle in advance and suggest a manoeuvre to the driver.

4.3.1.5 H2A Support in action (C)

Main Driver Task	Subtask	Information/HMI element	Device/display	
			Driver attentive	Driver distracted
Understand the expected support, i.e. the request for a manoeuvre	Receive the explanation of the expected support	Support representation	AR-HMI	AR-HMI

Table 15: AR-HMI strategy: H2A Support in action

In automated mode, the AR-HMI will help to engage the support in action from the driver by using graphical visualizations, e.g. when the automation requests the driver to decide a manoeuvre, like overtaking or following the front vehicle.

4.3.1.6 A2H Support in action (D)

Main Driver Task	Subtask	Information/HMI element	Device/display
Monitoring	Handle the current speed	none	none
	Be aware of the RPM	none	none
	Check the vehicle state	none	none
	Be aware of the automation state	none	none

Table 16: AR-HMI strategy A2H support in action

In the case of support in action from part of the automation, the AR-HMI will not display visualizations in order to avoid duplicating information displayed on the cluster or central panel and also to not divert the attention of the driver out of the normal HMI.

4.3.2 Improvements and implementation

4.3.2.1 Improvements

After the 2nd cycle, a few elements of the AR-HMI have been redesigned in order to improve the communication with the driver in an emphatical way. The concept of the corridor was reshaped to make it more visual appealing and to expand the messages within. Other elements have been added to give accurate information, e.g. a warning signal was added to inform the type and location of the risk, missing road lines, limitation of the sensor to perceive hidden vehicles. In this 3rd cycle the corridor is not only used to explain the behaviour of the vehicle, but also can be applied in a cooperative way for the "learning processes" connected with the Enabler 4.2 when the vehicle is in automated mode.

For this 3rd cycle, ideation sketches served visual and functional improvements of the AR-HMI (see Figure 20). Different ideas were researched to improve the graphical elements displayed by the AR-HMI.

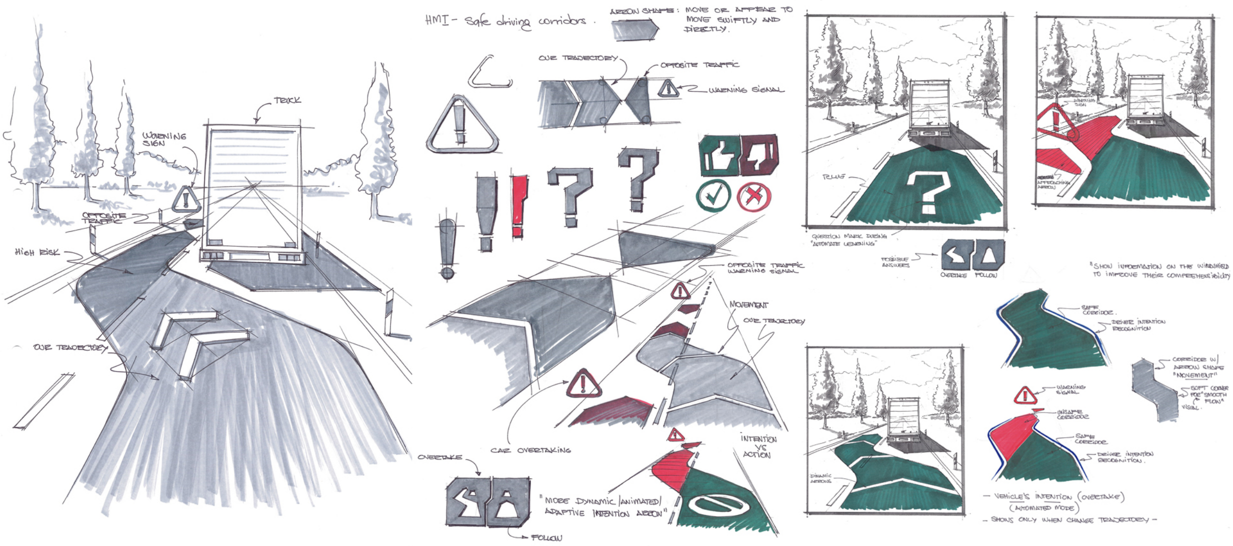


Figure 20: Ideation sketches for the 3rd cycle.

One of the elements removed for the 3rd cycle is the "blue" intention arrow mentioned in D4.4, chapter 3.7.2. This was replaced with an arrow with the shape of the corridor as the behaviour of the vehicle that will match with the intention (desire) of the driver. The intuitive perception of the shapes used in the AR-HMI to provide an efficient communication with the driver (see Figure 21).

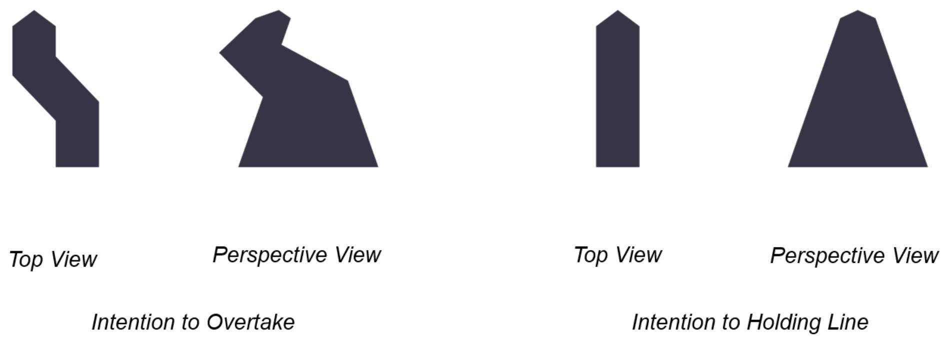


Figure 21: Intuitive shapes

The body of the corridor was split in two elements to codify different type of messages on the same figure (see Figure 22). In order to expand in the future the use of the graphics displayed for the AR-HMI, different colours were used to codify different messages, e.g. a bluer corridor can be used for the interaction with the driver by suggesting a different route or a different manoeuvre based on the traffic information through the V2X communication.

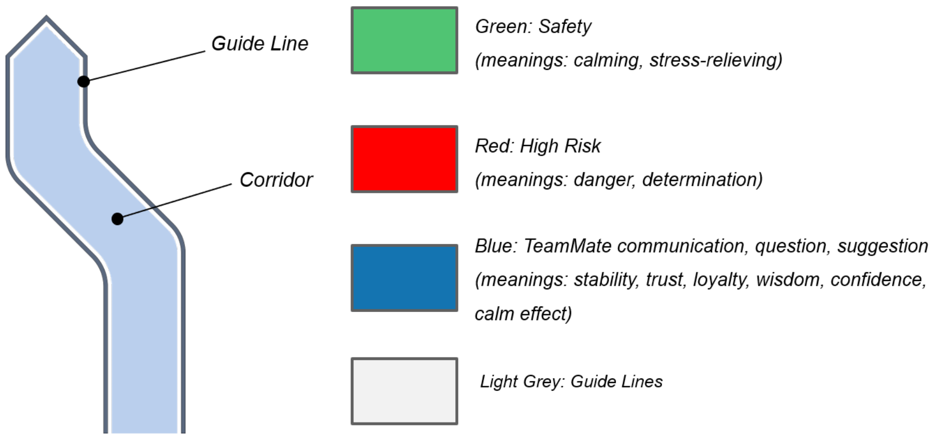


Figure 22: Corridor components and colour meanings

A storyboard was made to have a better understanding of the different states of the AR-HMI in the different scenarios (see Figure 23). The storyboard illustrates in Peter´s scenario, a vehicle approaching to a slower vehicle and the different manoeuvres that can be performed depending on the specific situation.

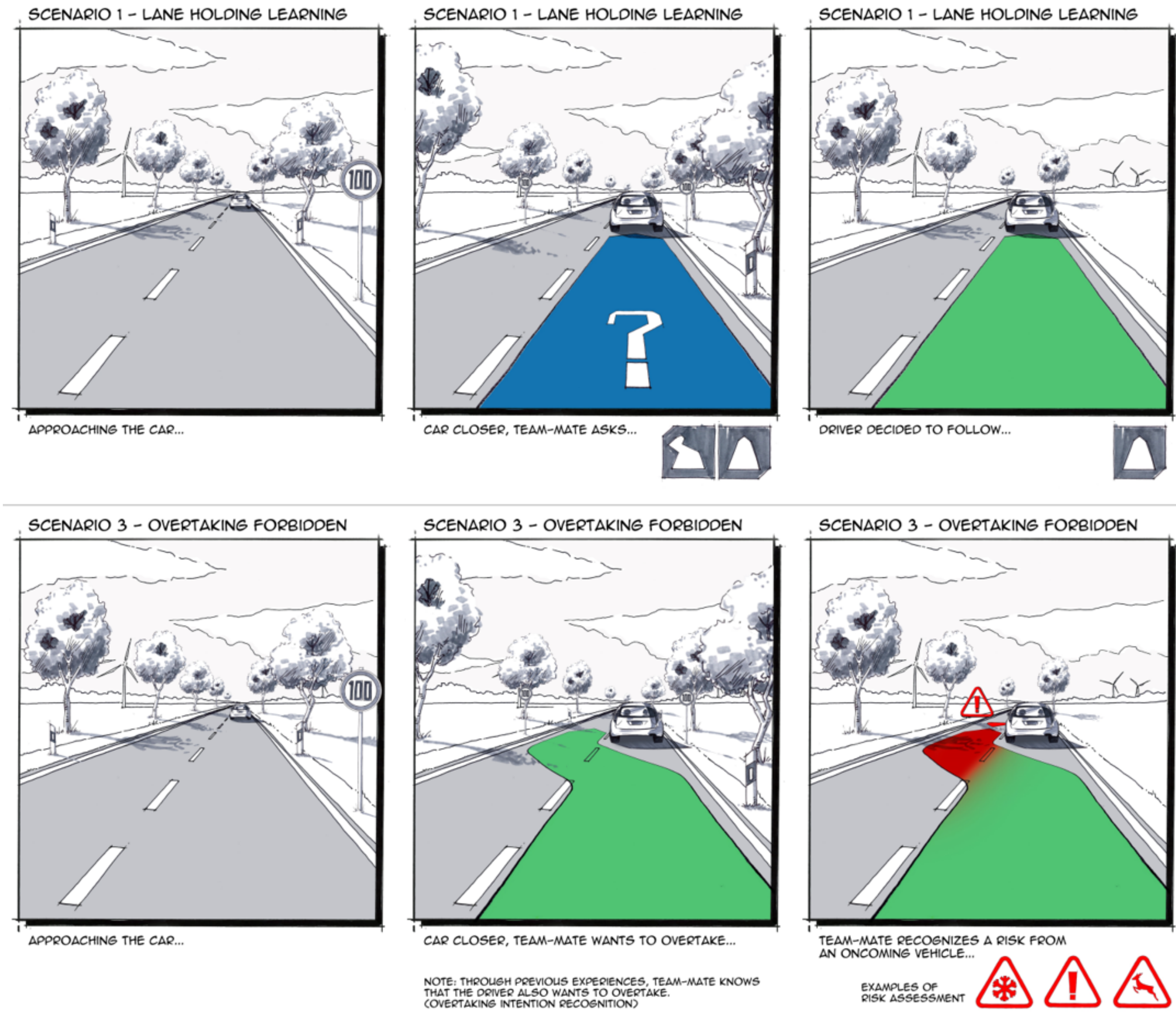
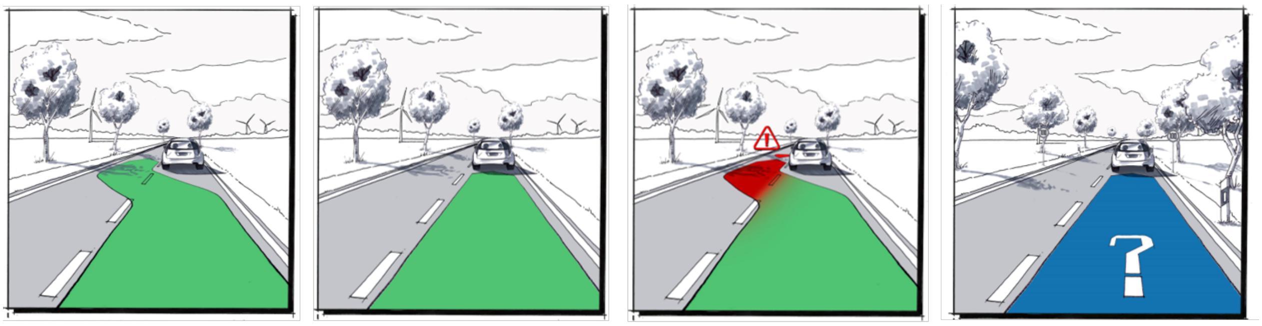


Figure 23: Storyboard of different Peter´s scenarios

Different functions of the AR-HMI are displayed in the different scenarios: Car Holding line, Overtaking, Overtaking forbidden plus a new scenario where the driver interact with the EGO vehicle in a cooperative mode (see Figure 24). The new visualizations relate to the enabler 4.2 of the “Learning of intention from the driver”, where the vehicle asks the driver which manoeuvre he/she would perform in a very early stage of the learning process, when the vehicle´s system starts to adjust to the driver´s driving style.



The TeamMate vehicle communicates to the driver that the vehicle will perform an overtaking manoeuvre via the "green overtaking arrow".

The TeamMate vehicle communicates to the driver that the vehicle will follow the lead vehicle via the "green car-following arrow".

The TeamMate vehicle communicates to the driver that the vehicle has recognized the driver's intention to overtake but deems the manoeuvre dangerous via the "red overtaking arrow".

Potentially, the TeamMate vehicle could propose an overtaking or following manoeuvre via the "blue overtaking arrow"?

Figure 24: Functions of the AR-HMI in Peter´s scenario

4.3.2.2 Implementation

For the implementation in SILAB simulator (ULM) a 3D software was used to provide with a coordinate system, the location of each vertices to be transferred in the simulator software. Also, it was used to try different shapes that visually will be perceived more appealing (see
Figure 25).

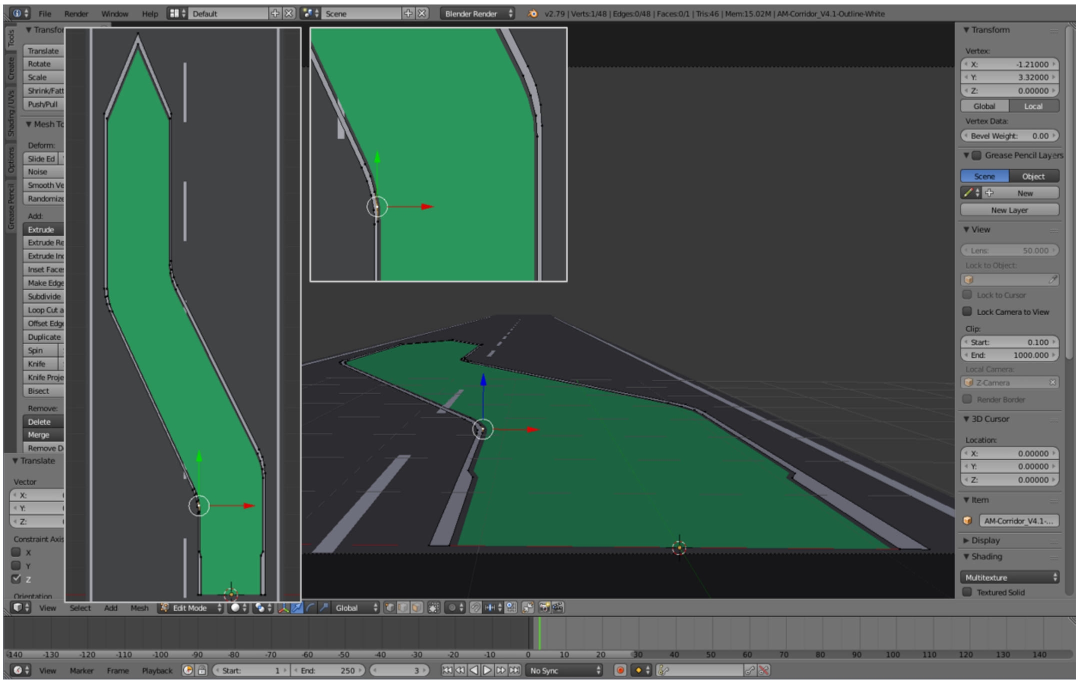


Figure 25: Corridor modelled in 3D software

OFFIS developed a library for SILAB, which allows to define OpenGL polygons using TriangleStrips, Quadstrips, Triangle Index List, etc. In this example three objects are created (two outlines in white + main part in green). Each object has approximate 30 vertices (the black crosses). The vertex coordinates for these polygons are derived at runtime using a SILAB specific mechanism. For any vehicle (example here the Ego) which is active in the simulation a so-called "cursor" point can be set up in the middle of the vehicle's current lane, next to the vehicles centre of gravity. Once a cursor is set up, it can be moved forwards and backwards along the current lane (alone the red line). The 3D coordinates from the cursor locations can be read, which allows to "sample" the centre of the driving lane (see Figure 26).

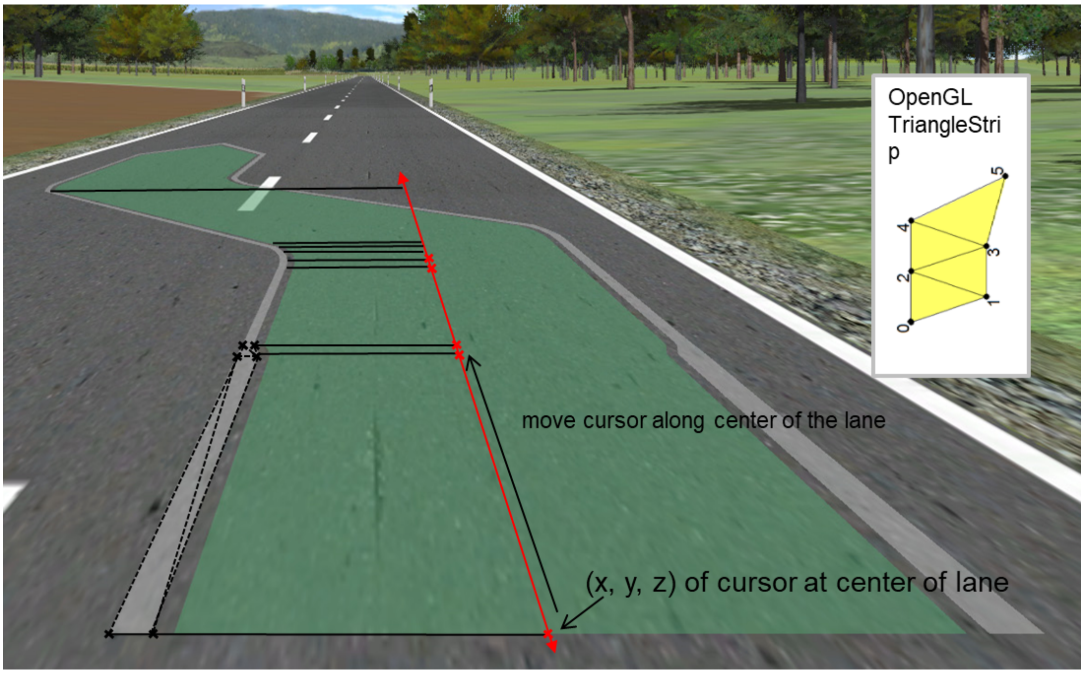


Figure 26: SILAB implementation

All the different functions of the AR-HMI were added in the SILAB simulator, e.g. safety corridor, unsafe corridor, interaction corridor, etc. (see Figure 27). Other elements were added as an improvement of the 2nd cycle that helps to fully understand the type of situation and where is located the risk or if the vehicle is communicating something (see Figure 28).

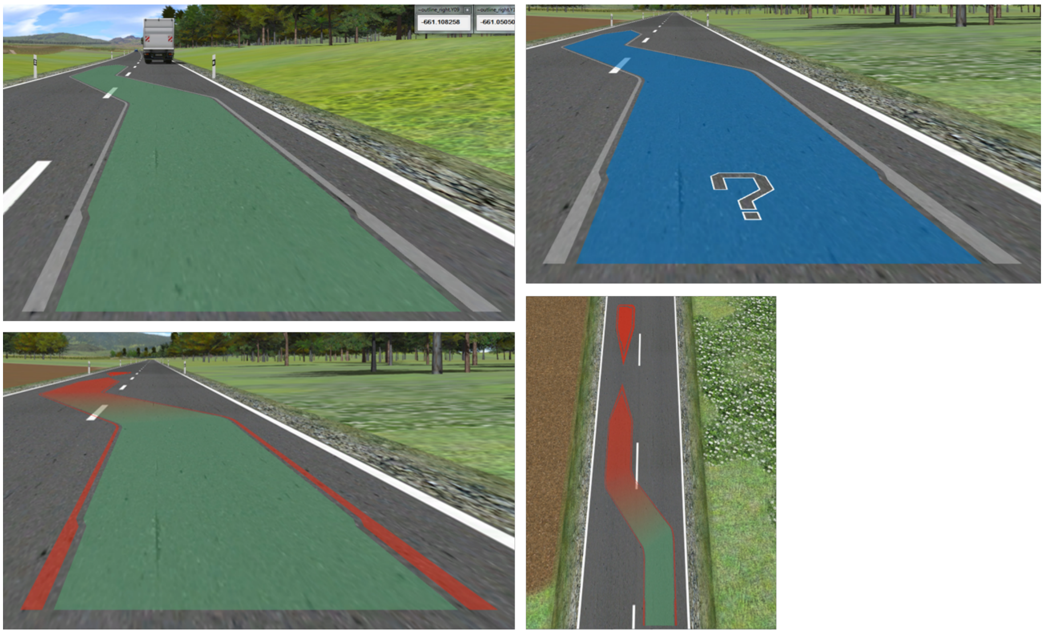


Figure 27: different visualizations displayed in SILAB

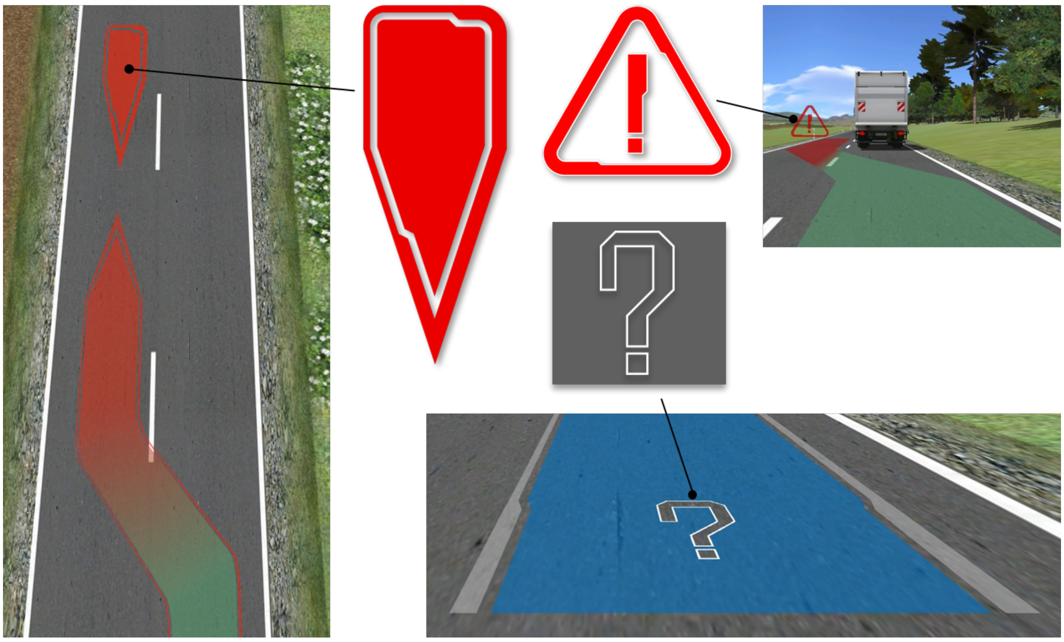


Figure 28: Communication symbols

4.3.3 Demonstrator in which E6.3 has been / will be implemented

4.3.3.1 Simulator implementation

The AR-HMI is already implemented and already tested in ULM´s simulator, due to the usage of the same software used in OFFIS´s simulator in Oldenburg, where the concept was first implemented. The implementation on ReLab and Vedecom´s simulator is ongoing. In these two specific cases, the software used is “SCANeR” from Oktal, different than used in ULM and OFFIS, and it requires access to the API and SDK. At the moment ReLab and Vedecom are working on the implementation.

For the implementation on ReLab and Vedecom simulator, the AR-HMI was extended to contemplate the other two scenarios (Eva and Martha). The procedure was similar than Peter´s scenario. A quick story board and conceptual sketches were made (see Figure 29 and Figure 30).

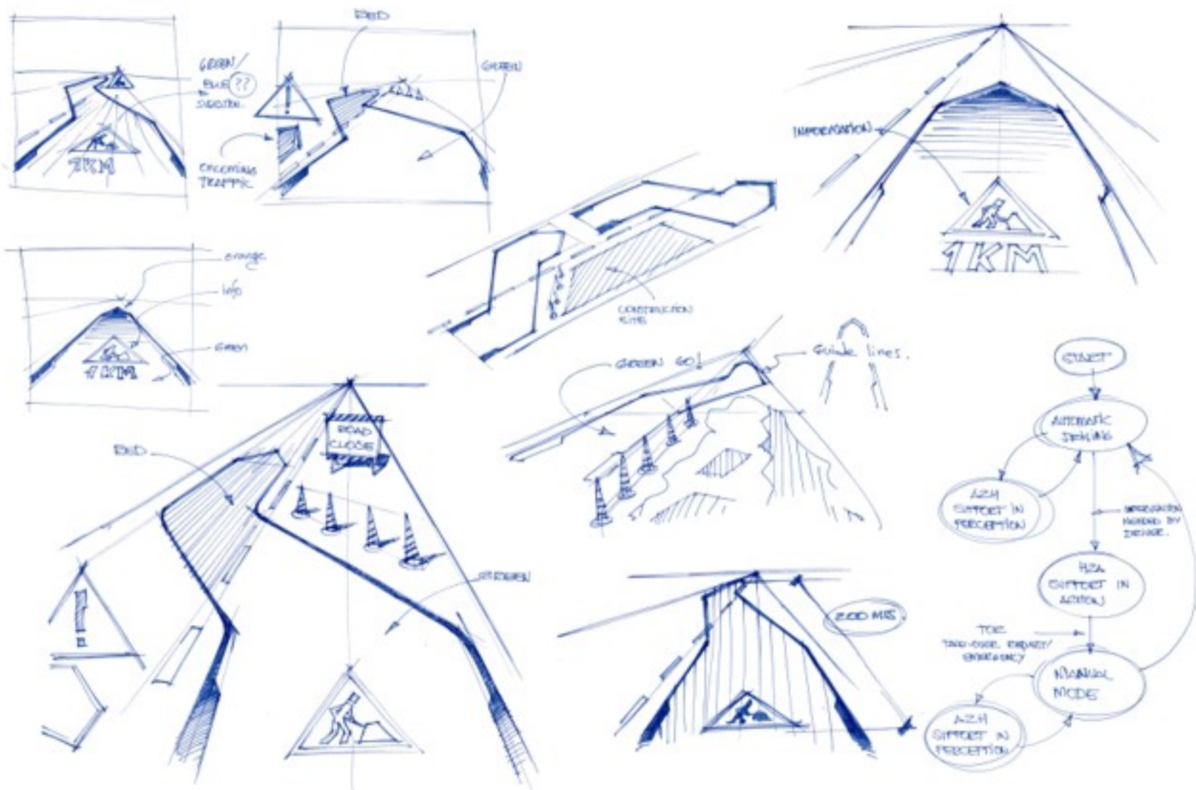


Figure 29: Sketches for Martha´s scenario

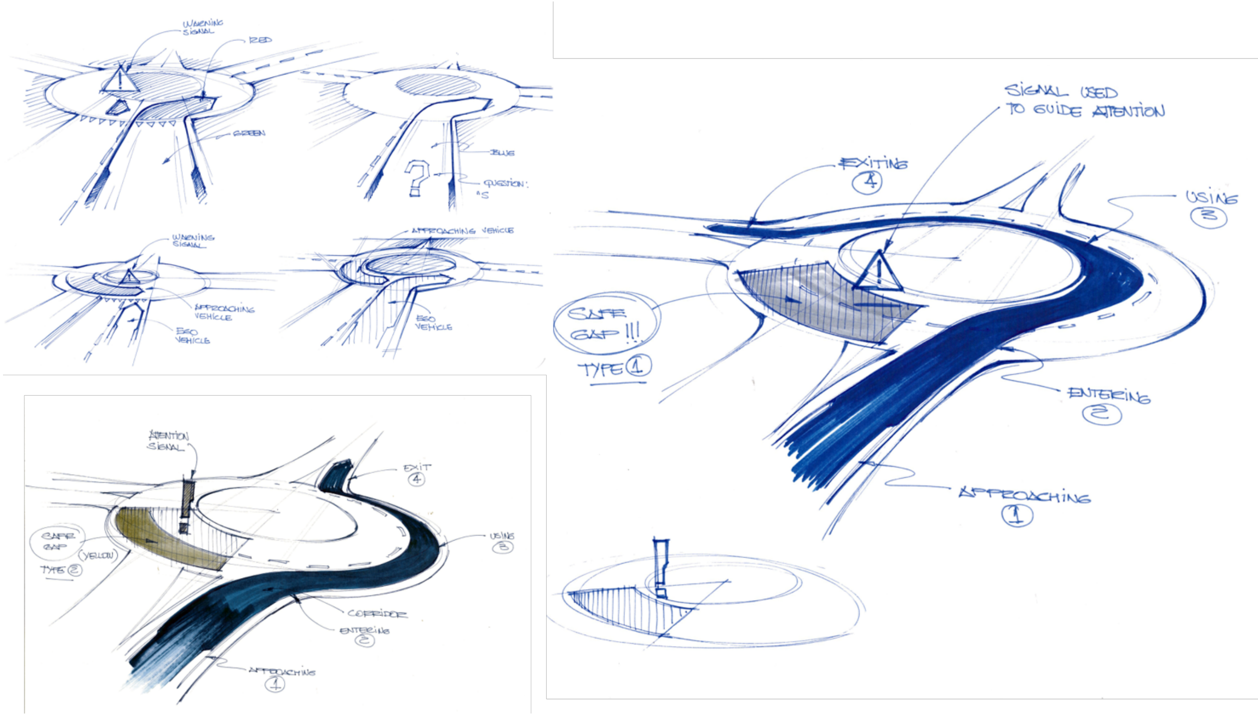


Figure 30: Sketches for Eva´s scenario

In order to expand the AR-HMI to Martha and Eva´s scenarios, a few visualizations were added to the Augmented Reality. In case of Martha, two main graphics were added to support the driver in perception. The first graphic displays the missing Road marking on a construction site 1km ahead (see Figure 31). The second graphic displays a corridor suggesting the lane changing with a representation of the construction site (see Figure 32).

Figure 31: AR-HMI missing Road marking graphic in Martha´s scenario

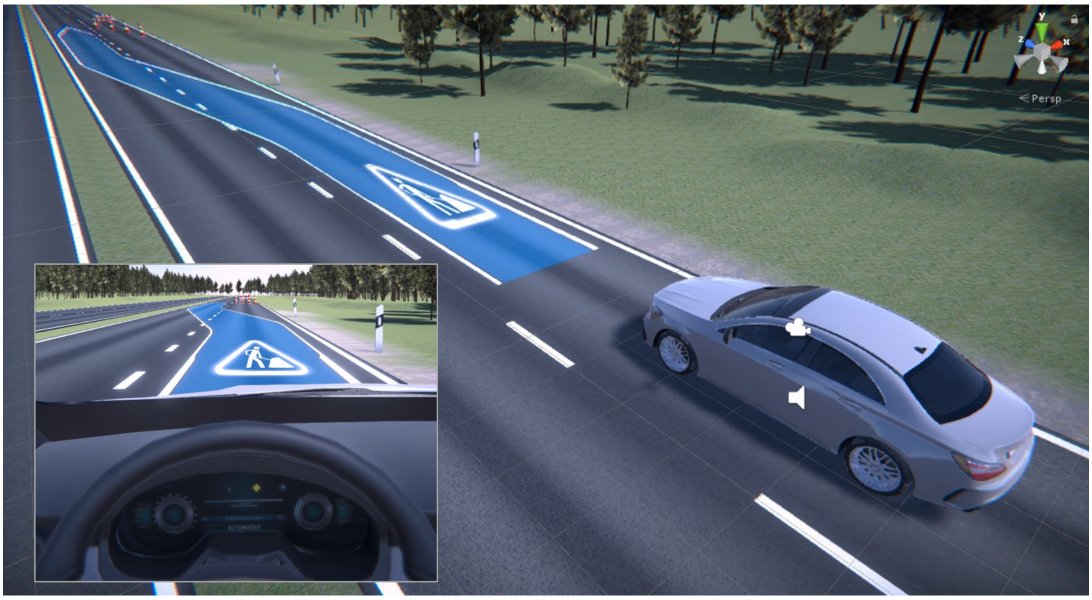


Figure 32: AR-HMI lane changing graphic in Martha´s scenario

For Eva´s scenario, the AR-HMI displays two main elements, a path displaying where the vehicle will drive through the roundabout in autonomous mode. The second graphic displays a representation of the "safe gap" in order to guide the attention of the driver in the direction where needs to check to give the command of entering the roundabout (see Figure 33).

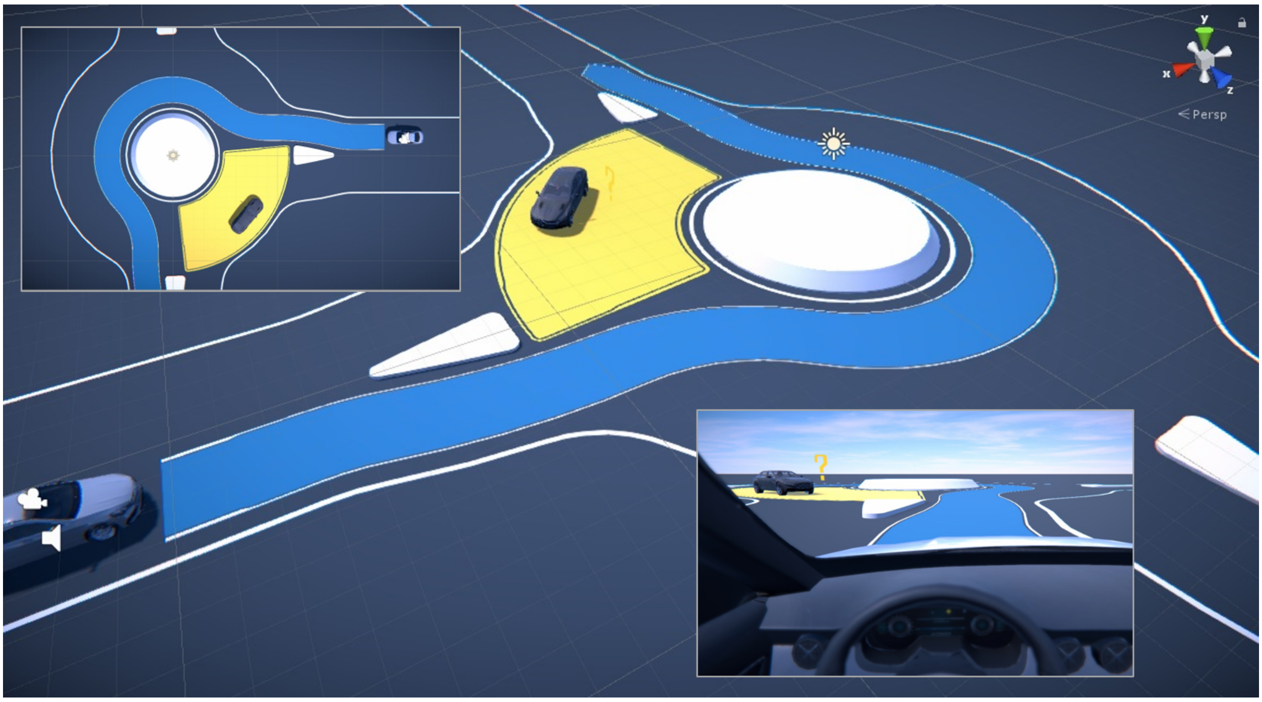


Figure 33: AR-HMI graphics in Eva´s scenario

In these two scenarios, AR-HMI graphics are still in development process, some changes may be needed in order to use the full potential of the AR-HMI in communication with the cluster and central panel HMI.

For Peter´s scenario, another graphic will be implemented to H2A Support in perception. In a recognized overtaking manoeuvre, a graphic displays a rectangle to highlight a potential risk ahead that can´t be detected by the sensors since are blocked for the vehicle in front. The TeamMate HMI will request the drive to observe the incoming traffic before to execute the lane change (see Figure 34).

Figure 34: AR-HMI sensor obstruction

4.3.3.2 Vehicle demonstrator implementation

Implementation on the real demonstrators is in development phase at this moment due to technical limitations. The HUDs used today are small screens that can be placed in the dashboard of the car, but would not be able to represent the main concept. However, this study of the AR-HMI will be useful for the new technologies developed in the future.

5 Validation

5.1 Overall approach to validation (REL)

The aim of the V&V process in the 3rd cycle was twofold: on one hand, the scope was to assess the improvements of the design and the implementation made in the first two cycles; on the other hand, the scope was to use this cycle as a bridge for the integration in demonstrators.
Figure 35 shows the role of the V&V process in the WPs in which are developed the enablers.

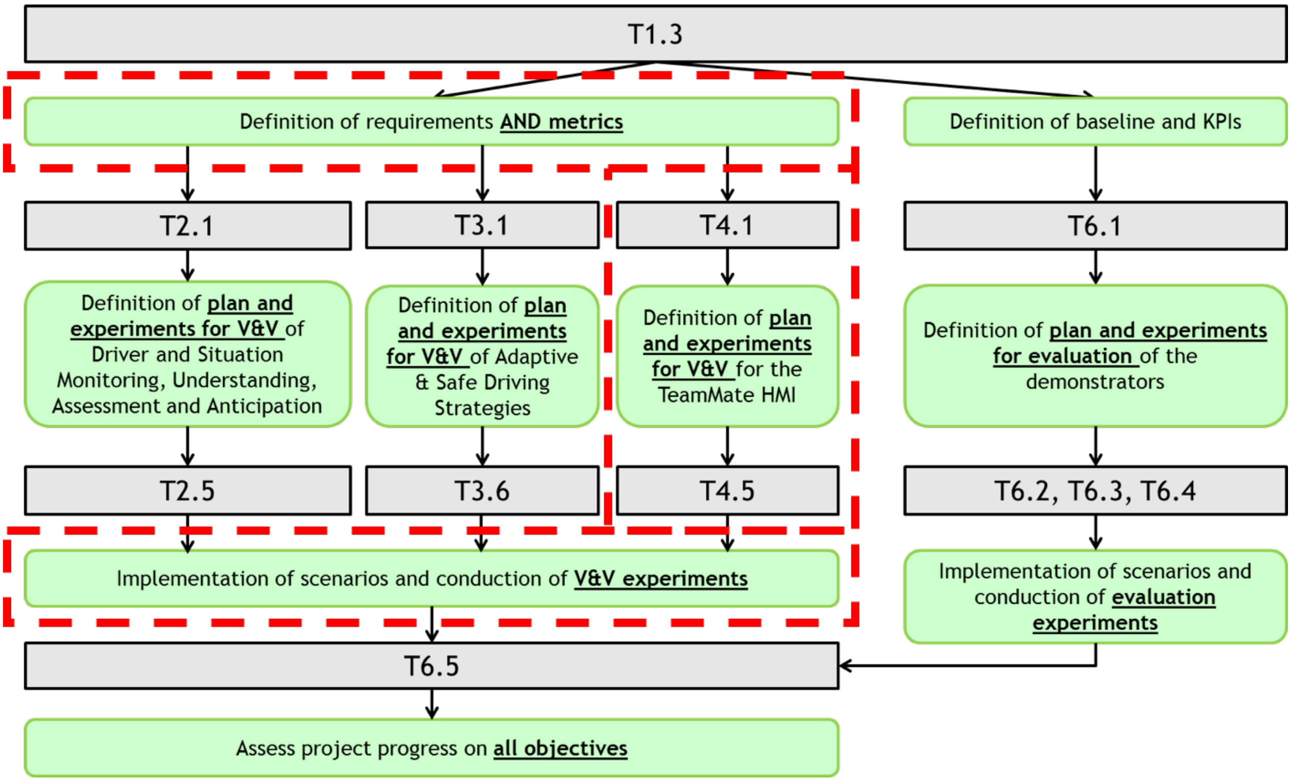


Figure 35: overall validation process described in D1.3

In this cycle the validation has been performed with experiments on the real scenarios, in order to be closer and as realistic as possible to the final result. Three complementary experiments have been performed to validate, each component that is part of enabler 6, i.e. the TeamMate HMI.

5.2 E6.1 - Interaction modality validation (ULM)

This chapter describes the results of the V&V process for the 3rd cycle. The scope is to assess the requirements defined in D4.5, with a specific focus on the multimodal interaction features developed in this cycle.
There was a special focus on derive the interaction guidelines with the result of the 3rd cycle analyses and the results from previous experiments.

5.2.1 Validation method

The experiment was conducted in the ULM driving simulator. The PETER scenario was implemented in four different scenarios to test the predefined requirements.

Errore. L'origine riferimento non è stata trovata.7 shows the requirements for E6.1 verified and validated in this and previous cycles.

Table 17: Requirements for E6.1 Validation

ID	Verification/ validation	Requirement	Metric
R_EN6_ INT1.1	Verification	The interaction strategy should be usable according to ISO 9241-11	Check: Y/N
R_EN6_INT1.2	Validation	The interaction modality must be usable	SUS > 80
R_EN6_ INT1.3	Validation	The trust for the system cannot be affected	Check: Y/N
R_EN6_ INT1.4	Verification	The most efficient channels of interaction should be used according to the situation	Check: Y/N
R_EN6_ INT1.5	Verification	The HMI should offer different actions on a manoeuvre level to the driver	Check: Y/N
R_EN6_ INT1.6	Verification	The system must provide a way of intervention by the driver in non-crucial situations.	Check: Y/N
R_EN6_ INT1.7	Validation	The interaction modality must be intuitive	Check: Y/N
R_EN6_ INT1.8	Validation	The system must distinguish between intentional and unintentional intervention.	Check: Y/N

5.2.1.1 Experiment(s) and participants

The experiment to validate E6.1 was performed in the ULM driving simulator. The test was designed as a within-subjects experiment. The order in which the participants had to interact with the different modalities was randomized.

After a training track to get familiar with the driving simulator the participants had to drive through the PETER scenario in different conditions. First there was a straight rural road where participants could overtake the slowly driving car without any critical factors. Afterwards the participants were on a curvy road where the driver intention recognition predicted that the driver does not want to overtake. The third scenario was a very foggy scenario with around 150 meters of free view to the front. And last there was oncoming traffic.

The Vehicle drove in automated mode but could not overtake on it´s own. Therefore it followed the slowly driving car, either until an overtaking manoeuvre was initiated by the participant or the slowly driving car turned away from the lane on a crossing.

26 subjects (13 males, 13 females) have been involved in the experiment. They had 27,4 years in average, they had 9,9 years of driving experience in average and drove around 10.000 km last year in average.

The following chapter will describe the result of the experiment conducted to validate the requirements related to E6.1.

5.2.2 Validation results

5.2.2.1 Requirement results

Table 18: Results of the E6.1 validation

ID	Requirement	Metric	Result	Was the req. met?
R_EN6_ INT1.1	The interaction strategy should be usable according to ISO 9241-11	Check: Y/N	No contradiction to ISO norm	Yes
R_EN6_INT1.2	The interaction modality must be usable	SUS > 80	SUS score of 75,1	No
R_EN6_ INT1.3	The trust for the system cannot be affected	Check: Y/N	Natural interaction trust score of 55,74 higher than touch (43,35)	Yes
R_EN6_ INT1.4	The most efficient channels of interaction should be used according to the situation	Check: Y/N	Most effective channel was chosen according to the guidelines	Yes
R_EN6_ INT1.5	The HMI should offer different actions on a manoeuvre level to the driver	Check: Y/N	Driver could choose between different manoeuvres	Yes
R_EN6_ INT1.6	The system must provide a way of intervention by the driver in non-crucial situations.	Check: Y/N	Driver could intervene at all time	Yes
R_EN6_ INT1.7	The interaction modality must be intuitive	Check: Y/N	None of the participants were confused or did not know how to interact with the system	Yes

R_EN6_ INT1.8	The system must distinguish between intentional and unintentional intervention.	Check: Y/N	Predefined thresholds distinguished between intentional and unintentional interactions	Yes

As seen in the table almost every requirement was met. That means that the participants liked the interaction concept and they even trusted the system more with the natural interaction.

One requirement (R_EN6_INT1.2 – Usability) was not met. The usability of the natural interaction was below the predefined value of 80 (M=75.10, SD=17.08). While debriefing the participants, most of them said that the lack of a haptic feedback was confusing to them. Therefore the usability should be improved when providing a haptic feedback so the participants know when the interaction was detected and accepted by the system.

The trust in the system was significantly higher using the natural interaction (M=55.74, SD=9.06) than the Touch interaction (M=43.35, SD=5.33); $t(25) = 7.38$, $p < 0.001$. People said that the feeling of control was higher while initiating the manoeuvre with the steering wheel.

None of the situations was critical and there was no possibility of a collision with other traffic participants. Therefore no signs of second thoughts were shown by the participants. Each participant initiated the overtaking manoeuvre.

There was no significant difference between the subjective workload experienced by the participants; $t(25) = 0.661$, $p = 0.515$. The workload of the natural interaction (M=28.40, SD=9.86) was slightly higher than the perceived workload using the touch interaction (M=27.60, SD=10.00).

5.3 E6.2 – Multimodal HMI validation (REL)

This chapter describes the results of the V&V process for the 3rd cycle. The scope is to assess the requirements defined in D4.5, with a specific focus on the multimodal interaction features developed in this cycle.
Moreover, since in the 2nd cycle of validation the results showed that ambient lights were considered as a powerful and effective tool to reinforce the perception of critical events (such as the moment in which the automation needs a support, in perception or in action), but the colours tested (i.e. yellow and red) have not been considered as effective, in this 3rd cycle we implemented the comments received in the previous experiments.

5.3.1 Validation method

The experiment to validate the E6.2 was performed at REL driving simulator. In order to allow a more realistic test, the validation was performed in a project scenario, i.e. Eva. The scenario was modified in order to tailor it to the needs of the research questions. In particular, since one of the focus of the experiment (and also one of the main topics of the 3rd cycle of WP4) was to measure the effectiveness of the Take Over Request (TOR), a use case with two different take over was implemented in the driving simulator.

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ID

ID	Verification / validation	Requirement	Metric
R_EN6_HMI1.4	Verification	The HMI must have different states for each automation mode	Check: Y/N
R_EN6_HMI1.6	Verification	The overall HMI concept must include a strategy to modify the ambient lights to improve the driver awareness on the automation state	Check: Y/N
R_EN6_HMI1.7	Verification	The HMI must have 3 visual displays: - an instrument cluster - a Central Stack Display - a Head Up Display	Check: Y/N
R_EN6_HMI1.9	Verification	Navigation info and surrounding view must be visible on the instrument cluster both in automatic and manual mode	Check: Y/N
R_EN6_HMI1.10	Verification	In “Handover”, the Instrument cluster must show the correct handover through a popup that informs the driver of the current transition	Check: Y/N
R_EN6_HMI1.11	Verification	Infotainment features must be mirrored on the instrument cluster only in Automatic Mode	Check: Y/N
R_EN6_HMI1.13	Verification	In Manual mode, the Central Stack Display must show redundant information on navigation and surrounding situation	Check: Y/N
R_EN6_HMI1.14	Verification	In Automatic mode, the Central Stack Display must allow to reach all the features of the NIT navigation menu	Check: Y/N
R_EN6_HMI1.19	Verification	The HMI must integrate all relevant information on traffic, driver and automation	Check: Y/N
R_EN6_HMI1.21	Verification	NCDC must display when the automated driving mode is switched on/off	Check: Y/N
R_EN6_HMI1.22	Verification	The HMI must clarify driver’s and system’s responsibility in order to prevent mode confusion	Check: Y/N
R_EN6_HMI1.23	Verification	NCDC must display the information on lateral vehicle control and the longitudinal vehicle control	Check: Y/N
R_EN6_HMI1.30	Verification	Driver must be alerted of possible dangers by using stimuli of different modalities	Check: Y/N
R_EN6_HMI1.43	Validation	The use of multimodal elements in the HMI must increase the level of situation awareness	Correct Rate > 90 %
R_EN6_HMI1.57	Validation	Users should understand the meaning of the haptic feedback as proxy of an imminent TOR	Correct Rate > 90 %
R_EN6_HMI1.58	Validation	Haptic feedback must reduce the time needed to take over the control (partial or total)	Reaction time with Haptic feedback < of 20% of reaction time without haptic feedback
R_EN6_HMI1.59	Validation	The HMI should allow the driver to take over the control within a maximum amount of time of 8 seconds as described in the state of the art	Time to take over < 8 seconds
R_EN6_HMI1.60	Validation	The HMI should allow the driver to take over the control before reaching the roundabout (to avoid a stop that can negatively impact the traffic)	Number of positive transitions > 90%

Table 19: Requirements for enabler E6.2 (Multimodal HMI)

5.3.1.1 Experiment and participants

The experiment to validate E6.2 was performed at REL driving simulator, in RE:Lab facilities. The test was designed as a between-subjects experiment, since all the subjects performed the same task.

The users were welcomed in RE:Lab facilities and were invited to sign a consent form module. They had to drive in a 15 minutes scenario, preceded by a 10 minutes phase of training. The simulation started in manual driving, and after a while the users where distracted (it was asked them to watch a video on a mobile phone located in the central tunnel).

Figure 36 shows the experimental setup at REL driving simulator.

Figure 36: Experimental setup at REL driving simulator

The vehicle, detecting driver's distraction, took control going in Automated Mode. Some minutes later the car, approaching a roundabout, showed a Take Over Request, since it detected that a transition of control was needed.

The scenario was repeated twice within the same simulation. The vibration on the seat cover was given to the driver only once, alternatively between the users in order to avoid a learning effect and to minimize the related bias.

11 subjects (5 males, 6 females) have been involved in the experiment. They had 28,9 years in average, they had the 9,2 years of driving experience in average, driving 13.000 km/years in average.

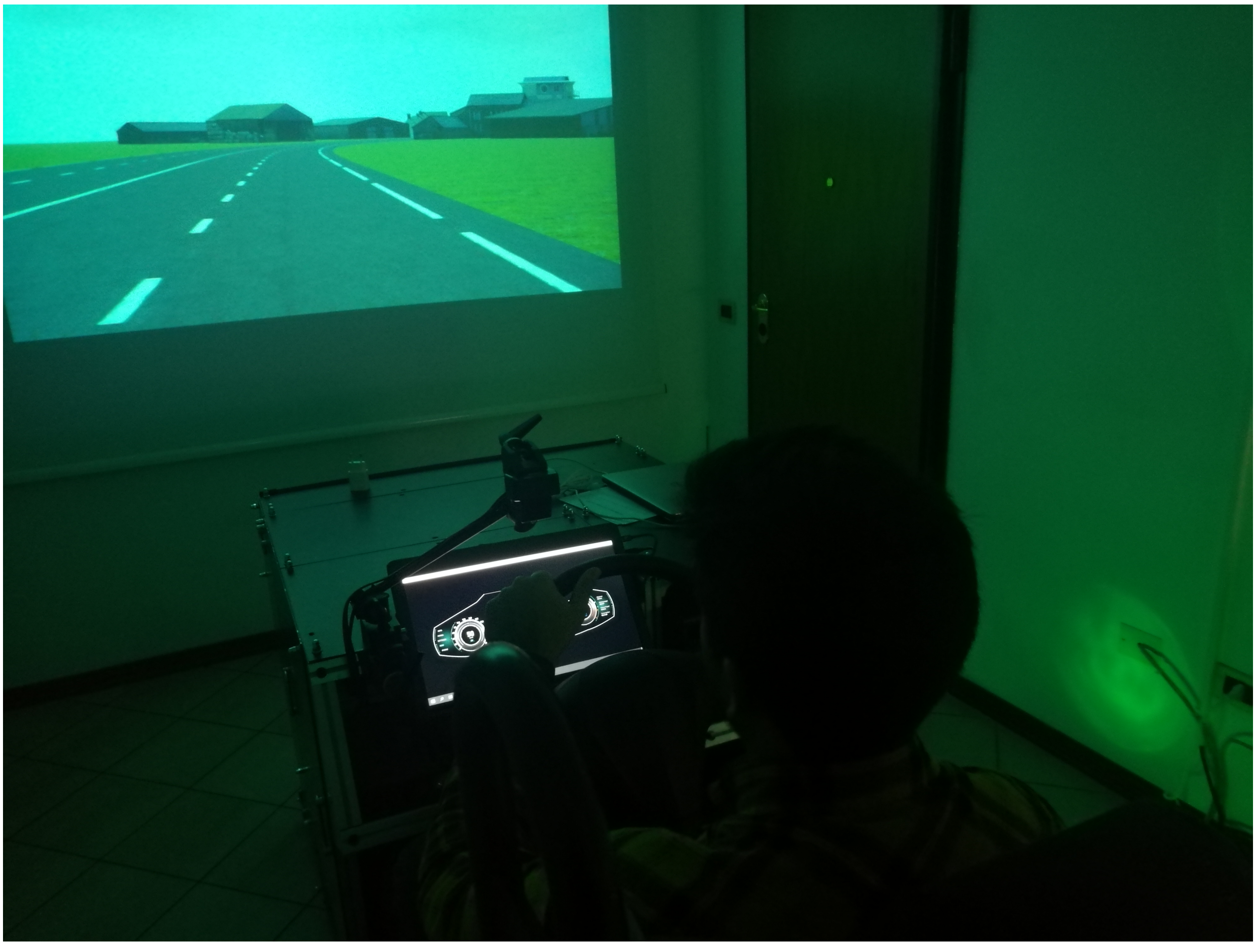


Figure 37: Experimental setup at REL driving simulator (with ambient lights)

The following chapter will describe the result of the experiment conducted to validate the requirements related to E6.2.

5.3.2 Results

5.3.2.1 Requirement results

In this chapter the results of the validation in relation to the requirements is reported.

ID	Requirement	Metric	Result	Was the req. met?
R_EN6_HMI1.4	The HMI must have different states for each automation mode	Check: Y/N	Yes	Yes
R_EN6_HMI1.6	The overall HMI concept must include a strategy to modify the ambient lights to improve the driver awareness on the automation state	Check: Y/N	Yes	Yes
R_EN6_HMI1.7	The HMI must have 3 visual displays: - an instrument cluster - a Central Stack Display - a Head Up Display	Check: Y/N	Yes	Yes
R_EN6_HMI1.9	Navigation info and surrounding view must be visible on the instrument cluster both in automatic and manual mode	Check: Y/N	Yes	Yes
R_EN6_HMI1.10	In "Handover", the Instrument cluster must show the correct handover through a popup that informs the driver of the current transition	Check: Y/N	Yes	Yes
R_EN6_HMI1.11	Infotainment features must be mirrored on the instrument cluster only in Automatic Mode	Check: Y/N	**Yes** (in other modes, no infotainment features on the instrument cluster)	Yes
R_EN6_HMI1.13	In Manual mode, the Central Stack Display must show redundant information on navigation and surrounding situation	Check: Y/N	Yes	Yes
R_EN6_HMI1.14	In Automatic mode, the Central Stack Display must allow to reach all the features of the NIT navigation menu	Check: Y/N	Yes	Yes
R_EN6_HMI1.19	The HMI must integrate all relevant information on traffic, driver and automation	Check: Y/N	**Yes** (info on navigation, automation state and distraction available in the HMI)	Yes
R_EN6_HMI1.21	NCDC must display when the automated driving mode is switched on/off	Check: Y/N	Yes	Yes
R_EN6_HMI1.22	The HMI must clarify driver's and system's responsibility in order to prevent mode confusion	Check: Y/N	Yes	Yes
R_EN6_HMI1.23	NCDC must display the information on lateral vehicle control and the longitudinal vehicle control	Check: Y/N	Yes	Yes
R_EN6_HMI1.30	Driver must be alerted of possible dangers by using stimuli of different modalities	Check: Y/N	Yes	Yes
R_EN6_HMI1.43	The use of multimodal elements in the HMI must increase the level of situation awareness	Correct rate > 90 %	100 %	Yes
R_EN6_HMI1.57	Users should understand the meaning of the haptic feedback as proxy of an imminent TOR	Correct Rate > 90 %	100 %	Yes

R_EN6_HMI1.58	Haptic feedback must reduce the time needed to take over the control (partial or total)	Reaction time with Haptic feedback < of 20% of reaction time without haptic feedback	RT without haptics = 7,76 seconds RT with haptics = 6,15 seconds Delta = 1,51 seconds = 20,75 %	Yes
R_EN6_HMI1.59	The HMI should allow the driver to take over the control within a maximum amount of time of 8 seconds as described in the state of the art	Time to take over < 8 seconds	RT without haptics = 7,76 seconds RT with haptics = 6,15 seconds	Yes
R_EN6_HMI1.60	The HMI should allow the driver to take over the control before reaching the roundabout (to avoid a stop that can negatively impact the traffic)	Number of positive transitions > 90%	100 %	Yes

Table 20: E6.2 requirement results

As emerged from the table, all the requirements have been met. The Multimodal HMI has proved itself as understandable, reliable and able to increase the driver's awareness.

In particular, the haptic modality has been considered as an important tool to increase the quality of the interaction.
These impressions are suggested by both subjective and objective data: the 100 % users recognized the meaning of the haptics; the 100 % of the users were able to understand what would happen after the vibration, i.e. in which mode the driving will be continued after the vibration.

The time to take over has been measured by calculating the delta time between the moment in which the HMI communicates the Take Over Request and the driver's resumption of control. As stated in D4.5, sources consider 8 seconds a relevant threshold for the take-over. The objective was to assess the effectiveness of the HMI as a means to encourage the transition of control. The average "Time to Take Over" without haptics was 7,76 seconds, while the same measure with haptic feedback was 6,15 seconds.

These results are highly relevant, since the haptics showed a significant improvement in terms of reaction times and safety. The reduction of the "Time to Take over" of 20,75% is in line with the expectations: the HMI reached all the requirements.

5.3.2.2 Qualitative results

In this paragraph are reported qualitative results, collected through subjects' comments, and other issues that, even if not covered by requirements, represented a relevant research issue for this project.

Regarding the haptics, some users would have found useful to have an oriented vibration in the seat cover, in order to receive more sophisticated information; other users accepted the simple info given with a single vibration, since in their opinion, a more complex message would have made the interaction too demanding.

Another relevant topic measured in the experiment performed at REL driving simulator concerned the ambient lights. At the end of the 2nd cycle, the ambient lights were evaluated in an experiment in order to measure the effectiveness of this solution as a mean to reinforce the quality of the interaction between driver and highly automated vehicles. At that stage, results showed that ambient lights were a well-understood and accepted concept, considered as an effective interaction modality for a given type of information.

However, the results showed that the colours selected (at that stage, respectively blue for H2A support in perception and yellow for H2A support in action) were considered as not effective (for detailed results, see D4.4).

In this cycle, the experiment has been repeated with different colours, in order to refine and assess the most appropriate communication strategy between the driver and the vehicle. The colours selected at this stage were green for H2A support in perception and orange for H2A support in action. The colours have been selected by following the comments collected in the 2nd cycle validation.

The results show that, in this cycle, only the 55% users find useful to have ambient lights for H2A support in perception, while 72 % of users find useful the ambient lights for H2A in action. In general, the subjects understood the meaning of the ambient lights: however, they would rather prefer an incremental strategy to increase their effectiveness. In particular, some users told that a strategy based on a “traffic light logic” (i.e. green for simple, yellow for medium and red for critical situations would have made the interaction more effective).

5.4 E6.3 - Augmented reality validation (HMT)

5.4.1 Validation method

For the validation of the augmented reality HMI enabler, an experiment was prepared formed by an online questionnaire, where several participants were asked to view a video and answer questions related to an image extracted from the video, showing a specific scenario (see Figure 38).
The version from the 2nd cycle is the baseline for this experiment, where we could compare against the requirements from the previous version that didn´t meet the CR described in the deliverable D4.4 section 4.4.1 as well as the new graphics that were added in order to improve the level of understanding.

Figure 38: Example of the image shown in the questionnaire

The videos were recorded using a cross-platform game engine called Unity, a software used in many industries as well as in Automotive & Transportation (see Figure 39). This software allowed us to design and test the different visualizations displayed for the AR-HMI.

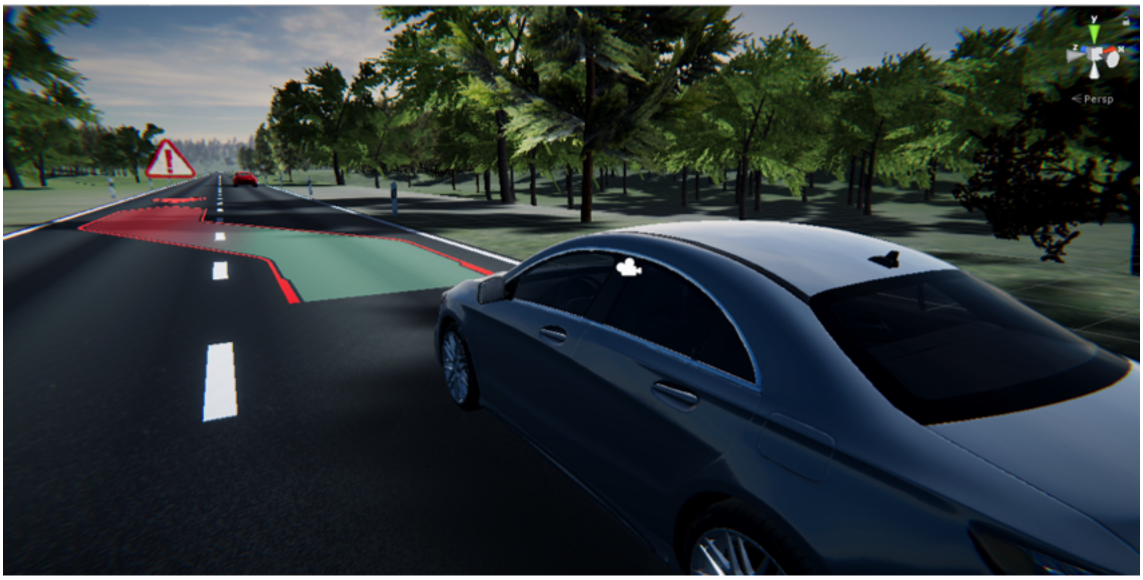


Figure 39: Unity development for AutoMate project

The questionnaire is constituted of three sections, a first section related to personal information of the participant, a second section regarding to the visualizations displayed on the AR-HMI and a third part about the usability of the system.
During the second section, six scenarios are presented within a video, as well as images and questions related to the scenarios. In these scenarios were represented the main functions of the Peter´s scenario: following corridor, overtaking corridor, non-overtaking corridor with two variants, incoming traffic and opposite traffic, and two scenarios for the cooperative mode (see Figure 40).

Figure 40: Questionnaire´s scenarios

Another visualizations that is tested in the questionnaire is a "return" corridor, where the vehicle communicates the intention to return in the right lane after the overtaking manoeuvre (see Figure 41).

Figure 41: Returning corridor

The requirements of the Enabler 6.3 tested through the online questionnaire are shown in the following table:

Table 21: Requirements for E6.3 validation

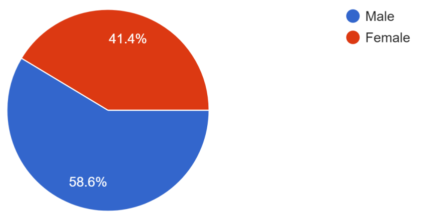
REQ ID	Requirement	Metrics (success criteria)	How to validate it
R_EN6_HMI 1.33	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the GUI
R_EN6_HMI 1.35	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the GUI
R_EN6_HMI 1.41	Validation	Situation awareness	The users will be asked to explain the meaning of the manoeuvre
R_EN6_HMI 1.42	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the GUI
R_EN6_HMI 1.51	Validation	Check: Y/N	Check if information is shown in the AR-HMI
R_EN6_HMI 1.52	Validation	Check: Y/N	Check if information is reduced to a minimum in the AR-HMI
R_EN6_HMI 1.53	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the AR-HMI

R_EN6_HMI 1.54	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the AR-HMI
R_EN6_HMI 1.55	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the GUI
R_EN6_HMI 1.56	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the GUI
R_EN6_HMI 1.61	Validation	CR for level of understanding >90%	The users will be asked to explain the meaning of the AR-HMI

5.4.2 Experiment(s) and participants

The participants were 29 in total, 17 (58,6%) of the participants were male, 12 (41,4%) were female with an overall average age of 37 years old. The participants own their driver licence with a minimum of 1 year and a maximum of 25 years. The kilometre average is 12.000 kilometres per year with a minimum of 100km and a maximum of 60.000km.
Only 1 of the participants have advanced driver assistance system in their own vehicle.

1. Gender
29 responses



6. Please state which percentage you normally travel on highways, rural roads and city roads. PLEASE PAY ATTENTION TO ALLOW EXACTLY 10...IBUTION! ADD TOGETHER WITHIN EACH LINE!

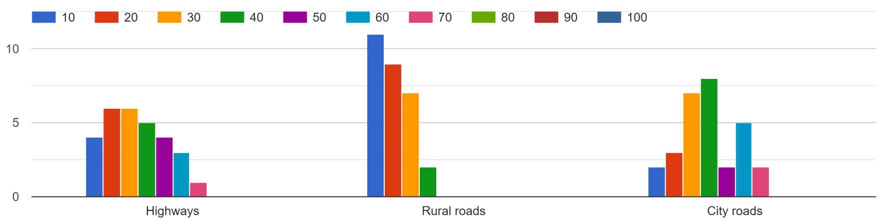


Figure 42: Personal questions of the participants

5.4.3 Validation results

As result of the validation some requirements met the CR of 90%, but others didn´t meet the rate due to different aspects. In the case of requirement R_EN6_HMI 1.33 where manual driving was needed, it was not possible to test through videos and images. For the requirement R_EN6_HMI 1.61, related to cooperation, the results didn´t meet the CR for the level of understanding (90%), because interaction is needed in order to understand the participants the meaning of the visualizations (see Figure 43Figure 43). This enabler should be tested in another experiment, perhaps in a simulator, where the interaction through several manoeuvres can be performed creating a learning effect.

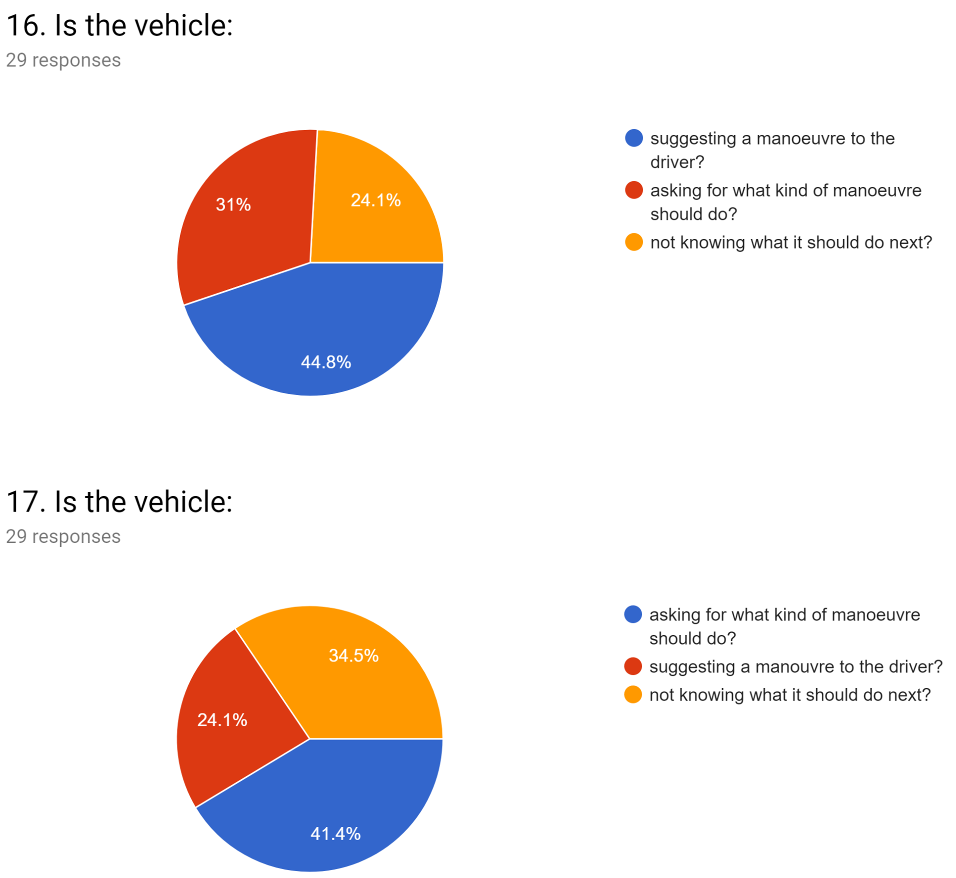


Figure 43: Questions related to cooperation

The requirements that met the CR of 90%, results were very positive, from 93,1% to 100% in some questions.
In case of requirements R_EN6_HMI 1.35 and R_EN6_HMI 1.54, manoeuvres must be comprehensible for the driver through graphical visualizations and requirements and in R_EN6_HMI 1.41 and R_EN6_HMI 1.55, where say that the HMI should communicate to the driver why the automation is acting in a certain manner in an understandable way, results showed that participants found them very clear to understand.
Requirements R_EN6_HMI 1.42; R_EN6_HMI 1.56 states that the driver needs to understand the meaning of the overtaking corridor visualized through the AR.
Results show clearly that understanding was of 100%.

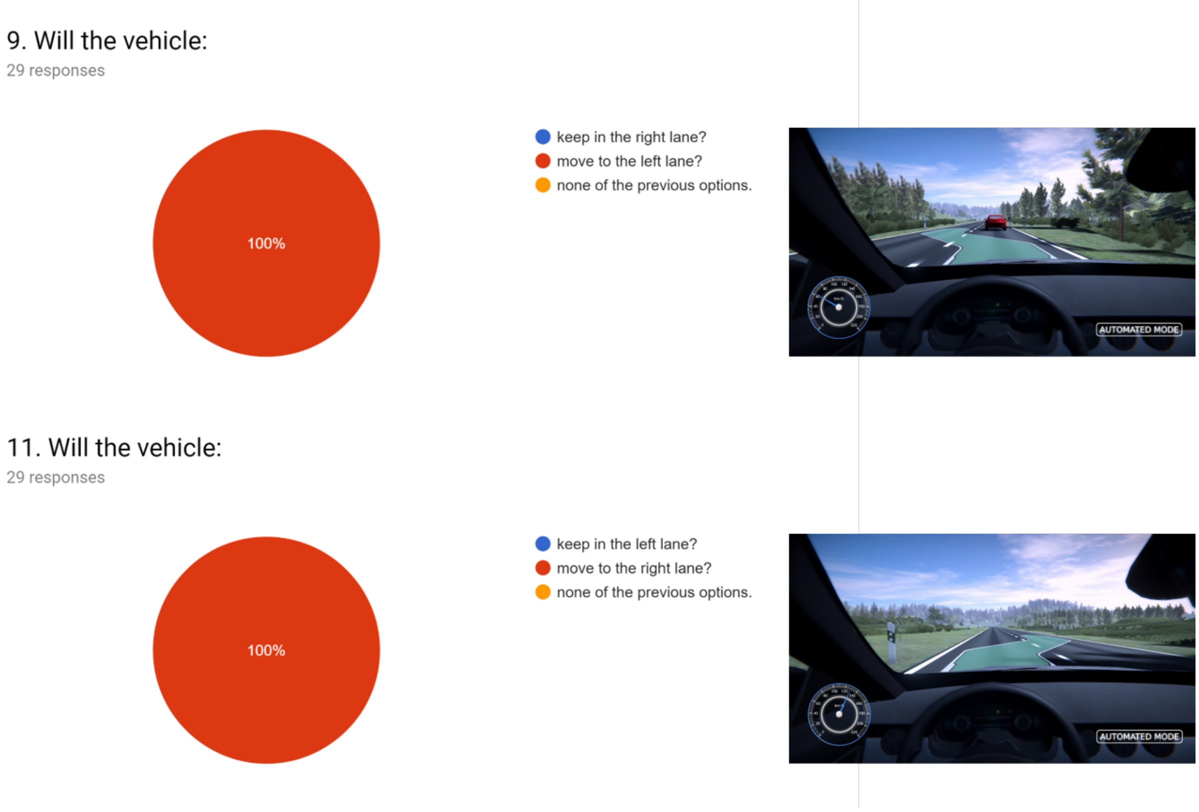


Figure 44: Overtaking and returning corridors

In requirements R_EN6_HMI 1.53 where in automated mode, augmented reality elements can be used to enhance the situation awareness, participants understood the situation through the meaning of the colors of the corridors by answer with a percentage higher than 93,1%.

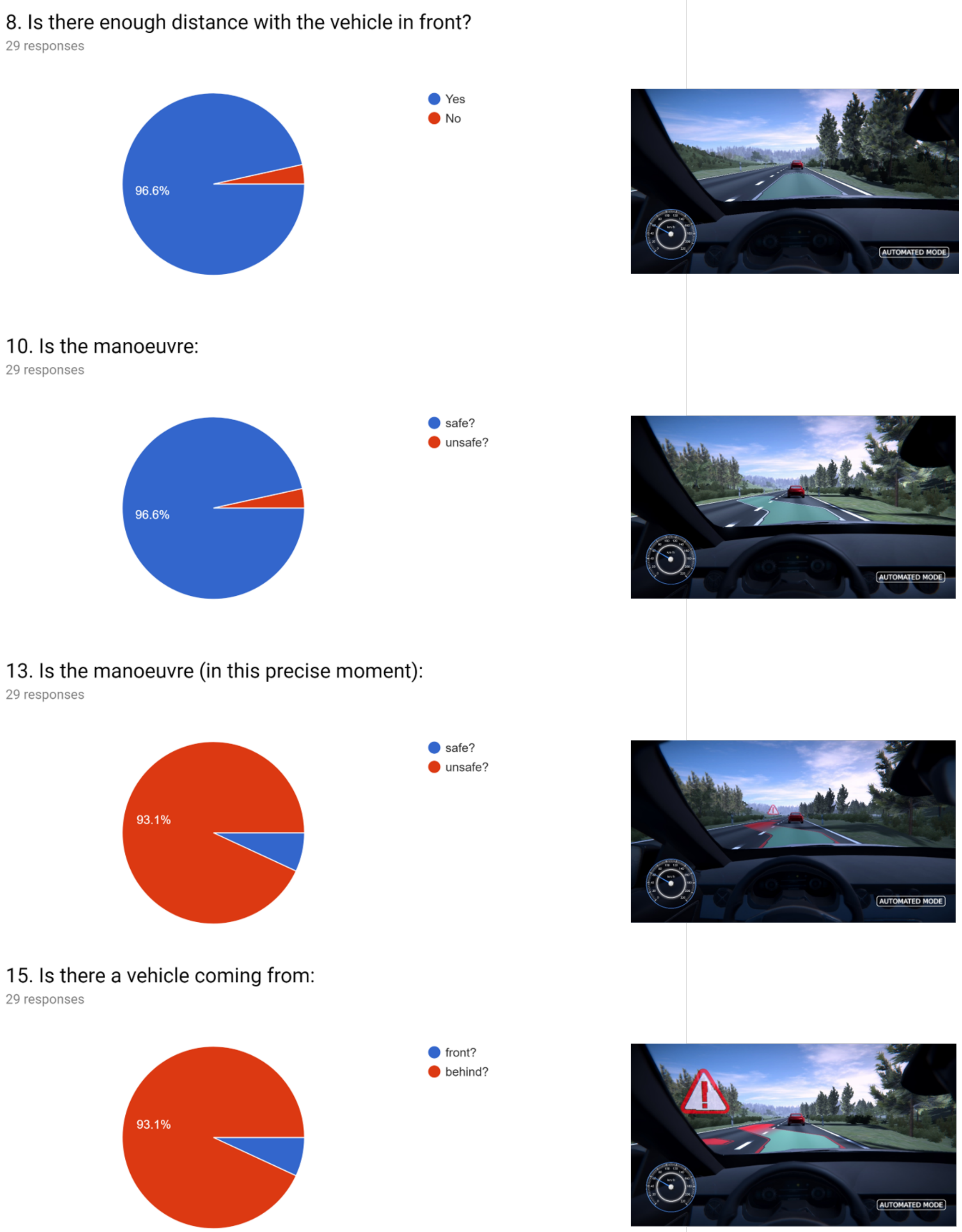


Figure 45: Safety awareness

In two questions, results didn't meet the expectations. In question number 7, many of the participants answered: "none of the previous options" instead of "keep in the right lane". A possible reason of that is not because they didn´t understand the meaning of the corridor, because in the next scenario, the same participants answered in the overtaking corridor with 100% of correct answer and none answered, "move to the left lane". That means that since it was the first scenario, a learning process were not be made at that moment and maybe they understood in another way the question.
In case of the question 12, 17,2% answered move to the left lane and 6,9% answered none of the previous questions, which means many participants were not clear about this visualization. Problem can be found due to the shape of the corridor that shows the "intention" of the vehicle in the future, when the risk is over, but not the action at that precise moment. This can be confusing to participants, because after to see the video, they knew that the vehicle will move to the left lane in the future. In this case a simulator´s experiment could test it better.
In case of question 7, safe factor is not critical since the vehicle in the video continues using the right lane with a constant distant.
In case of question 12, 75% of the participant understood the concept and 93,1% answered in the next question correct related to safety issue.

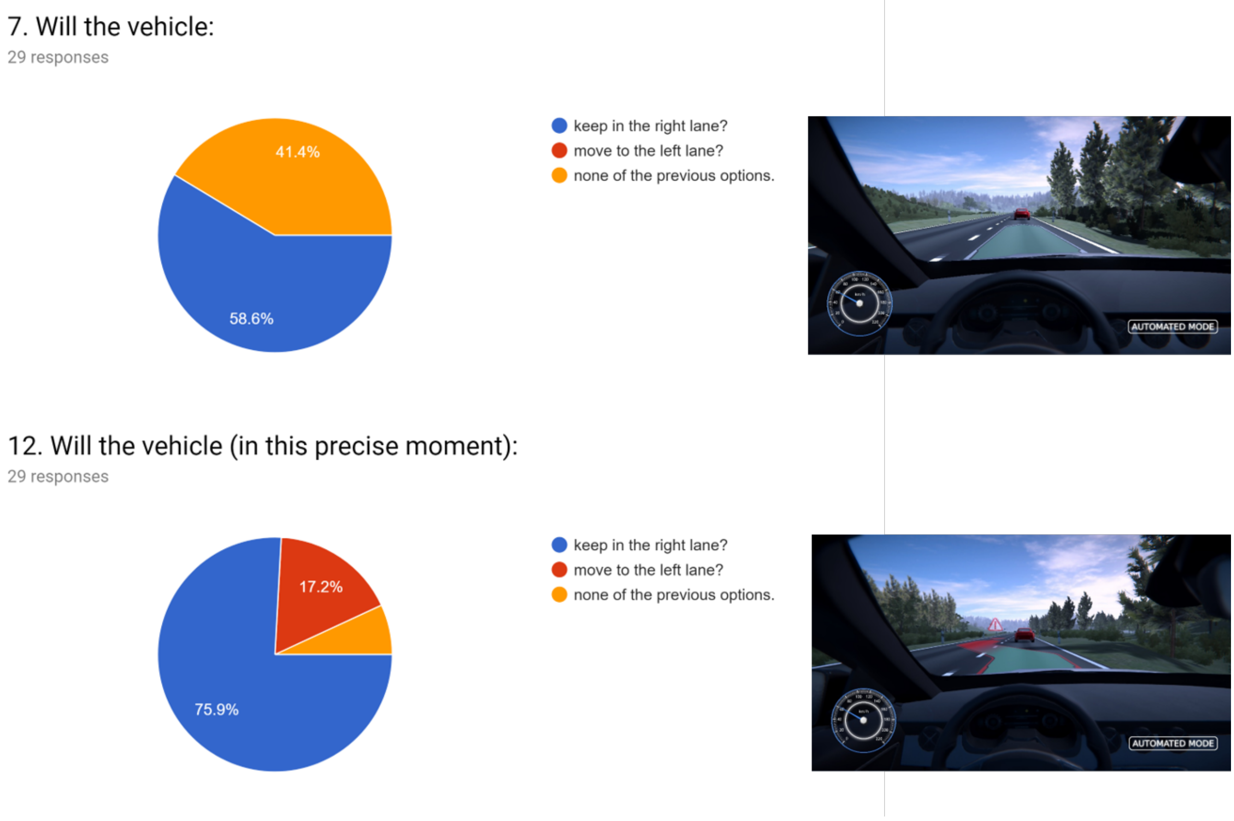


Figure 46: Questions with low results

5.4.3.1 Requirements results

In this section are described the result of the requirements listed in the Table 22.

Table 22: Results of the E6.3 validation

REQ ID	Requirement	Metrics (success criteria)	Result	Has the req. been met?
R_EN6_HMI 1.33	Validation	CR for level of understanding >90%	0%	NO
R_EN6_HMI 1.35	Validation	CR for level of understanding >90%	100%	YES
R_EN6_HMI 1.41	Validation	Situation awareness	Yes	YES
R_EN6_HMI 1.42	Validation	CR for level of understanding >90%	100%	YES
R_EN6_HMI 1.51	Validation	Check: Y/N	yes	YES
R_EN6_HMI 1.52	Validation	Check: Y/N	no	NO
R_EN6_HMI 1.53	Validation	CR for level of understanding >90%	93,15	YES
R_EN6_HMI 1.54	Validation	CR for level of understanding >90%	100%	YES
R_EN6_HMI 1.55	Validation	CR for level of understanding >90%	100%	YES
R_EN6_HMI 1.56	Validation	CR for level of understanding >90%	100%	YES
R_EN6_HMI 1.61	Validation	CR for level of understanding >90%	44,8%	NO

5.4.3.2 Qualitative results

At the end of the questionnaire, questions were asked related to analysis of the usability of the system and comments from the participants.
In the questions related to usability of the system, a SUS questionnaire was use. The results were positive, most of the participants would like to use the

system frequently. Most of the participants found that the system was easy to use.
As an overall conclusion, the system was mainly accepted in terms of usability.

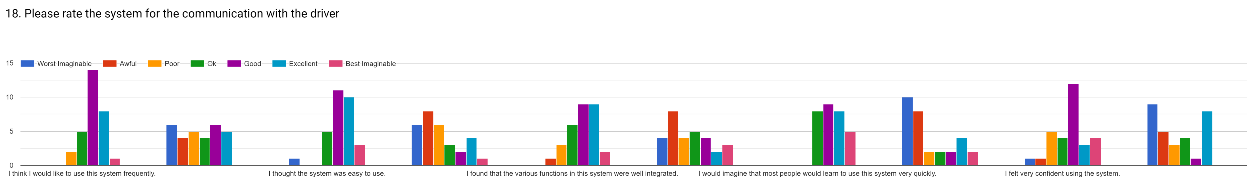


Figure 47: System usability results

In the open questions, the participants gave their opinion about the graphical visualization that were clear and easy to understand: *"simplicity, colours are clear", "Simple graphics", "The use of colors to communicate faster", "is easy to understand".*
Many of the participants commented about the enabler regarding to R_EN6_HMI 1.61 (the cooperating blue corridor) that the question mark on the visualization wasn´t clear enough, if were asking or suggesting or not knowing what the cars is going to do: *"I was not 100% sure about the graphics with the question mark. Was this a suggestion the car is making? Or is the automated system asking the driver what to do? ", "the question mark visualisation is not clearly to understand for me".*

Last questions were related to the confidence of use of the system and results were very positive, resulting in 69% confident to use the system, 3,4% NOT confident to use the system and 27,6% maybe would be confident by using the system.

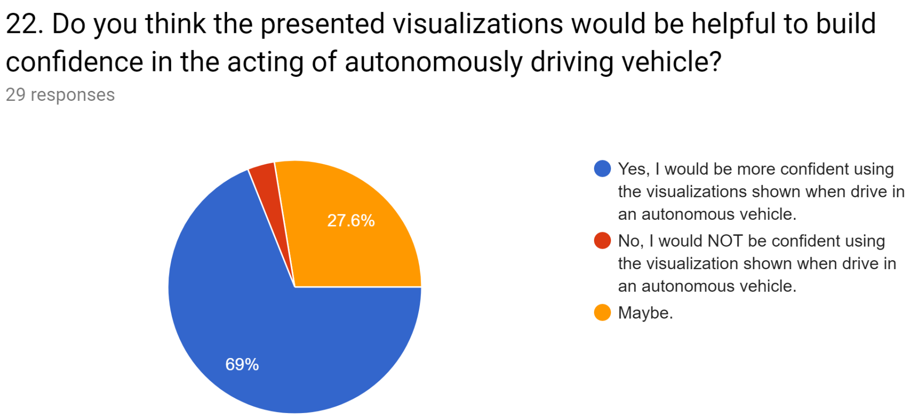


Figure 48: Confidence in the system

As a conclusion of the questionnaire, participants have mainly understood the meanings of the visualizations. Some visualizations were 100% understood, which shows how intuitive they are, in other visualizations they were above 90%, meeting the correct rate of the requirements. For those that didn´t meet the correct rate, more studies and experiments must be performed in order to test the level of understanding of the visualizations. The participants received minimal information about the visualizations in order to test how comprehensive to the participants are. In many cases the participants recommended to have sound or text to clarify the visualizations, but the aim of the test were to see how intuitive the visualizations are without the support of other medias, such as sound or text. That means if the participants can understand the visualizations without extra support, when these are supported with sound and text, the message of the AR-HMI will give no doubt to the drivers and will reinforce the confidence in autonomous vehicles.

6 Conclusions (REL)

The actions described in this document represent the last part of the activities performed in the framework of Work Package 4.
The focus of this work package was to design, implement and validate the TeamMate HMI, addressing the most relevant topics in academic and industrial research related to the Human-automation interaction.

The activities conducted in this framework allowed to finally integrate strategies, concept and software into driving simulators and real vehicles, in order to test the overall system in WP6.

The 3rd cycle has been the natural prosecution of the previous cycles. The main focus, at this stage of the project, was to validate the components according to the requirements defined in the previous phase of the activity and to integrate them into the demonstrators.

In order to do that, a final release of the components has been done in this cycle. The final version of the graphical elements has been designed and developed into a software. Moreover, the HMI has been extended in order to cover different use cases, including the final version of the use cases for the evaluation.

Finally, a last cycle of V&V has been performed. The results show that the HMI is well understood and accepted by the users. The introduction of multimodal elements (such as haptics) are used to reinforce the quality of the interaction and to increase the awareness of the users is effective, since they are able to reduce the reaction time and to increase the quality of the transition.

Finally, a guide on interaction modalities with highly automated vehicles has been provided, in order to deeply understand how to design interaction between people and technological systems.

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